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DECLARATION

I declare that the thesis, which I hereby submit for the degree of PhD (Agronomy) at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

Signature 1 October 2008

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And anybody I missed who deserves a mention.

LIST OF ABBREVIATIONS

a.e. - acid equivalent

a.i. - active ingredient

AYL - acceptable yield loss

CPWC - critical period of weed competion

CV - coefficient of variation

GDD - growing degree days

IWM - Integrated Weed Management

L_w - relative leaf area

MSIRI - Mauritius Sugar Industry Research Institute

MUR - Mauritian rupee

q - relative damage coefficient or relative competitiveness value

TD - transplanting date

WAH - weeks after harvest

WAP - weeks after planting

WAS - weeks after spraying

WAT - weeks after transplanting

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Weed management in sugar cane: critical periods of weed competition and mechanisms of interference from *Paspalum paniculatum* and *P. urvillei*

by

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ABSTRACT

The aim of this project was to provide sound scientific underpinning for the development of new weed management strategies in sugar cane by exploring competition from the major weeds, and explaining the different mechanisms of weed interference from *Paspalum paniculatum* and *P. urvillei*.

Critical periods of weed control (CPWC) were studied in six field trials. In ratoon cane, CPWC with natural weed infestations started between 228 and 916 growing degree days (GDD), and ended between 648 and 1311 GDD, depending on the site and cane variety. These results represented a maximum CPWC of 12 to 28 weeks after harvest (WAH). In plant cane, the CPWC started earlier (6 WAP) and was longer than those in ratoon cane.

Relative competitiveness 'q' values of eight common weed species showed that sugar cane was a stronger competitor than most of the weeds tested. The adverse effect of weed competition in sugar cane is not experienced before several weeks following weed emergence. Weeds transplanted 10 WAP caused no significant change in cane yield response as compared to those transplanted 4 WAP. *Paspalum paniculatum* was often found to be more competitive than *P. urvillei*, although the latter produced more leaf area and grew taller to intercept more light within the canopy. This indicated that other mechanisms of weed interference were involved and competition for light was more important during the earlier (tillering) growth stages. Root competition was shown to be as important as shoot competition. Root competition effects were observed several weeks after imposing competition, suggesting that it was more important than competition for light in the post-tillering phase. Application of root exudates from the two grasses to sugar cane confirmed an allelopathic effect on the

root biomass of sugar cane. One chemical identified in the leachates from both *Paspalum* species for the allelopathic effects was 2-propenoic acid, 3-(4-methoxyphenyl).

The main implications of the above findings for the Mauritian sugar industry would involve a change in the timing of application of herbicides. A new tank-mix consisting of trifloxysulfuron + ametryn and amicarbazone has been found to meet this objective. This strategy will enable a saving of at least one herbicide treatment per season.

Key words: relative competitiveness, shoot competition, root competition, allelopathy, herbicide

CHAPTER 1

INTRODUCTION

1.1 Sugar cane: a brief description

Sugar cane (*Saccharum* spp. L.) is a large perennial grass of the tribe Andropogoneae, family *Gramineae* (Roach & Daniels, 1987). Known to be one of the oldest cultivated plants in the world, sugar cane has been intensively hybridised and selected for its ability to accumulate sucrose (Alexander, 1973). Modern commercial varieties of sugar cane are derived from complex interspecific crosses between the wild canes (*S. spontaneum*) and the noble canes (*S. officinarum*).

Sugar cane is cultivated throughout the tropical and subtropical regions of the world in a wide variety of soils and climates; it attains full development only when a long, warm growing season alternates with a short, cool and dry ripening season. Sugar cane biomass (fresh weight) production can exceed 200 t ha^{-1} in one year. An average of 8 to 16 t ha^{-1} of sugar may be produced from the juice extracted from the cane stalks which represent 70 to 85% of the total biomass. Besides sugar, production cane can also be used for manufacturing of alcoholic liquors (rum), used as fodder (cane leaves), and for cogeneration of electricity (from bagasse). This plant is currently gaining tremendous importance for the production of ethanol, a renewable source of energy and bio-fuel (Thomas & Kwong, 2001; Jolly & Woods, 2004; Autrey & Tonta, 2005).

1.2 The island of Mauritius

Mauritius is a small volcanic island situated some 850 km east of Madagascar in the south-west Indian Ocean at latitude $20^0$32' South and longitude $57^0$46' East. The island covers an area of 1860 km^2 and consists of a coastal plain rising gradually towards a central plateau bordered by mountain ranges, with the highest peak 826 m above sea level.

Mauritius has two climatic seasons; the climate is sub-tropical in winter (May to October) and tropical in summer (November to April). Mean daily temperature ranges from 15 ^oC to 29 ^oC but the weather is highly dependent on the island's topography. The rainfall pattern varies significantly across the island and is in the range of 1000 to 4000 mm; the mean annual rainfall over the island as a whole is approximately 2100 mm (Padya, 1984). With respect to rainfall distribution, the island is usually divided into three agro-climatic zones; the sub-humid zone receiving less than 1250 mm of rain, the

humid zone (1250–2500 mm) and the super-humid zone with more than 2500 mm of rain (Fig. 1.1). Numerous microclimates and soil types are present in the same isohyet band. The occurrence of tropical cyclones during the summer months, with winds exceeding 120 km hr^{-1}, represents a severe threat to the island and its agriculture.

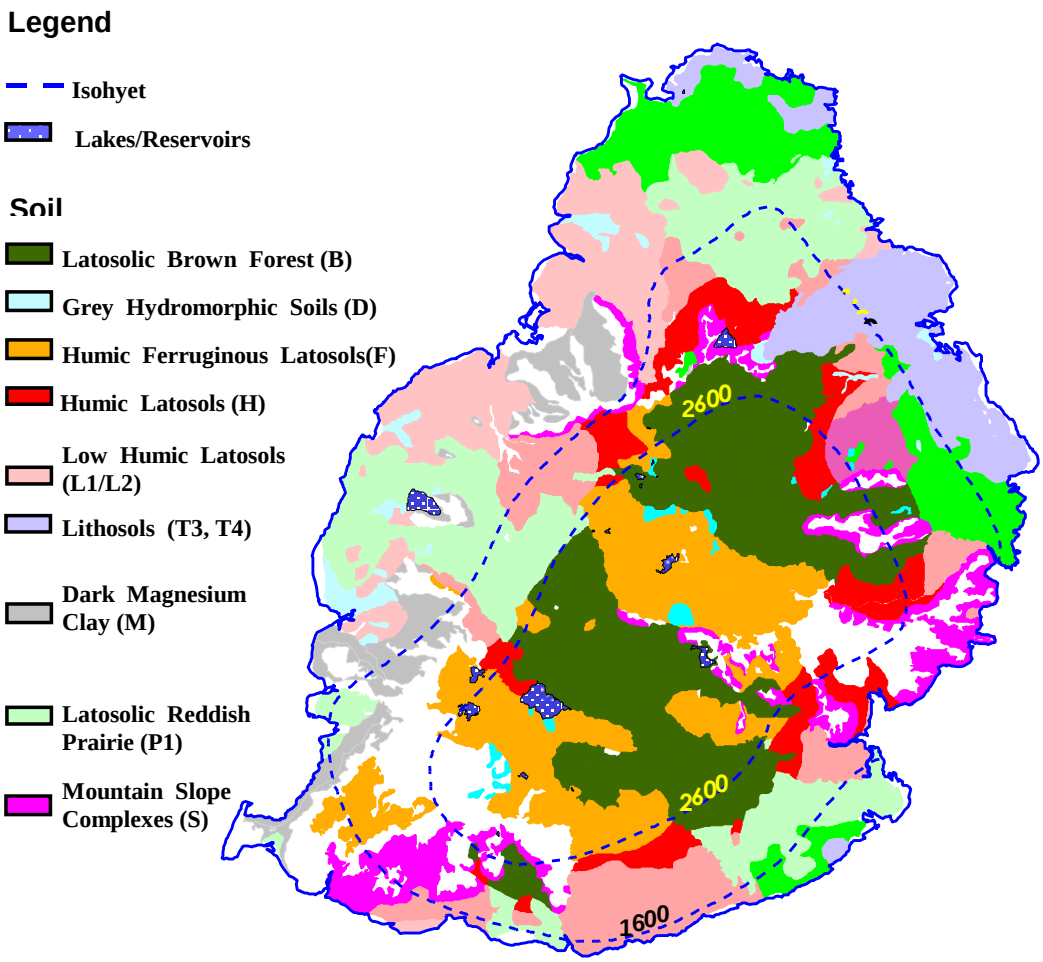


Fig. 1.1 Agro-climate of Mauritius and soil groups of Mauritius (after Parish & Feillafé, 1965)

In 1965, Parish and Feillafé published the first soil map of Mauritius with a scale of 1:100 000 (Fig. 1.1), which is still commonly used for agricultural purposes. The soils of Mauritius are classified within soil groups, each represents an area of fairly uniform climate and topography, and therefore of similar soils. The five main soil groups where sugar cane is cultivated are:

- Low Humic Latosols (L): a silty clay to silty clay loam texture with kaolinite as dominant mineral. This soil group covers approximately 16% of the island.
- Humic Latosols (H): clay texture consisting of equal quantities of kaolinite, goethite and gibbsite, and covers some 5% of the total area.

- Humic Ferruginous Latosols (F): strongly weathered soil occurring in the high rainfall regions and are rich in organic matter. The clay fraction is mainly gibbsite and goethite, with little kaolinite. This group is present on approximately 11.4% of the island.
- Latosolic Reddish Prairie (P): soil group found in lower rainfall areas and the texture varies from clay loams to silty clays. The clay fraction is dominantly kaolinite and this group covers some 20% of the total area of the island.
- Latosolic Brown Forest (B): the texture of the B soils varies from clay loams to clay. The clay fraction has lesser amounts of kaolinite and more gibbsite and goethite. This soil group is present on 17% of the island.

1.3 Introduction of sugar cane to Mauritius

Sugar cane was first brought to Mauritius in 1639 by the Dutch who established two sugar processing plants in 1641 (Koenig, 1988). By 1652, however, the manufacture of sugar was abandoned but the cultivation of sugar cane was continued for the production of 'arrack' (an alcoholic beverage similar to rum). The Dutch left the island in 1710 and during the French occupation (1721–1810), great impetus was given to sugar cane production and the first sugar factories were created; some 3 000 tonnes of sugar and 300 000 gallons of arrack were produced by the beginning of the 19th century. The British captured the island in 1810 and realized that sugar production could be the greatest asset of Mauritius; as a result the area under cane increased steadily and reached 11 000 ha in 1825. The island was already producing some 107 000 tonnes of sugar in 1854. The sugar industry has since undergone further expansion through increased acreage of sugar cane and significant technical progress due to research and development.

The country recorded its maximum sugar production in 1973 when 718 464 tonnes were yielded from a cultivated area of 87 384 ha (Koenig, 1988). Since then, owing to the conversion of cane land to other uses and small-growers abandoning their production due to increasing costs, production has been falling on average; from 706 839 tonnes in 1986 to 504 900 tonnes in 2006 (MSIRI, 2006). The current area under cane is less than 67 000 ha (MSIRI, 2006). The decrease in area and production has been faster within the last five years as more lands have been converted to other new emerging sectors such as manufacturing (mainly textile), the information and telecommunication technologies (ICT) and integrated resort schemes (IRS).

1.4 Cultural practices of sugar cane

Sugar cane is usually propagated by planting portions of the stems, called cuttings or setts; each of which usually has three to five buds (STASM, 2003). The setts are planted in furrows approximately 0.15 m deep and spaced between 1.30 m and 1.62 m. The total number of setts varies between 25 000 to 30 000 per hectare, representing between 6 and 9 tonnes of planting material. Cane is ideally planted when both optimum temperature (25-30 ^{o}C) and soil moisture are present (Van Dillewijn, 1952). Germination of the buds (primary shoots) starts a few days after planting and secondary shoots, called tillers, are produced a few weeks later (tillering phase). Shoots start to elongate while in the tillering phase; peak tillering is reached between 22 to 36 weeks and is followed by suppression of excessive tillers. The final number of cane stalks (millable stalks) is a characteristic of the variety; Mauritian varieties reach the harvesting stage with 80 000 to 100 000 millable stalks per hectare. The elongation phase is overlapped and followed by the cane maturation phase. Cane maturation is favoured in winter when cane growth is slowed and the lower night temperatures and dry conditions enhance sucrose accumulation.

Harvest extends from June to December in Mauritius. The plant cane is usually harvested after 12 to 14 months (short season: crop season planting) or 16 to 20 months (long season: intercrop planting) (STASM, 1990). The ratoon crop (cane regrown from stools left after the previous crop was harvested) is normally harvested every 12 months over a period of 6–8 years. Under favourable conditions, sugar cane can produce more than 200 t ha^{-1} of total biomass of which 70% to 80% would consist of millable cane stalks. In Mauritius, the average cane and sugar yields were 79.0 t ha^{-1} and 8.84 t ha^{-1}, respectively, in 2001 (MSIRI, 2002).

The cultural practices of sugar cane vary according to agroclimatic conditions and the level of field mechanization. Weed control remains one of the most important cultural practices of sugar cane, as its long period of growth before complete crop canopy formation may result in the crop being exposed to several flushes of weeds. For plant cane, canopy closure occurs between 18 and 28 weeks after planting, depending on growth conditions (agro-climatic conditions). For ratoon cane, as tillering and elongation start earlier, canopy closure is reached between 12 and 24 weeks after harvest (Van Dillewijn, 1952).

There has been considerable progress with mechanization of cultural practices, particularly harvest, during the last 15 years; more than 17 000 ha were harvested mechanically in 2005 (MSIRI, 2006). The latter mechanized operation is considered as one of the reasons for direct and indirect reduction in cane productivity in recent years because mechanized harvesting results in more plant

material being left in the fields than with hand harvesting. The machines also cause some physical damage on the cane stools and harvesting under humid conditions increases the risk of soil compaction.

1.5 Weeds of sugar cane

1.5.1 Major weeds of sugar cane in Mauritius

In Mauritius more than a hundred weed species have been identified in sugar cane fields; some sixty of the most commonly found weeds have been described by Mc Intyre (1991). Rochecouste (1967) showed that weed distribution depends mainly upon soil type and moisture. Some weeds are more specific to certain regions whereas others may be found growing in all climatic zones. *Cyperus rotundus* (Linn.) (purple nut sedge) and *Cynodon dactylon* (L.) Pers. (bermuda grass), which are considered as two of the world's worst weeds (Holm *et al.*, 1977), grow under all agroclimatic conditions of the island, whereas species such as *Drymaria cordata* (L.) Willd, *Panicum maximum* Jacq., *Colocasia esculenta* (L.) Schott etc. are adapted to specific regions. However, some weeds have developed a wider adaptation with time; e.g. *Digitaria horizontalis* Willd var. *porrantha* (steud.) Henr., which was known to be particularly adapted to the high rainfall areas, is now also found growing in lower rainfall areas. The competitive effect of weeds also varies with the season; e.g. *C. rotundus* is more competitive during the summer months, and then particularly in the lowlands.

For weed control purposes, weeds are usually grouped into three broad classes, namely: broad-leaved weeds, grasses and sedges (Cyperaceae) (Colvin, 1980). Grasses are more troublesome to control in sugar cane due to the difficulty of achieving good selectivity from available herbicides. This was confirmed in a survey carried out (unpublished data) in 2004 among the large sugar cane producers, and covering an area of 48 000 ha, where eight grasses were listed among the ten weeds identified by the growers as difficult to control. These eight grass weeds were *Brachiara eruciformis* (J.E. Sm) Grisab, *C. dactylon*, *D. horizontalis*, *P. maximum*, *Panicum subalbidum* Kunth., *Paspalum paniculatum* Linn., *Paspalum urvillei* Steud and *Digitaria timorensis* (Kunth.) Balans. The other two weeds listed were *C. rotundus* and *Ageratum conyzoides* Linn. *Panicum maximum* is mostly found at lower altitudes and is controlled mostly at planting and with localised application of glyphosate. Similarly, *B. eruciformis* is mostly found in the warmer and drier parts of the island. *Panicum subalbidum* has emerged as an important weed in the humid zone after not being controlled by the

standard herbicide treatments applied between 1985 and 1995 but a change in the treatments thereafter has brought satisfactory control.

Paspalum paniculatum and *P. urvillei* have been focused on in this project/thesis to study and describe weed competition in sugar cane, as they are listed among the five most common weeds in the humid and superhumid areas, representing more than 60% of cane-growing area, and because the cane growers include them in their list of more intractable weeds (see above). Other reasons for their selection in this study include their diverse morphological characteristics, despite them being closely related, plus the relative ease with which they can be established.

1.5.2 *Paspalum paniculatum*

Botanical classification

Paspalum paniculatum Walt. is from the Poaceae (Grass) family and synonyms include *Paspalum compressicaulis* Raddi, *Paspalum multispica* Steud., *Paspalum polystachium* Salzm., *Paspalum strictum* Pers. Its common or vernacular name in Mauritius is 'Herbe duvet'.

Description

Paspalum paniculatum is a coarse tussocky perennial, 0.3-2.2 m high with culms erect or geniculately ascending, moderately stout, and glabrous (Fig. 1.2). The leaf-sheaths are keeled with the nodes densely bearded, usually stiffly hairy to nearly glabrous; ligule is truncate and very short. The leaf blades are linear to narrowly lanceolate, acute, 9-50 cm long, 6-25 mm wide, flat, stiffly hairy to almost glabrous (Hubbard & Vaughan, 1940).

The inflorescence is 5-30 cm long and is made up of numerous racemes (7-60). The latter are 2.5-12 cm long, very slender, dense and finally spreading with their axes 0.5 mm wide. The spikelets occur in pairs and are rotundate-elliptic, obtuse, measuring 1.2-1.5 mm long. They are straw-coloured to purplish-brown and minutely hairy, the upper glume and lower lemma being 5-nerved.

Ecology and distribution

Paspalum paniculatum produces large quantities of fertile seeds which germinate rapidly under favourable conditions to invade new areas. It can also propagate from split tussocks as a result of certain cultural practices carried out in the fields. It grows well even in shaded places.

Paspalum paniculatum is a dominant species of the humid and superhumid areas of Mauritius, growing mostly along roadsides and in fallow fields from where it encroaches onto sugar cane fields. Today, it is quite common in sugar cane fields.

Fig. 1.2 *Paspalum paniculatum* (Photo courtesy: Mc Intyre, 1991)

1.5.3 *Paspalum urvillei*

Botanical classification

Paspalum urvillei Steud. is from the Poaceae (Grass) family and synonyms include *Paspalum griseum* Hack., *Paspalum dilatatum* var. *parviflorum* Doell and *Paspalum velutinum* Trin. Its common or vernacular name in Mauritius is 'Herbe cheval'.

Description

Paspalum urvillei is an erect perennial, growing in dense tussocks about 30 cm in diameter and 0.75-2.5 m high (Fig. 1.3). The culms are moderately stout and glabrous. The base of the stalks and leaf-sheaths is hairy and bluish in colour. The leaf-sheaths are keeled upwards with the lower ones being

coarsely hairy whereas those found on the upper parts are less hairy or are glabrous. The ligules are 3-5 mm long; leaf blades are erect, linear, acute, 12-50 cm long and 3-15 mm wide. They are flat and long-hairy at the base, otherwise glabrous (Skerman & Riveros, 1990).

The inflorescence is erect or slightly nodding, 10-40 cm long, and is composed of 6-25 dense, mostly erect racemes. The lower racemes are 6-14 cm long, whereas the upper ones become gradually shorter, each with their axis about 0.8 mm width. The spikelets are paired, broadly ovate-elliptic, abruptly acute and are 2-3 mm long. They are green or purplish in colour; the upper glume and lower lemma are 3-5 nerved and are fringed with long silky hairs (Skerman & Riveros, 1990).

Ecology and distribution

Paspalum urvillei is a perennial plant which spreads fairly quickly under favourable moist conditions with its heavy seed production; it can also regenerate from split tussocks. It prefers full sunlight and does not grow well in shade. Its vigorous, erect growth allows it to compete successfully with other plants and crops.

Paspalum urvillei is a high rainfall grass occurring mostly in the humid and super-humid areas of Mauritius, along roadsides and in fallow fields from where it extends its range to cultivated fields. It is commonly found in sugar cane fields nowadays.

Fig 1.3 *Paspalum urvillei* (photo courtesy: Mc Intyre, 1991)

Thus, *P. paniculatum* has a somewhat more prostrate growth habit than *P urvillei* and grows at a relatively lower height within the cane canopy. The size and growth habit of *P. urvillei* when well developed causes manual application of herbicides and uprooting (hand-weeding) to be more difficult than in the case of *P. paniculatum*. Because of its physical presence higher within the crop canopy, growers consider *P. urvillei* as more competitive than *P. paniculatum*.

1.6 Weed control in sugar cane

Since the early 1950s, the introduction of selective herbicides has been one of the main factors enabling intensification of agriculture in developed countries (Kropff & Lotz, 1992a; Kropff & Walter, 2000). In Mauritius, prior to the introduction of the herbicides MCPA and 2,4-D in the late 1940s, weed control in sugar cane was achieved mainly by manual weeding. Some cultural practices such as trash lining ("relevage") and ridging ("buttage") also helped to suppress weeds (De Sornay, 1926). The availability of residual herbicides from the 1950s and research showing the advantages of chemical control, resulted in a major shift in methods of control; use of herbicides increased significantly thereafter to reach a peak with more than 700 tonnes of active ingredient applied to approximately 80 000 ha of cane in the 1980s (Fig. 1.4).

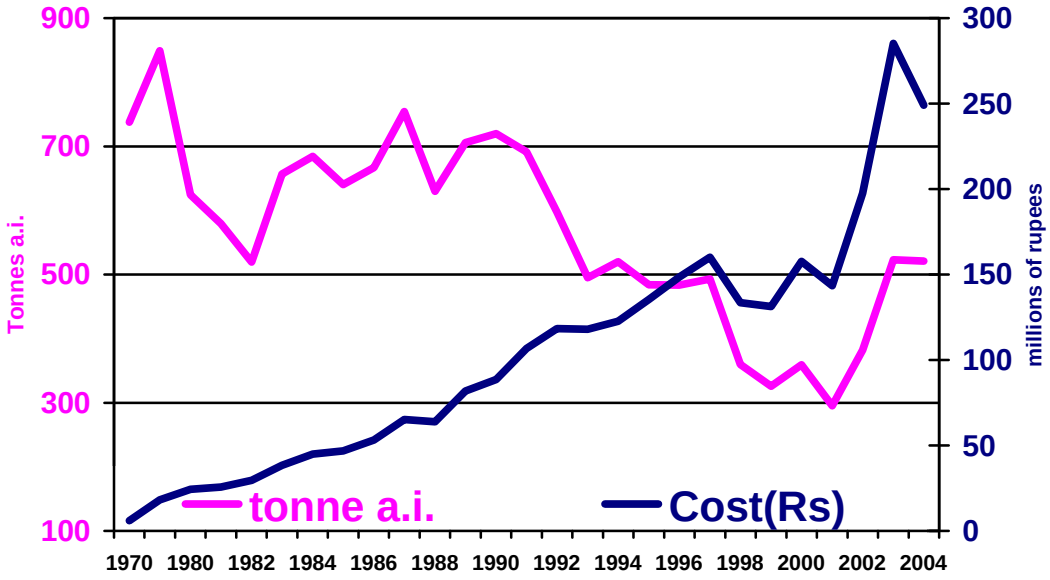


Fig. 1.4 Amount (tonnes of active ingredients) and costs of herbicides used in sugar cane. (1 US$ = ~30 MUR)

More than 125 herbicides have been tested in sugar cane during the last 50 years, and more than 25 of them have been recommended for commercial use (Rochecouste, 1967; MSIRI annual reports 1953-2006). Research in Mauritius during that period was also herbicide driven (Van Der Zweep & Hance, 2000). The amount of herbicides applied, particularly pre-emergence ones, has declined in the last decade with the increased adoption of "green cane trash blanketing", a practice recommended in 1992 for better soil moisture conservation and weed control (Seeruttun *et al*., 1992). An increase in the total amount of herbicides imported was recorded in 2003 and 2004 as a consequence of an early retirement scheme in the sugar industry in 2003 where the majority of the female labourers above the age of 50 years old were allowed to depart with a special package. As this group of labourers was involved in manual weeding, more herbicides were purchased by the sugar estates as a countering measure. The amounts purchased and stocked were rapidly found to be in excess of what was required to compensate for the reduction in labour force and the amount of herbicides imported/used regressed thereafter. The practice of trash blanketing is, however, not recommended in the superhumid areas as it adversely affects cane growth in those regions (Seeruttun *et al.*, 1999).

After planting, sugar cane may take between 20 and 26 weeks before the cane forms a complete leaf canopy. The length of this period depends on the cane variety and on climatic conditions. The standard practice of weed control in Mauritius has been the application of a pre-emergence herbicide just after planting or harvesting (in ratoon crops), followed by one or two post-emergence applications until canopy closure (Fig. 1.5).

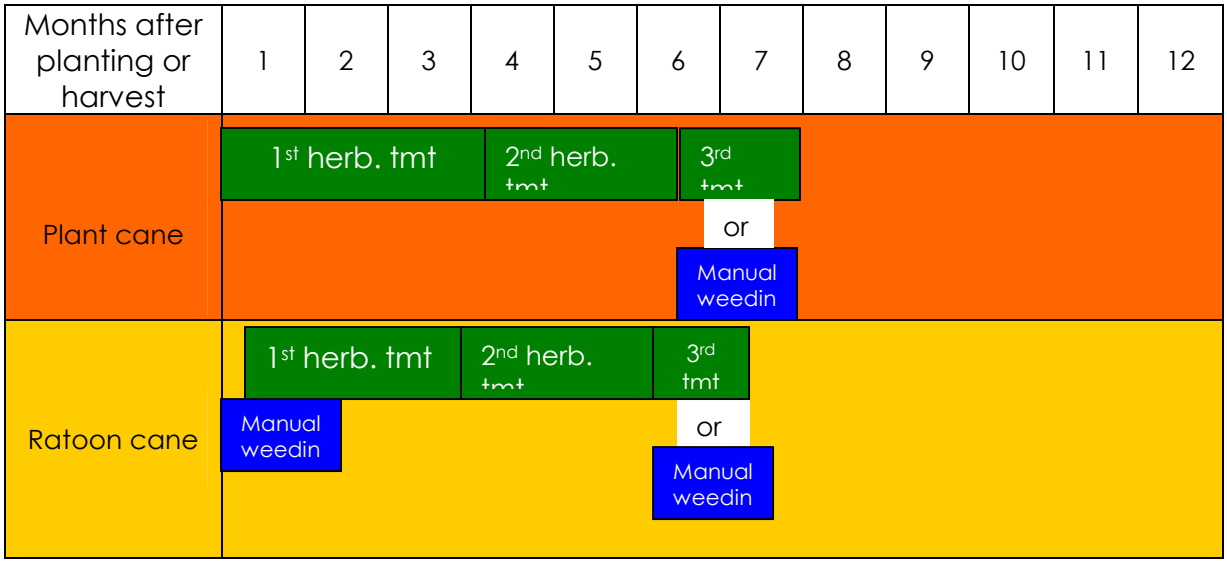


Fig. 1.5 Timing of weed control and herbicide applications in sugar cane

The residual action of the first herbicide treatment usually lasts between 10-14 weeks, thus necessitating a second application consisting of one or two pre-emergence herbicides tank-mixed with a post-emergence one to control emerged weeds and, at the same time, to prevent others from emerging. Under certain circumstances, when canopy closure is retarded for reasons such as climate, cane variety and row spacing, a third herbicide application may be necessary usually as a full or spot treatment (Fig. 1.5). This application is sometimes replaced by manual weeding depending on the availability of labour (especially during the intercrop period). Manual weeding is also resorted to when certain weed species are not controlled by the standard treatments.

In sugar cane fields, the presence of more than 15 weed species consisting of broad-leaved weeds, grasses and sedges is quite common. For this reason, tank-mixing of two or more herbicides to achieve a broader spectrum of control is a common practice in sugar cane production. Pre-emergence herbicides represent more than 60% of the total amount (active ingredients) of herbicides used in sugar cane. The most important ones are diuron, atrazine, tebuthiuron, acetochlor, metolachlor and oxyfluorfen (Table 1.1). The two main post-emergence herbicides applied in sugar cane in the last 30 years have been 2,4-D amine salts and ioxynil+2,4-D ester.

Table 1.1 Herbicides recommended and used in sugar cane in Mauritius*

Year recommended	Herbicides	
	Pre-emergence	Post-emergence
1950 - 1959	diuron	TCA, MCPA, 2,4-D derivatives, dalapon, sodium chlorate
1960 - 1969	atrazine	picloram, paraquat
1970 - 1979	metribuzin, hexazinone, linuron	2,4-D ester + ioxynil, asulam, glyphosate
1980 - 1989	acetochlor, metolachlor, oxyfluorfen	
1990 - 1999	tebuthiuron	glufosinate-ammonium, triclopyr, halosulfuron, metsulfuron,
2000 - 2005	sulfentrazone, diclosulam, isoxaflutole	terbuthylazine + bromoxynil, fluroxypyr,

* Sources: Rochecouste (1967), Recommendation Sheets, MSIRI.

In addition to those listed in Table 1.1, some specific herbicides are also used for the control of certain problem weeds, which are resistant to the conventional treatments; examples include triclopyr, picloram or fluroxypyr for control of shrubs and vine weeds, halosulfuron for control of sedges (*C. rotundus*) and metsulfuron-methyl for control of *Colocasia esculenta* and *Alternanthera philoxeroides* (Mart.) Griseb. Glyphosate is mainly used for general weed control pre-planting of sugar cane.

1.7 Sugar cane in the Mauritian economy

Mauritius has no natural mineral resources and thus tropical agriculture has played a fundamental role in its economy. Historically the country was totally dependent on the monoculture of sugar cane; sugar represented 93.5% of exports in 1967 (Koenig, 1988). Since the 1970s, the role of sugar in the economy has changed with the share of sugar in the gross domestic product (GDP) dropping from 25% in 1970 to less than 4% in 2005. This change has occurred due to the diversification of the economy with new economic sectors like tourism and the manufacturing industry emerging in the 1970s and 1980s, followed by developments in the finance sector and information and communication technologies in recent years.

In 2002 about 45% of the total area of the island was cultivated and about 90% of that area (87 000 ha, excluding forests) was under sugar cane. The area under sugar cane has undergone a reduction within the last 20 years; 87 384 ha of sugar cane were grown in the record year of 1973, and less than 70 000 ha in 2006. Similarly, the number of persons employed in the sugar industry has also experienced a significant reduction in recent decades. Despite these reductions, income from the export of sugar has remained an important source of foreign earnings. The bulk of Mauritian sugar is exported to the European Community, principally to the United Kingdom, under the Sugar Protocol between the ACP/EU. Based on this agreement, Mauritius has benefited from an annual export of some 500 000 t at a guaranteed price till 2005 (Mauritius Chamber of Agriculture, 2006; Ministry of Agro-industry and Fisheries, 2006).

The erosion of preferential access to our traditional export markets for sugar, and the challenges imposed by the trade liberalization process (World Trade Organization - WTO), have called for urgent action by the local sugar industry. Because of the increasing costs of production of sugar in the late 1990's, coupled with the threats and challenges ahead (i.e. the real risk of Mauritian sugar exports

losing their competitive edge in a liberalized trade environment), a strategic plan was implemented by the Government in 2001. In its Sugar Sector Strategic Plan (SSSP) 2001-2005, the Government fixed a production target of 620 000 t of sugar. Additionally, the cost of production of 14 US¢ per pound would have to be reduced to 10-12 ¢ per pound by 2008 (Ministry of Agriculture, Food Technology and Natural Resources, 2001). This plan was still not completely implemented when the EU announced its reform in the Sugar Regime that would lead to a cumulative 36% reduction in the price of sugar (523 Euros t^{-1}) as from 2006 and completed in 2009. This drastic reduction has jeopardized the industry as a whole and several actions are being taken to minimize the impact and save the industry. All these actions are enforced in the Multi Annual Adaptation Strategy (MAAS) Plan (Ministry of Agro-Industries and Fisheries, 2006).

Among the various actions listed in the MAAS, efforts will have to be made to reduce the cost of production by mechanization of cultural practices, and by other means. Both the SSSP and MAAS plans imply a review of the costs for weed control within the industry, as all herbicides used in Mauritius are imported. This aspect is particularly important, as both plans tend to promote increased use of herbicides to replace the more costly manual workers (labourers) opting for voluntary retirement schemes.

1.8 Development of weed management strategies

The traditional weed management practice has been to eradicate practically all weeds from sugar cane fields irrespective of the species present, their levels of infestation, and the stage of growth of the cane. To achieve this level of control and to cope with the reduction in, or non-availability of, labour in the sugar industry in the 1980's, cane producers have resorted to more pre- and post-emergence herbicides. Although a slight reduction in the total amount of active ingredients had been noted during the last decade due to new molecules/formulations using less active ingredients, as well as the adoption of trash blanketing in the sub-humid areas, the total costs of herbicides have increased significantly (except for 2003 and 2004 as explained previously) (Fig. 1.4). This is mainly due to the exchange rate of the Mauritian rupee *vis à vis* the US dollar and the pound Sterling; all herbicides used locally being imported. The average cost of herbicides exceeds MUR 3 500 ha^{-1} (110 US$) and the total costs for weed control in the sugar industry was estimated at more than MUR 450 000 000 in 2004. Costs for weed control vary between 4% and 8% of the total cost of production.

The reduction in sugar price has made it necessary to reduce production inputs including herbicides. Furthermore, there is increasing pressure on farmers across the world to optimize their use of pesticides in order to reduce environmental effects. In sugar cane in Mauritius, with the exception of a fungicide treatment of cane setts at planting, herbicides are the only pesticides used, as control of pests and diseases is achieved by biological control and development of resistant cane varieties. A study undertaken between 1996 and 1999 has revealed that despite continuous use of herbicides such as atrazine or diuron over the last 40 years, the amount of herbicide residues measured in the underground water and rivers are negligible and were well below the threshold stipulated by the World Health Organization (WHO) standards (MSIRI/ACIAR, 2001). However, these findings should not preclude efforts to minimize the amount of herbicides used.

The optimization of herbicides to reduce environmental effects and to minimize costs has led to development of strategies for Weed Management or Integrated Weed Management (IWM) and the use of alternative methods for weed control. IWM involves a combination of cultural, mechanical, biological, genetic, and chemical methods for effective and economical weed control (Swanton & Weise, 1991). The new approach is aimed at management of weed populations and includes a better understanding of crop-weed(s) interactions, identifying critical periods of weed competition with respect to crop growth and weed emergence and infestation, improved agronomic practices, etc. Any weed management system developed for a particular crop should not be geared towards yield losses only in the current year but should consider longer term issues including consequences for the level of weed infestation that is likely to arise in subsequent years. The latter includes the impact on the weed seedbank of seeds produced from surviving weeds.

1.9 Objectives of thesis

The change from the traditional methods of ‘total’ or ‘all-time’ weed control to new integrated weed management approaches has been a priority in the Research and Development Programme of the MSIRI since 1998 (MSIRI, 1998). This approach has included timing weed control interventions to have maximum impact during the competition period, choosing treatments targeted at the weed species present and according to their infestation level, as well as integrating weed control with other agronomic practices to reduce herbicide use. Several projects have been initiated at the MSIRI, based on this approach, for the development of weed management strategies for the sugar industry by

exploiting different non-chemical means of weed control (including improved cultural practices) and a rationalization of herbicide use.

The main aim of this PhD study is to provide sound scientific underpinning for the development of new weed management practices for sugar cane in Mauritius. The research has explored in detail competition between sugar cane and the major weeds present in cane fields and has endeavoured to explain the different mechanisms of weed competition in sugar cane by comparing the interference from two important weeds found in sugar cane fields in Mauritius, namely *P. paniculatum* and *P. urvillei*, two closely related species with some distinct morphological differences. This study has the following specific objectives:

1. To determine the critical periods of weed competition in sugar cane in order to enable development of specific weed management strategies for the different agroclimatic zones and production systems.
2. To quantify competition from different weed species in sugar cane, and to compare their relative competitiveness with the aim of using the data to predict yield losses, and hence, to choose appropriate control measures, possibly within a decision support system.
3. To understand the mechanism of competition for light between sugar cane and weeds (represented by *P. paniculatum* and *P. urvillei*), and the change in competition (relative competitiveness) with time, i.e. at different stages of cane and weed growth.
4. To separate the effects of shoot and root competition between the weeds *P. paniculatum*, *P. urvillei* and sugar cane.
5. To elucidate weed interference based on allelopathy in sugar cane by determining if root exudates from the two *Paspalum* species have allelopathic properties, and to determine whether the two weed species differ in terms of the growth responses elicited from different sugar cane varieties.
6. To develop new herbicide strategies for the effective control of the two grass species based on research findings.
7. To formulate general recommendations based on the study for developing new weed management strategies in sugarcane, and to identify avenues for future research in this field.

CHAPTER 2

CRITICAL PERIODS OF WEED CONTROL IN SUGAR CANE IN MAURITIUS

2.1 Introduction

One of the challenges of the Mauritian sugar industry remains the lowering of its high costs of production, as discussed in Chapter 1. This has become more imperative with the implementation of the price reduction of 36% as from 2009 by the EU, the main importer of Mauritian sugar. Traditionally, weed control in sugar cane in Mauritius has aimed at total removal of weeds from the time of planting, or from harvesting in ratoon cane, up to complete canopy closure. In the humid and super-humid areas of Mauritius the latter may take between 20 and 30 weeks, necessitating three herbicide applications per season costing more than 400 US $/ha.

The development of weed management strategies to reduce the amount of herbicides used for weed control in sugar cane, for both economical and environmental reasons, is now even more of a priority than it has been in the recent past. An integrated approach to weed management is needed. Integrated Weed Management (IWM) involves a combination of cultural, mechanical, biological, genetic, and chemical methods for effective and economical weed control (Swanton & Weise, 1991). This approach focuses on the management of weed populations in accordance with economic threshold levels, rather than their total elimination. To achieve this there is a need for better understanding of crop-weed interactions, identification of critical periods of weed competition with respect to crop growth, weed emergence and infestation level, as well as improved agronomic practices. Critical period for weed control (CPWC) is defined as the specific minimum period of time during which the crop must be free from the adverse effects of weeds to prevent crop yield loss (Zimdahl, 1993). Knezevic *et al.* (2003) reported the CPWC as a key component of any IWM program. The CPWC represents the time interval between two separately measured components: the maximum weed-infested period – the length of time that the weeds emerging with the crop can remain before they begin to interfere with crop growth, and the minimum weed-free period – the length of time a crop must be free of weeds after planting to prevent yield losses. These components can be experimentally determined by measuring crop yield loss as a function of successive times of weed removal or weed emergence, respectively (Weaver *et al.*, 1992). The CPWC has been found to vary

with location, year, cultivar, nitrogen application rate, row spacing, etc (Cousens, 1988; Knezevic *et al*., 2003; Van Acker *et al*., 1993).

Critical periods of weed competition in sugar cane have been reported from experiments carried out in plant cane only. Lamusse (1965) reported, from a field experiment carried out in Trinidad, that weed competition from *Paspalum fasciculatum* Wild (bamboo grass) had little adverse effect on the sugar content and yield of sugar cane when infestation started as late as 12 weeks after planting; however those beginning earlier were detrimental to final yields. Promkun (1984, cited by Suwanarak, 1990), in an irrigated area of Thailand, showed that delaying the first removal of weeds by 3 and 4 months may decrease yield by 44% and 65% respectively while Suwanarak (1982) observed that non-irrigated sugar cane required a weed-free period of 4-5 months after planting. From a field trial carried out in Ivory Coast, Marion and Marnotte (1991) showed that a weed-free period between the first and third months after planting was required in order to restrict maximum yield loss to 5%. As Mauritian conditions are different, and because ratoon cane represents more than 85% of the cultivated area, the objectives of this part of the project were to study the CPWC mainly in ratoon cane (plus one trial in plant cane) in the super-humid and humid areas of Mauritius, where cane canopy closure takes longer and weed competition is expected to be higher. It is expected that results obtained under such difficult conditions may be extrapolated for the development of weed management strategies for other regions of the island.

2.2 Materials and methods

Sites and trial characteristics

Six field trials, five in ratoon cane and one in plant cane, were established between 1999 and 2003 in the humid and super-humid areas of Mauritius; the characteristics of the different sites are shown in Table 2.1. All trial sites except Olivia (Trial III) receive more than 3000 mm of rain annually; the mean annual rainfall at Olivia is around 2500 mm. Trial II was initiated after the previous crop was harvested early in the season (July), whilst the four other trials in ratoon crops were established in October following harvesting of the late maturing cane varieties grown (Table 2.1). After harvesting the ratoon crop, conventional crop husbandry practices such as trash management and fertilizer application for each site were maintained; the rate of N fertilizer applied was as per recommendation (STASM, 1990); i.e. 1.4 kg of N applied per tonne of cane produced. A herbicide treatment consisting

of 2,4-D amine salt (2.0 kg a.e. ha^{-1}) was applied to kill or suppress all emerged weeds in the weed-free treatments, prior to the start of all the ratoon experiments.

For Trial V, cane variety M 52/78 (early maturing variety) was planted on 20 March 2002 following the standard cultural practices; fertilizer (NPK) were applied in the furrows at planting. The standard pre-emergence herbicide treatment just after planting was not applied to allow weeds to emerge.

Weed infestation treatments

A naturally occurring population of mixed weed species was present at all sites; they were either kept for increasing periods of time or were removed for weed-free treatments for corresponding periods. The treatments were imposed only when the first homogeneous flush of weeds started to emerge; this resulted in different treatment start dates as weed emergence varied across the six trials. In ratoon cane, weed infestation or weed-free periods started from 8 to 14 weeks after harvesting (WAH) of the previous crop and were maintained for up to 23-31 weeks depending on the trial (Table 2.1), whereas treatments in plant cane (Trial V) were imposed as from the first week after planting and continued up to 30 weeks. The interval between different treatments (weed-free or weedy) was usually three or four weeks for trials in ratoon cane while a five-week interval was established for the trial in plant cane (Table 2.1).

For the weed-free treatment and at the end of each weed infestation period, the plots were sprayed manually with a knapsack sprayer using double cone-jet nozzles delivering 450 L ha^{-1} of spray volume at a working pressure of 300 kPa. The herbicide treatments were a tank-mix of diuron (2.5 kg a.i. ha^{-1}) + 2,4-D amine salt (2.0 kg a.e. ha^{-1}). Diuron was replaced in the treatment by hexazinone + atrazine (0.6 + 2.0 kg a.i. ha^{-1}) at Olivia (Trial III) due to the susceptibility of the variety grown. Where the weed infestation was planned to start later (10 to 20 weeks after harvest/planting), reduced rates (25% of the full rate) of the diuron or hexazinone + atrazine were applied at the beginning of the experiment to keep the plots weed-free initially. The few weeds not controlled by the herbicides were removed manually.

Table 2.1 Trials characteristics and weed infestation periods

Trial	Soil Group *	Mean annual rainfall (mm)	Cane Variety	Crop Cycle	Date of previous harvest/planting	Weed-free/Weed infestation periods (WAH/WAP)	Treatments used to maintain infestation periods	Date of harvest
I – Astroea[+]	Humic Ferruginous Latosol	3496	M 3035/66	Ratoon	2 Oct 1999	8, 12, 16, 20, 24, 28	Diuron + 2,4-D amine salt	20 Sept 2000
II – Union Park[+]	Latosolic Brown Forest	3530	M 52/78	Ratoon	4 & 5 Jul 2000	12,15, 18, 21, 24, 27	Diuron + 2,4-D amine salt	18-20 Jul 2001
III – Olivia[++]	Mountain Complex	2378	R 570	Ratoon	28 Oct 2000	8, 11, 14, 17, 20, 23	Hexazinone + atrazine + 2,4-D amine salt	22 Oct 2001
IV – Belle Rive[+]	Humic Latosol	3341	M 3035/66	Ratoon	16 Oct 2001	14, 17, 22, 25, 28, 31	Diuron + 2,4-D amine salt	17 Oct 2002
V – Union Park[+]	Latosolic Brown Forest	3530	M 52/78	Plant Cane	20 Mar 2002	5, 10, 15, 20, 25, 30	Diuron + 2,4-D amine salt	1-3 July 2003
VI – Belle Rive[+]	Humic Latosol	3341	M 3035/66	Ratoon	17 Oct 2002	8, 12, 16, 20, 24, 28	Diuron + 2,4-D amine salt	29 Oct 2003

* According to Parish and Feillafé (1965)

WAH – weeks after harvest, WAP – weeks after planting

[+] super-humid zone; [++] humid zone

Two weed infestation levels were evaluated, namely a 100% situation and one where a 50% infestation level was created. For the latter, each cane row (10 m long and spaced at 1.6 m) was divided into quadrats of 1.6 m X 2.0 m (0.8 m from the centre of the cane on each side) and each quadrat was further divided into four sub-quadrats of 1.0 m X 0.8 m. Two of these four sub-quadrats were assigned randomly to receive the appropriately timed weed infestation treatments whilst the other two were kept weed-free, thus halving the weed pressure (50% weed infestation). The weed-free sub-quadrats were established and maintained either by the use of herbicides (pre-em & post-em) or by manual weeding, as described above. Herbicide application within the sub-quadrats was restricted by using wooden-board separators of the same width as the sub-quadrats (1.0 x 0.8 m) and spraying was done inside them to avoid any drift of herbicides. A knapsack sprayer with an air-inclusion flat-fan nozzle delivering 250 L ha^{-1} at a working pressure of 300 kPa was used.

Experimental design

At all sites, the plot size consisted of four cane rows, each 10 m long with a row spacing of 1.6 m. The various treatments were laid adown in a randomized complete block design with three replications of a factorial arrangement of increasing weed infestation or weed-free periods and two infestation levels.

Data collection

The main weeds present in all trial sites were recorded (Table 2.2). Data on weed biomass were collected only in Trials I and III; the amount of weeds present two weeks after creating the two levels of infestation at weeks 8-28 (Table 2.1) was compared in Trial I while the amount of weeds left at the end of each infestation period was quantified at Olivia (Trial III). Dry weight of weeds were recorded from two quadrats (1.0 m x 0.8 m) placed in the external (adjacent to the first and fourth cane rows) cane interrows (destructive sampling) on the respective experimental plots; the amount (dry weight) of weeds in each sub-quadrat from the 50% infestation level were expressed as the amount per full quadrat. When the cane was mature the two middle cane rows within each plot were harvested manually and weighed in all trials.

Daily maximum (T_{max}, ^{o}C) and minimum (T_{min}, ^{o}C) temperature data for trials at Belle-Rive and Union Park were obtained from the meteorological station at these sites. For the Olivia and Astroea sites, temperature records were obtained from the National Meteorological Services.

Statistical analysis and fitting regression curves for critical periods

The data for weed biomass in Trials I and III were subjected to analysis of variance (ANOVA). Cane yields from the different treatments were expressed as percentages of corresponding yields on weed-free plots. Relative yield data were then used to fit regression models, as they have been suggested as a more appropriate and useful means for determining the critical period (Cousens, 1988); regression analysis can be used to determine CPWC based on a maximum allowable/acceptable yield loss (AYL). The Gompertz model has been shown to describe the relationship between relative yield and increasing duration of weed-free periods (Cousens, 1988).

- Gompertz function (asymmetrical s-shaped increasing curve)

$$Y = ae^{-eb-cx}$$

Where Y is the % of season-long weed-free yield, x the length of weed-free period, and a, b, c are constants.

Hall *et al*. (1992) showed that for critical periods the increasing weedy period curve was best fitted with a logistic (inverse s-shaped decreasing) curve; the logistic curve is as follows:

$$Y = a + c/(1 + \exp(-b*(x - m)))$$

Where Y is the % of season-long weed-free yield, x the length of weed interference period, a the yield asymptote and b, c, m are constants.

As the six trials were conducted under different agroclimatic conditions and cane varieties in different years, growing degree days (GDD) were used to express the duration (x axis in the above regression models) of weed interference or length of weed-free period after harvesting or planting. Knezevic *et al.* (2002) recommended the use of GDD accumulated from crop emergence or planting as the unit of time to quantify the duration of weed presence and length of weed-free period because it (a) is a more meaningful measure of time needed for plant growth and development, (b) is a means to compare data from different locations, years and planting dates, and (c) provides a continuous and precise scale for the x-axis (Knezevic *et al*., 2002). A base temperature (T_b) of 16.0 ^oC was used as the minimum temperature for sugar cane growth (Inman-Bamber, 1994). GDD was calculated from the following formula for each day:

$$GDD = \frac{T_{max} + T_{min}}{2} - T_b$$

The harvest date of the previous crop was used as the reference point for accumulation of GDD for the trials in ratoon cane while the planting date was used for Trial V. The logistic equation used to determine the beginning of the critical period was fitted using the statistical package GenStat (GenStat, 2005) and the Gompertz equation to determine the end of the critical periods by CurveExpert 1.3 (CurveExpert, 1995-2001). An arbitrary acceptable yield loss (AYL) of 5% (95% of weed-free yield) was used to determine the onset and end of the critical periods from the fitted logistic and fitted Gompertz equations, respectively.

2.3 Results and discussion

Weed species and infestation levels

The main weed species present in each trial are listed in Table 2.2. In Trials I, IV and VI some grass weeds, namely *P. paniculatum, P. urvillei* and *D. horizontalis* were recorded as the cane variety grown (M 3035/66) was harvested late in the season (October/November) when the temperatures were higher and more conducive for germination of these grasses. Variety M 52/78 (Trials II & V) was harvested in June/July, a period of the year when broad-leaved weeds such as *A. conyzoides* and *Solanum nigrum* L. were predominant. Although Trial III (Olivia) was also initiated late in the season, only *Phyllanthus* spp. and *A. conyzoides* were common, as the site was at a lower altitude and is less humid than the other sites.

Table 2.2 Main weed species present at different trial sites

Trial I (Astroea)	Trial II (Union Park)	Trial III (Olivia)	Trial IV (Belle Rive)	Trial V (Union Park)	Trial VI (Belle Rive)
Solanum nigrum	*S. nigrum*	*Phyllanthus* sp.	*A. conyzoides*	*A. conyzoides*	*A. conyzoides*
Paspalum urvillei	*D. cordata*	*A. conyzoides*	*D. horizontalis*	*D. cordata*	*Conyza canadensis*
Paspalum paniculatum	*Kyllinga bulbosa*		*P. urvillei*	*S. nigrum*	*Bidens pilosa*
Digitaria horizontalis			*Lactuca indica*		*K. elata*
Drymaria cordata					*Oxalis corniculata*
Ageratum conyzoides					*P. urvillei*
Kyllinga sp.					*Youngia japonica*

The methodology for creating a reduced weed infestation (approx. 50%) on the critical period of weed competition was quite satisfactory, e.g. two weeks after imposing the weed infestation treatments in Trial I at Astroea, the mean amount of weeds recorded in plots with 100% and 50% infestation were 287.8 g m^{-2} and 162.7 g m^{-2}, respectively (Table 2.3); the ratio was also maintained irrespective of the type of weeds, i.e. for broad-leaved weeds, grasses or sedges.

Table 2.3 Weed infestations (weed dry weight expressed as g m^{-2}) two weeks after imposing treatments in Trial I

	Weed dry weight (g m^{-2})	
	100 % Infestation level	50% Infestation level
Broad-leaved weeds	161.8	80.9
Grasses	80.6	55.9
Sedges	45.4	25.9
Total	*287.8**	*162.7**

Values are means of 5 dates and 3 replications. *Standard error (s.e.) of difference of means (total) between two infestation levels = 29.7 (d.f.=18).

The amounts of weeds were found to vary with time, as the infestation periods were quite prolonged. In Trial III (Olivia), where annual broad-leaved weeds predominated, the amount of weeds (*Phyllanthus* sp. and *A. conyzoides*) was significantly ($P< 0.05$) lower towards the end of the infestation periods (Table 2.4), and both weeds had senesced completely by the last weed infestation period (week 20 - week 23). Visual observation indicated that sites having more grass weeds seemed to maintain relatively more consistent weed populations for the duration of the experiments.

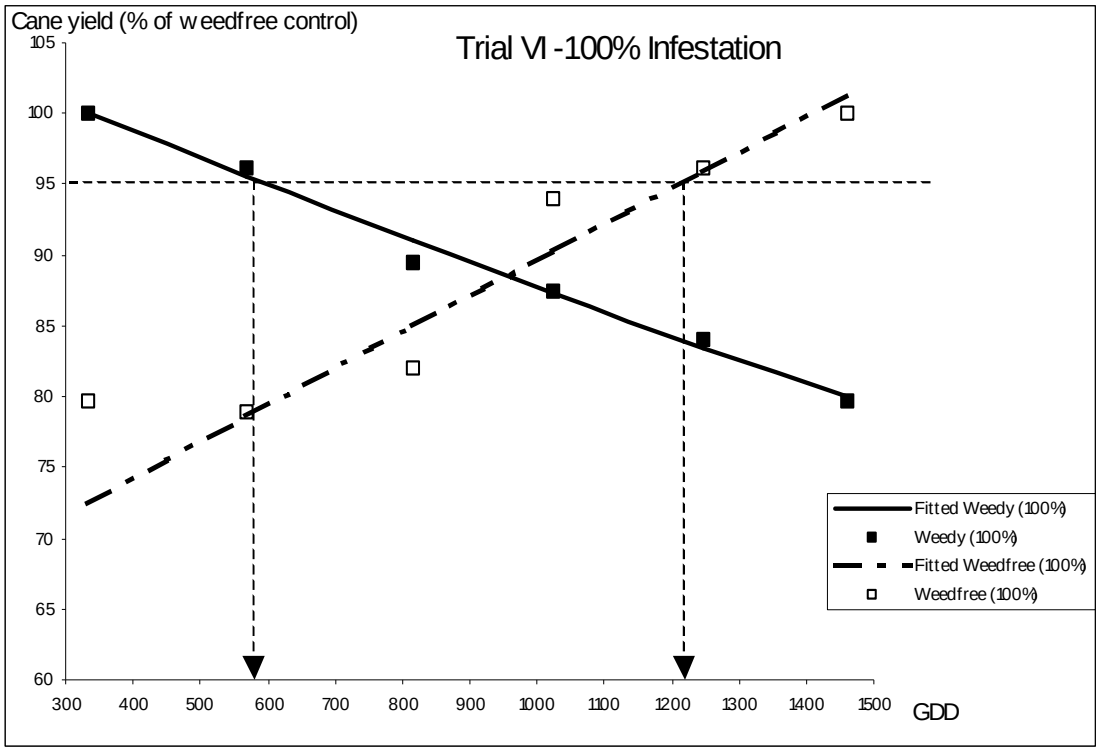
Table 2.4 Evolution of weed infestations in Trial III as a result of increased delay in the weed control treatment

Level of weed	Weed dry weight (g m^{-2})				
Infestation	WK 8-11 (15/2/01)	WK 8-14 (5/3/01)	WK 8-17 (22/3/01)	WK 8-20 (19/4/01)	WK 8-23 (4/5/01)
50%	30.3	21.7	28.2	23.2	-
100%	113.9	126.8	84.0	54.9	-
**Standard error)*	*35.8*	*36.3*	*26.9*	*8.1*	

*Standard error for difference between means

Effect of varying weed infestation periods on cane yield and critical periods of weed control

Cane yield in the weed-free treatments were 61.6, 106.3, 85.0, 56.1, 82.9 and 89.1 t ha^{-1} in Trials I to VI, respectively. Yield differences can be explained by variation in cropping year, crop cycle, cane variety and agroclimatic conditions. At all sites, with one exception (Trial I – 50% infestation level), cane yield was found to decrease with increasing weed infestation periods, and to increase with extension of weed-free periods. An example of the cane response to different weed interference and weed-free periods for Trial VI is shown in Fig. 2.1.



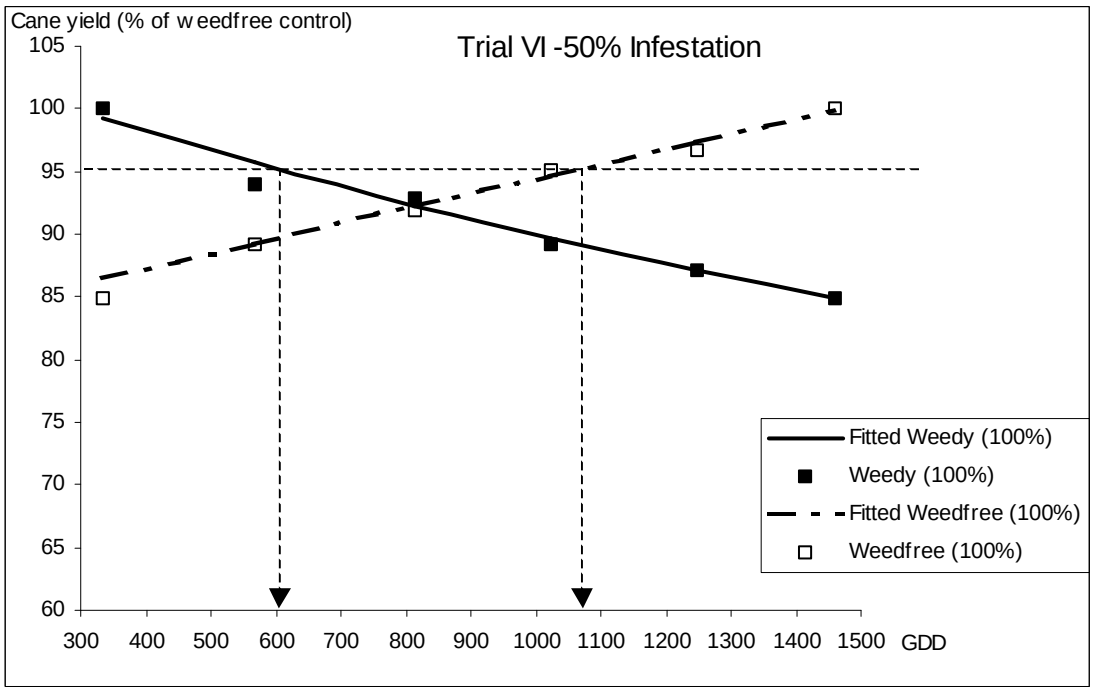


Fig. 2.1 Effect of increasing duration of weed interference (solid line) fitted by the logistic equation and increasing weed-free periods (dashed line) fitted by the Gompertz equation on yield of sugar cane (ratoon crop) at Belle Rive (Trial VI). Dots represent observed data. Horizontal dashed line indicates the 5% acceptable yield loss used to determine the critical periods of weed competition (CPWC), whereas vertical dashed lines indicate the start and end of the CPWC.

The relative yield data at each site fitted the respective models quite well with r^2 values varying between 0.68 and 0.99 (Tables 2.5a & 2.5b), with one exception. In Trial I at Astroea, increasing weed infestation periods for the 50% infestation level resulted in no difference in cane yield.

Table 2.5a Parameter estimates for the Gompertz equation* used to fit yield data for increasing weed-free period in sugar cane.

Trial	Infestation level	S.E.	r^2	a	b	c
Trial I Astroea (R)	100%	4.97	0.89	855.6	0.916	0.00011
	50%	5.76	0.89	157.5	-0.15	0.0005
Trial II Union Park (R)	100%	4.74	0.95	715.7	0.91	0.00032
	50%	9.29	0.75	954.9	0.957	0.0002
Trial III Olivia (R)	100%	1.89	0.99	270.6	0.46	0.00032
	50%	0.94	0.99	264.1	0.449	0.00033
Trial IV Belle Rive (R)	100%	3.47	0.87	698.3	0.808	0.00009
	50%	8.59	0.85	173.5	0.255	0.00063
Trial V Union Park (PC)	100%	3.01	0.98	1007.9	1.16	0.00036
	50%	4.94	0.95	654.2	0.968	0.00038
Trial VI Belle Rive (R)	100%	3.54	0.96	203	0.146	0.00035
	50%	0.57	0.99	454.8	0.533	0.00008

* $Y = ae^{-eb-cx}$, where Y is the % of season-long weed-free yield, x the length of weed-free period, a, b, and c constants. S.E. = standard errors

Table 2.5b Parameter estimates for the Logistic equation* used to fit yield data for increasing weed infestation period in sugar cane

Trial	Infestation level	S.E.	r^2	b	m	c	a
Trial I Astroea (R)	100%	4.62	0.82	-0.054	882	20.3	76.9
	50%	12.4	N/a	-	-	-	-
Trial II Union Park (R)	100%	4.45	0.84	-0.007	244	48	69.7
	50%	3.35	0.84	-0.003	-855.9	824.2	71.9
Trial III Olivia (R)	100%	4.56	0.85	-0.033	1060	23.5	71.7
	50%	1.54	0.98	-0.005	1217	41.1	59.0
Trial IV Belle Rive (R)	100%	3.81	0.68	-0.006	757.6	20.8	85.4
	50%	2.53	0.93	-0.008	913.9	23.0	77.8
Trial V Union Park (PC)	100%	5.71	0.90	-0.0001	-3407	4676	-10.1
	50%	0.52	0.99	-0.008	552.0	40.51	62.5
Trial VI Belle Rive (R)	100%	1.25	0.97	-0.0002	-21410	8175	0.2
	50%	1.43	0.93	-0.0004	-8500	1624	60.5

***** $Y = a + c/(1 + \exp(-b*(x - m)))$, where y is the % of season-long weed-free yield, x the length of weed interference period (weeks), a the yield asymptote and b, c, m are constants. S.E. = standard errors

With the total weed infestation level (100%) and for an AYL of 5%, the onset of the critical periods of weed control (CPWC) in ratoon cane were found to vary between 228 GDD and 916 GDD (Table 2.6); this equated to 14 WAH and 15 WAH at the same respective sites. For the trial in plant cane (Trial V), the start of the CPWC was 278 GDD. The end of the CPWC for the trials in ratoon cane ranged from 648 GDD to 1311 GDD; Trial V (in plant cane) reached the upper limit at 835 GDD. The six trials differed as regards the response of the different cane varieties to CPWC; the late maturing cane varieties (M 3035/66 and R 570 - harvested in September-October as in Trials I, III, IV & VI) started their critical periods of weed competition at a higher GDD compared to the early variety M 52/78, either harvested in July (Trial II) or planted in March (Trial V). Nayamuth *et al.* (1999) showed that an early variety differs agronomically and physiologically from a late variety, the early

variety produced fewer tillers and a lower leaf area index (LAI) but formed cane stalks earlier. The slower initial development of the early variety (M 52/78) explains the earlier onset of the CPWC due to more competition from weeds present; the winter period is predominated by broad-leaved weeds such as *S. nigrum* which can grow quickly and produce a relatively high leaf area. But as the early varieties also start stalk formation quicker than the late varieties, and exhibit a more efficient partitioning of above-ground dry matter into cane (Nayamuth *et al*., 1999), this means that they can grow faster beyond that stage and are less susceptible to weed competition. The latter results in early varieties reaching the end of the CPWC at lower GDDs. In plant cane, the CPWC was longer than in ratoon as it is known that germination, tillering and start of the elongation phase take more time. The results obtained for the onset of the CPWC in plant cane, i.e. six and eight weeks for the 50% and 100% infestations respectively, are similar to those reported by Suwanarak (1990) and Marion and Marnotte (1991).

Table 2.6 The onset and end of critical periods* expressed as GDD in ratoon and plant cane with two weed infestation levels in the super-humid and humid areas of Mauritius. Values in parentheses indicate equivalent WAH or WAP.

Trial	Start of critical period (GDD)		End of critical period (GDD)	
Weed infestation Level	100%	50%	100%	50%
Trial I – Astroea (R)	843 (19)	n/a	1201 (27)	1065 (24)
Trial II – Union Park (R)	228 (14)	219 (13)	648 (25)	604 (24)
Trial III – Olivia (R)	916 (15)	805 (14)	1295 (21)	1293 (21)
Trial IV – Belle Rive (R)	782 (18)	785 (18)	1311 (28)	1219 (26)
Trial V – Union Park (PC)	278 (6)	380 (8)	835 (29)	818 (28)
Trial VI – Belle Rive (R)	586 (12)	609 (13)	1211 (23)	1054 (21)

WAH – weeks after harvest, WAP – weeks after planting
* - with an acceptable yield loss (AYL) of 5%

The reduced weed infestation level (50%) was found not to differ from the full (100%) infestation, particularly with respect to the start of the CPWC (Table 2.6). A lower infestation would be expected to delay the onset of the CPWC but this was the case only in Trials V & VI. Similarly, a lower infestation should reach the upper limit of the CPWC earlier; such a reduction was noted at most

of the sites. The lack of difference between the two infestations with respect to the onset of the CPWC may be explained partly by the fact that weed interference in sugar cane must persist for several weeks before any significant reduction in growth or yield is observed and cane stalks have reached a minimum mean dewlap height of 35 to 40 cm (unpublished data by authors); the start of the CPWC being nearer to the start of the weed infestation period was possibly not showing the relative adverse effect of weed competition. Furthermore, the methodology used for simulating the reduced infestation level may not have been completely efficient, particularly during the early phase of competition. The four sub-quadrats used for creating the 50% infestation by keeping two of them weed-free were 1 m long and were arranged in a 2 x 2 with the centre of the cane row running in their centre. Weeds growing adjacent to the weed-free sub-quadrats may have had an effect on the latter due to the relatively short distance (1 m) between the sub-quadrats; this would have been more pronounced if some of the weed species were also exhibiting root competition. The start of the CPWC for the 100% and 50% infestation levels at Olivia may also have been influenced by the senescence of the weeds; the 100% infestation recorded a more severe reduction in amount of weeds (Table 2.4). As the weed infestations following the longer 'increasing weed-free' treatments were imposed when the cane stalks had reached more than 35-40 cm height, this may explain the differences observed with respect to the end of the CPWC between the two infestation levels tested.

Weed management based on critical periods

The above results show that the classical weed control approach, i.e. applying herbicide treatments immediately after planting, or after the previous harvest in ratoon cane, is not justified and the first herbicide treatment may be delayed according to the cane variety grown and the temperatures (GDD) expected during the growing phase. Rochecouste (1967) reported that weeds adversely affect young cane and thus applying a herbicide treatment pre-emergence of cane and weeds was important. This was mainly due to the early post-em treatments available in those days (e.g. diuron + 2,4-D amine salt or ioxynil + 2,4-D ester) not being totally selective to young cane shoots and their spectrum of control was limited. This approach of applying a treatment pre-emergence of cane has remained as a standard practice and had been the focus of research in the late 1980's with the screening of treatments exhibiting longer residual activity. For example, the tank-mix oxyfluorfen + diuron was recommended in 1989 as it provided residual activity of 14 to 16 weeks after planting (Mc Intyre & Barbe, 1995).

The outcome of this study has been used to develop new weed management strategies for sugar cane in Mauritius; one of them has been to control the weeds during the CPWC and to avoid applying

herbicides throughout the growing period till complete canopy closure. The latter approach would succeed only if herbicide treatments are able to knock down all weeds present prior to the onset of the critical periods and can provide a fairly long residual activity until the end of critical periods are reached. In 2005, a new herbicide containing trifloxysulfuron and ametryn (one product) tank-mixed with amicarbazone at 1.5 + 1.075 kg a.i. ha^{-1}, has been recommended for such purpose, as it was found to be well tolerated by young cane shoots (from four to six weeks after planting or harvest) and provided a wide spectrum of control when applied both pre- and post-emergence of weeds (Seeruttun *et al*., 2007, see also Chapter 7). This new treatment permits the delay of the first application nearer to the onset of the CPWC and with its residual activity varying between 14 and 16 weeks, one herbicide application may be sufficient to reach the end of the CPWC. In worst cases, two applications may be enough to reach the 26^{th} to 28^{th} week after harvest or planting. In any case, this approach will lower herbicide treatments by at least one application per season. Many growers are already adopting this strategy to manage their weed infestations in order to reduce costs of production.

2.4 Conclusion

In ratoon cane, the CPWC vary between 225 GDD and 1300 GDD under the worst cane growing conditions. The CPWC is influenced mostly by agroclimatic conditions, time of harvesting (GDD) and the cane variety grown. The level of weed infestation seems to have more influence on the end of the critical period than the start. Results from the trial established in plant cane showed that a longer period of control is required; the critical period starting earlier (6 WAP) and ending later (29 WAP). Results confirm that the traditional weed control method of applying a pre- and post-emergence herbicide treatment immediately after harvesting the crop in Mauritius is not justified. A more effective weed management strategy would be to delay the first treatment until the beginning of the critical period. This approach will enable effective weed control in ratoon cane with only one pre/post-emergence treatment per season in many areas of Mauritius.

CHAPTER 3

WEED COMPETITION IN SUGAR CANE: THE RELATIVE COMPETITIVENESS OF DIFFERENT WEED SPECIES

3.1 Introduction

Weed competition and management

Worldwide, 10% loss of agricultural production can be attributed to the competitive effect of weeds, in spite of intensive control measures in most agricultural systems (Zimdahl, 1980). According to Van Heemst (1985), without weed control, yield losses may range between 10% and 100%, depending on the competitive ability of the crop. Therefore, weed control or management is one of the key elements of most crop systems. The use of herbicides since the early 1950s has been one of the main factors enabling intensification of agriculture in developed countries (Kropff & Lotz, 1992b; Kropff & Walter, 2000).However, increasing herbicide resistance in weeds, the necessity to reduce costs of inputs, widespread concern about environmental side effects of herbicides, and, more recently, development of 'organic' farming, have resulted in the development of strategies for integrated weed management based on the use of alternative methods of weed control and rationalization of herbicide use. In Mauritius, the extremely high costs of weed control with herbicides and environmental concerns have necessitated and motivated the development of new weed management strategies. This approach involves changing from a system trying to eradicate all weeds from a sugar cane field, from planting or harvesting until complete canopy closure, to one based on minimising the effects of weeds only during the so-called critical period. This approach has been questioned by cane growers as trials have demonstrated that critical periods of weed competition from weed infestations in sugar cane in Mauritius only started 12 WAH and ended at 26 WAH under normal growth conditions in ratoon cane, whilst control measures may need to be maintained up to 29 weeks after planting in order to keep yield losses below 5% in plant cane (see Chapter 2). These weed-free periods are much shorter than the prolonged weed-free approach of growers in the past.

Development of weed management strategies based on critical periods of competition requires insight on crop-weed interactions within that period and into the dynamics of the weed populations, as the onset and end of those periods will be influenced by the rate of cane and weed growth, weed species, density of weed infestations, etc. Furthermore, as critical periods are theoretically based on

the length of a weed-free period during the critical period, the effect of a few weeds, left in the field because of the treatment applied prior to start of the critical period not being 100% efficient, needs to be known. Similarly, the impact of a few weeds emerging within the critical periods would require a decision to control or not based on their impact on cane growth and the costs of the treatment. The application of weed control thresholds in weed management decisions may also contribute to less herbicide use. The success of weed management programmes, which are directed towards minimizing herbicide use, largely depends upon the ability to predict the effects of weeds on crop yield (Kropff & Spitters, 1991). Weeds emerge in numerous flushes and the number of species present at any time in a sugar cane field may vary from 10 to more than 25; therefore, the relative competitiveness of each individual weed is important for predicting their impact on cane growth and yield.

Weed competition models

Many empirical models or regression equations have been developed to describe the responses of crop yield to one or more parameters with which weed infestation can be characterized; the models and their derivations have been reported by Kropff and Spitters (1991) and Kropff and van Laar (1993). The most important parameters in the models are weed density (Spitters, 1983; Cousens, 1985) and relative time of emergence of the weeds with respect to the crop (Hakansson, 1983; Cousens *et al*., 1987). Cousens (1985) introduced a hyperbolic yield loss - weed density equation which involves an additional parameter (compared to that of Spitters, 1983) that permits a maximum yield loss of less than 100% (m):

$$YL = a\, N_w / (1 + a\, N_w/m) \qquad \text{(Eqn 1)}$$

Where YL is the relative yield loss (%), N_w the weed density (plants m^{-2}), 'a' is the parameter that describes the effect of adding the first weed, and 'm' is the maximum relative yield loss.

Although this equation for the relationship fitted closely the experimental data and Cousens (1985) demonstrated the superiority of this equation over others by statistical means, the value of the parameter 'a'may vary greatly over years and locations, primarily as a result of differences in the period between crop and weed emergence and differences in growing conditions (Cousens *et al*., 1987; Kropff, 1988). In practice, weeds of the same species differ in size because weeds often emerge in flushes. This was addressed by an additional variable introduced in the hyperbolic yield loss - weed density equation to account for the effect of differences in the period between crop and weed

emergence (Hakansson, 1983; Cousens, 1987). Mathematically, Cousens (1987) formulated a regression model as follows:

$$YL = \frac{x\, N_w}{\text{Exp}(y \bullet T_{cw}) + (x/z)\, N_w} \qquad \text{(Eqn 2)}$$

In which YL is the relative yield loss, N_w is the weed density (plants m^{-2}), T_{cw} is the period between crop and weed emergence (days), x, y and z are non-linear regression coefficients. One problem of this approach was identified as the great need for data, because the effect of weed density has to be studied at a range of dates of weed emergence. Secondly, every flush of weeds has a different competitive ability and weed densities of different flushes have to be distinguished. Therefore, an alternative approach was needed to predict yield loss by weeds in weed management systems.

An alternative approach was suggested by Spitters and Aerts (1983) and Kropff (1988) after they showed that the competitive strength of a species is strongly determined by its share in leaf area at the moment when the canopy closes and interplant competition starts. Based on these findings, a new simple descriptive regression model for early prediction of crop losses by weed competition was developed by Kropff & Spitters (1991) as follows:

$$YL = \frac{q\, L_w}{1 + (q-1)\, L_w} \qquad \text{(Eqn 3)}$$

where YL is the yield loss, Lw is the relative leaf area of a weed species (weed leaf area / crop + weed leaf area) , and q the 'relative damage coefficient'. Parameter q is a measure of the competitiveness of the weed species with respect to the crop and is thus species specific. The relative damage coefficient q approaches unity and a linear relation (the diagonal 1:1 line; Fig 3.1) is obtained when the crop is grown at such a density that monoculture yield reaches its maximum value and the crop and weeds have identical physiological and morphological characteristics. When the weed is a stronger competitor than the crop, the relative damage coefficient 'q' will be larger than one and a convex curve is found above the diagonal. When the crop is a stronger competitor, q will be smaller than one and a concave curve is found under the diagonal line. The theoretical relations for different values of the relative damage coefficient q are shown in Fig 3.1. (copied from Kropff and Spitters, 1991).

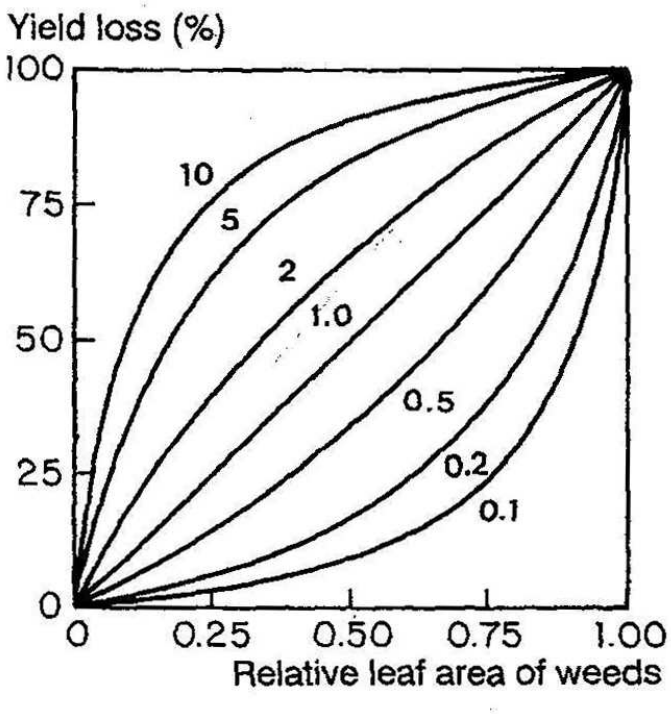


Fig. 3.1 Theoretical relationships between yield loss and relative leaf area of weeds at different values of the parameter q. (Copied from Kropff & van Laar, 1993; source: Kropff and Spitters, 1991)

The above regression model based on leaf area has been applied in sugar cane to study weed competition from different weed species under both glasshouse and field conditions. Seven trials have been carried out between 2000 and 2004; the objectives were to study and quantify competition from each of the species at varying weed densities on cane tillering and growth, and to compare the relative competitiveness of some weed species commonly found in sugar cane fields in Mauritius. As it was not possible to continue either the field experiments or those done in containers through to crop maturity, these calculations of relative competitive ability have been based on the growth of the crop attained at conclusion of trials. Such assessments may not fully reflect the competitive ability of the species tested, as later growth could increase (or decrease) the effect of the weeds on the crop. However, earlier work has shown that the main competitive effects of the weeds occur before canopy closure and so the competitive values calculated here would probably reflect most of their final competitive impact on the crop. Additionally, as weeds were introduced at almost the same growth stages and the period of weed infestations did not vary too much (13-21 weeks), it is assumed acceptable to use the results to compare the relative competitive abilities of the different species.

Eight weed species commonly found in sugar cane were chosen for comparing their relative competitiveness. *Ageratum conyzoides* and *Bidens pilosa* (L.) represented the broad-leaved weeds as

they are found under all agroclimatic zones of Mauritius and grow throughout the year. *Digitaria horizontalis, P. paniculatum, P. urvillei* and *Setaria barbata* (Lam.) Kunth are among the most important grass weeds found in sugar cane locally and are considered by growers as very important and relatively difficult to control (see Chapter I; MSIRI, unpublished data). *Paspalum commersonii* Lam. and *Paspalum conjugatum* Berg., though not very widely found, are important weeds in the humid and super-humid zones and were included mostly for comparisons with the two other *Paspalums*.

3.2 Materials and methods

This aspect of the study was aimed at exploring the impact of individual weed species on cane growth. Two approaches were used: a) field trials with specific weeds, b) container experiments with individual weed species. The former were difficult to manage in practice because of variability in densities and the uncertain success in establishing/transplanting the weeds. The latter had the drawback that as large containers were needed to provide appropriate conditions for the cane, only a limited number of treatments and replicates could be included. The experiments in the trays also had to be ended before the cane reached full maturity.

3.2.1 Trial I - Weed competition from *Ageratum conyzoides* under field conditions

Trial site and plant material

A trial was laid down at Belle-Rive (Humic Latosol soil group according to Parish & Feillafé, 1965) to study weed competition from *A. conyzoides* on young cane shoots. Cane variety M 3035/66 was planted at a row spacing of 1.5 m on 10 April 2000 and a reduced rate of diuron at 1.5 kg a.i. ha^{-1} was applied with a knapsack sprayer delivering 375 l ha^{-1} of spray solution at a working pressure of 300 kPa over the whole field one week after planting. Cane germination was homogeneous and a natural infestation of weeds comprising mainly *A. conyzoides* emerged from the month of July/August throughout the field and was left to grow and compete with the cane. Other broad-leaved weeds namely *Emilia sonchifolia* (L.) DC., *Lobellia cliffortiana* Linn., *Bothriospermum tenellum* (Horneur) Fish. and Mey, and *Youngia japonica* (Linn.) D.C., which were emerging among the *Ageratum*, were regularly hand-weeded.

Treatments and data collection

Unreplicated treatments with different levels of weed infestation, including weed-free plots, were identified in the field on 9 September 2000. Nine small plots of 2.0 m long and 1.5 m wide were marked and established at a distance of 0.75 m from the centre of the cane rows to each side of the plot. The weed infestation treatments consisted of two weed-free plots and seven others with varying densities of *A. conyzoides*.

The weeds were uprooted from each plot, roots removed and the above-ground plant material weighed (fresh weight); a sub-sample was then brought (in sealed plastic bags) to the laboratory for

leaf area measurements. The dewlap height of each cane shoot within the plots was measured before being cut for leaf area measurements in the field. Sub-samples representing approximately 20% by weight (fresh weight) of both cane and weed leaf biomass were taken for determination of leaf areas. The leaf area of cane was measured by a portable leaf area meter (Laser Area Meter C1-203 from CID, Inc., Vancouver, USA) and for *A. conyzoides*, a leaf area meter with a video camera (Area Measurement System from Delta-T Devices, Cambridge, UK) was used. The latter system was used for *A. conyzoides* as it was more practical to place all the small leaves continuously on the conveying system of the equipment. Small leaves are not easily handled through the portable leaf area meter.

Regression analysis

Regression curves were fitted for relationship between weed density and cane growth parameters (cane dewlap height and tillering) using the rectangular hyperbolic (linear-by-linear) function (y = A + B/(1+D*X) in Genstat (Genstat, 2005). The latter model is similar to the Cousens model (1985) – Eqn 1 - where A is the asymptotic yield loss and D is the yield loss at low densities, and B is the total yield loss taking into account the fact that yield loss at zero density is not always zero (Fig. 3.2).

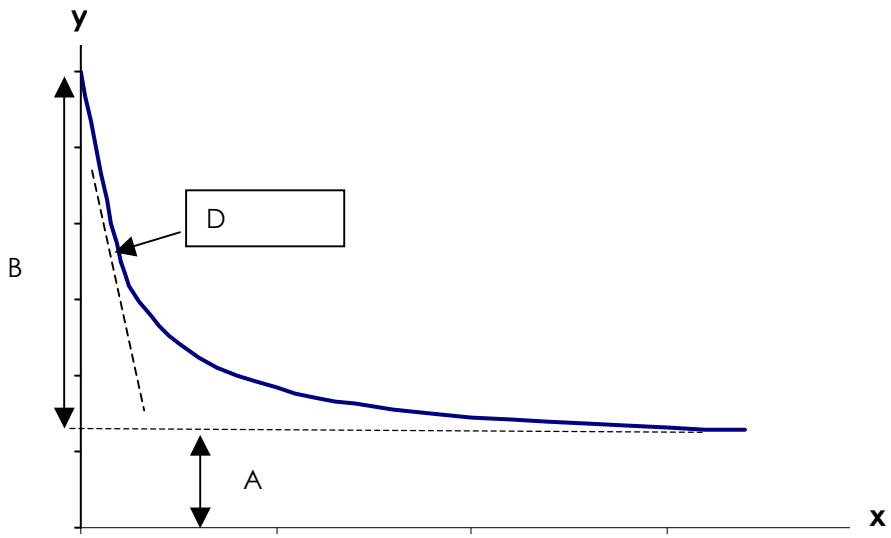


Fig. 3.2 Example of a rectangular hyperbolic (linear-by-linear) model showing parameters.

The difference between the total dewlap heights of each weed-infested treatment and the mean of the two weed-free plots was used to express the loss in total dewlap height due to weed competition. Leaf area data of cane and weeds were used to estimate the relative leaf areas, which together with the dewlap loss (cm m^{-2}) data were fitted into the weed competition regression model

(Eqn 3) developed by Kropff and Spitters (1991) using Genstat (Genstat, 2005) to estimate a relative damage coefficient ('q' value) for *A. conyzoides*.

3.2.2 Trial II - Competition from *Bidens pilosa, Digitaria horizontalis* and *Paspalum urvillei* on sugar cane grown in trays

Plant material

A glasshouse trial was established to study competition of *B. pilosa*, *D. horizontalis* and *P. urvillei* on young sugar cane shoots. Conditions inside the glasshouse were similar to those outside as all openings (wire mesh to prevent insects, etc.) were left opened to maintain almost the same temperatures. Sugar cane was planted on 14 April 2001 in trays 1 m x 0.4 m x 0.3 m and filled with soil (Humic Latosols according to Parish and Feillafé, 1965) collected in fields at Réduit Experiment station. All trays were irrigated by applying manually the same amount of water to keep the soil humid and avoid any water stress on the crop. No extra fertilizer was added as soil analysis had shown a sufficient amount of NPK was present.

Ten two-budded cane setts of variety R 570 were planted in each tray, in double rows in the centre of the tray. Eight weed densities (7 + 1 weed-free control) were established for each weed. Seeds of *B. pilosa* were sown directly in the trays on 10 May 2001 at increasing densities and some thinning was carried out after germination. For *D. horizontalis* and *P. urvillei*, young plants were uprooted from abandoned fields and leaves were pruned to reduce transpiration at transplanting. The two grasses were transplanted on 15 May 2001 at densities of 13, 23, 30, 35, 45, 55 and 68 plants m^{-2}.

Cane measurement and data collection

Cane measurements (no of shoots/tray and dewlap height of individual shoots) were carried out on 8 June 2001 (3 weeks after transplanting – WAT), 22 June 2001 (5 WAT), 6 July 2001 (7 WAT), 23 July 2001 (10 WAT) and 22 August 2001 (14 WAT). All trays (cane shoots and weeds) were harvested on 7 September 2001 for leaf area and dry weight measurements. The leaf areas of cane and *P. urvillei* weeds were measured with the CID portable leaf area meter whereas for *B. pilosa*, the Delta-T leaf area meter with a video camera was used (see Trial I for details). Sub-samples of the plant material were subsequently dried at 105 ^{o}C for 48 hours before being weighed. The estimation of the relative leaf area of *D. horizontalis* was not possible as the small leaves had started to senesce and

their small size prevented use of the portable leaf area meter; the relative dry weights were instead calculated (weed dry weight / (weed dry weight + crop dry weight).

Statistical design and regression analysis

Due to the limited space in the greenhouse, the treatments were not replicated; all treatments with same weed species were blocked together. Leaf area data and the total dewlap height loss (loss relative to total dewlap height (cm m^{-2}) of weed-free treatment) were fitted to the regression analysis or weed competition model (Eqn 3) developed by Kropff and Spitters (1991) using Genstat (Genstat, 2005) for estimating q values for the respective weed species.

3.2.3 Trial III - Weed competition from *Paspalum paniculatum* and *Paspalum urvillei* on sugar cane under field conditions

Plant material

A field experiment was initiated in October 2001 at Réduit, L soil group (Parish & Feillafé, 1965), to study competition on sugar cane from *P. paniculatum* and *P. urvillei*. Sugar cane, variety R 570, was planted on 7 September 2001 using three-eyed cuttings obtained from a plant cane field on the station at a row spacing of 1.5 m. Young plants of the two weeds were collected from abandoned fields in the Belle-Rive regions and were transplanted after pruning of the upper part of the leaves to reduce transpiration. Weed control in the plots was achieved by applying a selective treatment consisting of atrazine at 2.0 kg a.i. ha^{-1} after transplanting of weeds and by regular manual weeding of emerged weeds (mostly grasses). Other agronomic practices were the same as in commercial sugar cane crops.

Treatments and experimental layout

Paspalum urvillei and *P. paniculatum* were both transplanted at densities of 6.7, 10, 15, 20 and 33.3 plants m^{-2} on 13 October 2001 (5 weeks after planting cane). A weed-free plot was also included. Each plot consisted of three cane rows of 1.4 m long with a row spacing of 1.6 m. The statistical design was a split-plot; main plots consisted of the two weeds, sub-plots were six weed densities. Each treatment was replicated three times.

Data collection and regression analysis

A first cane measurement was made on 19 December 2001 (9 WAT). Cane stalk number and height, together with leaf area measurements of cane and weeds with the portable leaf area meter were made during the first week of February 2002 (16 WAP). Sub-samples were dried at 105^{o}C for 48 hours before being weighed again.

The relative leaf area was calculated from the cane and weed leaf area data, and the effect of competition on cane as total dewlap height loss (loss relative to total dewlap height (cm m^{-2}) of the weedfree treatment). Regression curves were fitted for relationships between weed density and cane growth parameters (cane dewlap height and tillering) using the rectangular hyperbolic (linear-by-linear) function (y = A + B/(1+D*X) in Genstat (Genstat, 2005) (see Trial I).

The relative leaf area and dewlap loss data were subjected to non-linear regression analysis after weed competition model (Eqn 3) developed by Kropff and Spitters (1991) using Genstat (Genstat, 2005) to estimate q values for the two weed species.

3.2.4 Trial IV - Competition from *Bidens pilosa* on sugar cane grown in trays (glasshouse)

Plant material

A trial to study competition of *B. pilosa* on young sugar cane shoots was established in the glasshouse in April 2002. The conditions inside the glasshouse, irrigation regime and fertilization were similar to those described for Trial II. Ten one-eyed cuttings of cane variety R 570 were planted in double rows in the centre of a fibreglass tray on 18 April 2002. The size of each tray was 1.0 m x 0.4 m x 0.3 m and it was filled with soil (Humic Latosols according to Parish and Feillafé, 1965) collected in fields at Réduit Experiment station. Seeds of *B. pilosa* were sown on the same date sugar cane was planted, and were allowed to germinate in trays before being transplanted on 25 May 2002 (5 weeks after planting cane).

Treatments and experimental design

A completely randomized block design with three replicates was used; each block had eight trays consisting of six weed densities, namely 10, 20, 40, 60, 80 and 100 plants m^{-2} and two weed-free trays. The weeds were distributed evenly in the trays. Both cane and weed were irrigated regularly to field capacity and any other weed species emerging was hand-weeded.

Cane measurement and data collection

Cane measurements (number of shoots per tray and dewlap height of individual shoots) were taken on 4 June 2002 (2 WAT), 24 June 2002 (4 WAT), 16 July 2002 (8 WAT), 19 August 2002 (12 WAT) and 9 September 2002 (16 WAT). Cane shoots and weeds in all trays were harvested on 9 September 2002 for leaf area and dry weight measurements. The leaf areas of cane were measured by the CID portable leaf area meter, whereas for *B. pilosa*, a Delta-T leaf area meter with a video camera was used (see Trial I for details).

Statistical design and regression analysis

Data collected at each cane measurement date were used to conduct analysis of variance (ANOVA); the mean dewlap heights and number of shoots were compared to the weed-free treatments. All statistical analyses were carried out using Genstat (Genstat, 2005).

Regression curves were fitted for relationships between weed density, or the relative leaf area of the weed, and cane growth parameters (dry weight and cane dewlap height) using the rectangular hyperbolic (linear-by-linear) function (y = A + B/(1+D*X) in Genstat (Genstat, 2005) (see Trial I). Leaf area data and the total dewlap height loss (loss relative to total dewlap height (cm m^{-2}) of weed-free treatment) were fitted into the weed competition model (Eqn 3) developed by Kropff and Spitters (1991) using Genstat (Genstat, 2005) for estimating q values for the respective weed species.

3.2.5 Trial V - Weed competition from *Paspalum paniculatum* and *Paspalum urvillei* on sugar cane grown under glasshouse conditions

Plant material

A trial was established in the glasshouse where competition from two *Paspalum* species on sugar cane was compared. The conditions in the glasshouse, irrigation regime and fertilizer application were similar to those described for Trial II. Young plants of *P. urvillei* and *P. paniculatum* were collected from abandoned fields in the Belle-Rive region and were transplanted in trays planted with two-eyed cuttings of cane variety R 570.

Treatments and experimental layout

Sugar cane was planted on 19 October 2002; six two-eyed cutting were planted in trays 1.0 m X 0.4 m X 0.3 m. The weeds were both transplanted on 4 December 2002 at densities of 5, 10, 20, 30, 40 and 50 plants m^{-2}; the upper leaves of the weeds were cut off to reduce transpiration. Weed-free trays were also included. The statistical design was a split-plot with two replicates; the main plots consisted of the two weeds and the sub-plots of the eight weed infestation treatments (six weed densities + 2 weed-free trays per block).

Data collection and regression analysis

Measurements of cane shoots in each tray were made on 30 December 2002 (4 WAT), 23 January 2003 (8 WAT) and on the final day of the experiment, 6 March 2003 (14 WAT). On the final day, samples were also taken for dry weights and leaf areas of cane and weeds; leaf area was measured with the portable leaf area meter. The sub-samples were weighed and dried for 48 hours at 105^{o}C before being weighed again.

Relative leaf area was calculated from the cane and weed leaf area data, and the effect of competition on cane as total dewlap height loss (loss relative to total dewlap height (cm m^{-2}) of weed-free treatment). Regression curves were fitted for relationships between weed density, or relative leaf area, and cane growth parameters (cane dewlap height or loss in dewlap heights) using the rectangular hyperbolic (linear-by-linear) function (y = A + B/(1+D*X) in Genstat (Genstat, 2005) (see Trial I).

Relative leaf area and dewlap loss data were subjected to non-linear regression analysis according to weed competition model developed by Kropff and Spitters (1991) and using Genstat (Genstat, 2005) to estimate q values for the two weed species.

3.2.6 Trial VI - Weed competition from *Paspalum commersonii* and *Paspalum conjugatum* on sugar cane grown under glasshouse conditions

Plant material

A glasshouse trial (under same conditions as described for Trial II) was established at Réduit experiment station to compare weed competition from two other *Paspalum* species, namely *P. commersonii* and *P. conjugatum* on sugar cane. *Paspalum commersonii* is a perennial grass reaching a height between 30 and 75 cm and characterized with a leaf blade 15 to 30 cm x 1.2-1.5 cm (Mc

Intyre, 1991). *Paspalum conjugatum* is more of a creeping perennial, with long stolons, rooting at the nodes, and with shorter leaves 5-10 cm x 0.6 to 1.3 cm. Young plants of the two species were collected from abandoned fields in the Belle-Rive region and were transplanted in trays pre-planted with two-eyed cuttings of cane variety R 570. The cane setts were obtained from a field on the station planted 11 months earlier; the cane setts were treated (cold dip) against 'pineapple' disease (caused by *Ceratocystis paradoxa*) with a solution of benomyl at 0.3 g per litre.

Treatments and experimental layout

Sugar cane was planted on 19 December 2003; six two-eyed cutting were planted in trays, each 1.0 m X 0.4 m X 0.3 m, placed in the centre of the glasshouse on concrete blocks to have approximately 30 cm space from the floor. The filling material used in the trays consisted of soil (L soil group according to Parish and Feillafé, 1965) collected from fields on the station. The weeds were both transplanted on 30 January 2004 at densities of 10, 20, 40, 60 and 80 plants m^{-2}; a weed-free treatment was also included. The statistical design was a split-plot with two replicates; the main plots consisted of the two weeds and the sub-plots represented six weed densities (five weed densities + 1 weedfree tray per block). All trays were regularly irrigated to field capacity.

Data collection and analysis

Measurements of cane shoots in each tray were made on 21 February 2004 (3 WAT), 25 March 2004 (8 WAT) and 4 May 2004 (13 WAT). The experiment was stopped on 13 May 2005 when all cane shoots and weeds were harvested for dewlap height and number of shoots, dry weight and leaf area measurements. Leaf area of cane and weed was measured with the portable leaf area meter.

The effect of competition on cane as total dewlap height loss and regression curves were fitted for relationships between weed density, or relative leaf area of weed, and cane growth parameters (cane dewlap height) as described for Trial III. Similarly, q values for the weed species were estimated as described for the previous trials.

3.2.7 Trial VII - Weed competition from *Ageratum conyzoides* and *Setaria barbata* on sugar cane grown in trays outdoors

Plant material

A trial was established in 2004 at Réduit experiment station to compare weed competition from *A. conyzoides* and *S. barbata* on young sugarcane shoots grown in trays placed outdoors. *Ageratum conyzoides* is an annual broad-leaved weed which can reach 30 to 50 cm high while *S. barba*ta is a tussocky annual, initially prostrate, then erect and reaching 90-100 cm in height (Mc Intyre, 1991). Both weed species are more commonly found in the humid and super-humid areas of Mauritius. Young plants of the two weeds were collected from abandoned fields in the Belle-Rive region and were transplanted in trays pre-planted with two-eyed cuttings of cane variety R 575. The cane setts were obtained on the station in a plant cane field; the cane setts were treated (cold dip) against 'pineapple' disease (caused by *Ceratocystis paradoxa*) with a solution of benomyl at 0.3 g per litre. The filling material used in the trays consisted of soil (L soil group according to Parish and Feillafé, 1965) collected from fields on the station. No additional fertilizers were required as soil analysis showed sufficient amount of NPK for cane development for the duration of the trial.

Treatments and experimental layout

Sugar cane was planted on 25 March 2004; six two-eyed cuttings were planted in trays, each 1.0 m x 0.4 m x 0.3 m, placed outdoors on concrete blocks to be approximately 20 cm from the ground. The weeds were both transplanted on 15 and 16 April 2004 at five densities, namely 10, 20, 40, 60 and 80 plants m^{-2}; a weed-free treatment was also included. The statistical design was a split-plot with four replicates; the main plots consisted of the two weeds and the sub-plots of six weed densities (five weed densities + 1 weed-free). All trays were regularly irrigated to field capacity and any other weed species emerging in the trays were regularly hand-weeded.

Data collection and regression analysis

Measurements of cane shoots in each tray were made on 18 May 2004 (4 WAT) and 25 June 2004 (9 WAT). The experiment was stopped on 16 July 2004 (13 WAT) when all cane shoots and weeds were harvested for dewlap height, tiller density, dry weight and leaf area measurements. Leaf area of cane and *S. barbata* was measured with the portable leaf area meter, whereas that of *A. conyzoides* was estimated from digital photos of known amount (dry weight basis) of leaves placed on an A4 white

paper and the area extrapolated from readings obtained using the Aequitas^{TM} Image Analysis software (http://www.aequitas.co.uk). The digital photos were analysed using the Aequitas® software and the leaf area was estimated by assessing the green pixels.

The effect of competition on cane as total dewlap height loss (loss relative to total dewlap height (cm m^{-2}) of weedfree treatment), regression curves showing relationships between weed density or relative leaf area of the weeds and cane growth parameters (cane dewlap height, leaf area of cane and weed and loss in dewlap heights), and estimation of q values for the two weed species were carried out in the same manner as for Trial IV.

3.3 Results

3.3.1 Trial I - Weed competition from *Ageratum conyzoides* under field conditions

3.3.1.1 Cane stalk elongation and total dewlap height

The density of *A. conyzoides* varied between 11 and 44 plant m^{-2}. Although cane growth was relatively slow due to the low temperatures and reduced sunshine as a result of regular rainfall that was experienced during that period of the year at Belle Rive, a clear relationship between *A. conyzoides* plant density and cane total dewlap height and tillering was observed (Fig. 3.3). The response curves fitted by the rectangular hyperbolic equation showed that the total dewlap height decreased with increasing weed density, and this decrease was mainly due to a reduction in tillering with increasing weed density. The mean dewlap height of the stems of the crop was not affected by the presence of weeds.

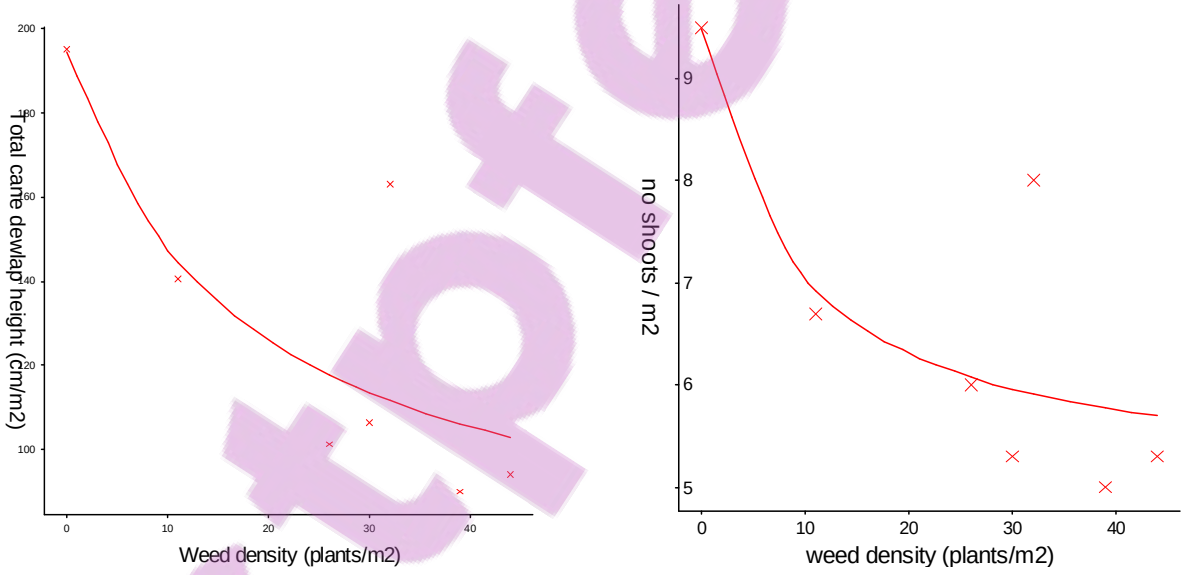


Fig. 3.3 Relationship between the density (plants m^{-2}) of *A. conyzoides* and *left* - total dewlap height (cm m^{-2}) and *right* - tillering (no. of shoots m^{-2}) of sugar cane. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density; for total dewlap R^2= 0.49 and parameter values D= 0.06 (0.121), B= 126 (84.9) and A= 68.1 (85.8), and for shoot density R^2= 0.50, D= 0.12 (0.241), B= 4.5 (2.23) and A= 4.98 (2.01). (Values in parentheses are standard error of the estimates).

3.3.1.2 Relative 'competitiveness' of *A. conyzoides*

Data on leaf area of weeds revealed a relatively good correlation between weed density and leaf area (Fig. 3.4). In general, the leaf area of cane was found to decrease with increasing leaf area of the weed (Fig. 3.4).

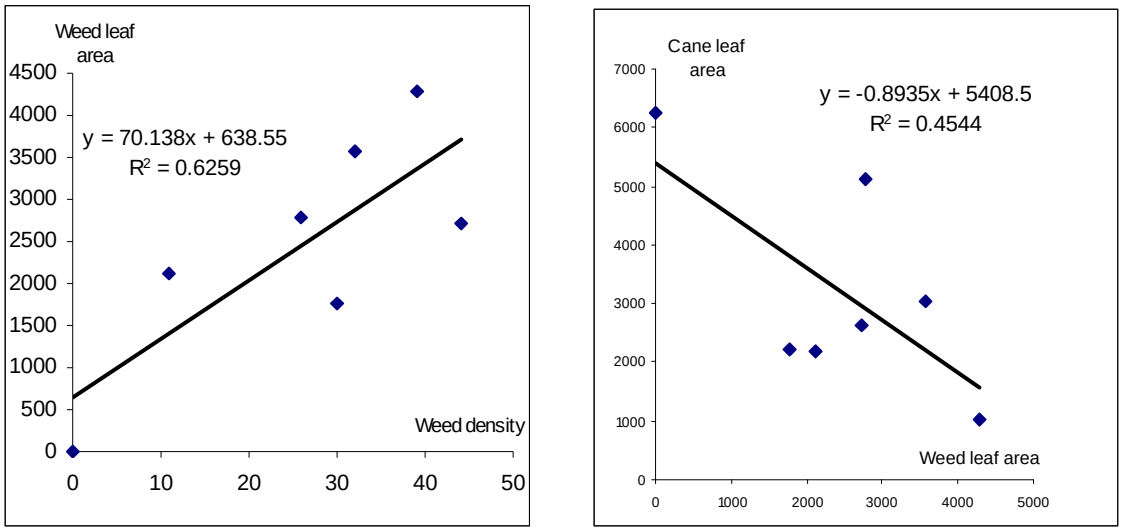


Fig. 3.4 Relationships between the density (plants m^{-2}) and leaf area (cm^2 m^{-2}) of *A. conyzoides* (left) and between the leaf area of *A. conyzoides* (cm^2 m^{-2}) and leaf area of sugar cane (cm^2 m^{-2}) (right)

The relative leaf area (L_w) and yield loss (expressed as loss in dewlap height compared to the weed-free control) fitted the weed competition model by Kropff and Spitters (1991) quite well; a relative competitiveness value 'q' of 0.88 (*s.e.* = 0.154) was obtained for *A. conyzoides*. This value showed that although severe competition occurred, the weed was less competitive (q value less than one) than sugar cane.

3.3.2 Trial II - Competition from *Bidens pilosa, Digitaria horizontalis* and *Paspalum urvillei* on sugar cane grown in trays

3.3.2.1 Density of *B. pilosa* and weeds development

Bidens pilosa was tested at higher densities than *D. horizontalis* and *P. urvillei*. While the seven densities (13, 23, 30, 35, 45, 55 and 68 plants m^{-2}) of the two grasses were set at transplanting, the final densities of *B. pilosa* were 70, 92, 98, 120, 124, 140 and 197 plants m^{-2}. *Paspalum urvillei* showed a better consistency in development (increasing weed biomass and leaf area) as compared to *B. pilosa* which senesced at the end, whilst *D. horizontalis* also showed some yellowing and drying-off of leaves towards the end of the trial.

3.3.2.2 Effect of weed competition on tillering and cane growth

Cane measurements showed that germination and tillering were relatively slow due to the low temperatures during that period of the year; the number of shoots did not increase during the assessment period in the weed-free treatments. Weed competition from *B. pilosa* seemed to have little effect on cane tillering except at the four highest densities (Fig. 3.5). There was also a tendency toward a reduction in the number of cane shoots with increasing density of *D. horizontalis*. *Paspalum urvillei* at the densities tested showed no adverse effect of weed competition on tillering.

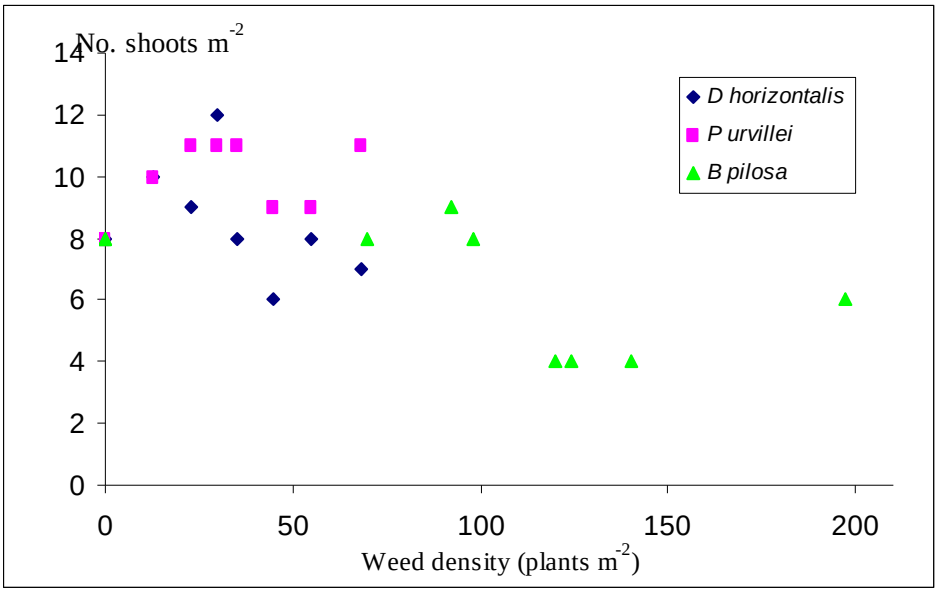


Fig. 3.5 Effect of different weed densities of *B. pilosa*, *D. horizontalis* and *P. urvillei* on cane tillering 14 WAT.

The mean dewlap height (cm plant^{-1}) of sugar cane seemed to be less affected by *B. pilosa* compared to *P. urvillei* and *D. horizontalis* (Fig. 3.6). Some lower weed densities, particularly for *B. pilosa* could have caused an etiolating effect of the cane stalks. *Paspalum urvillei* possibly caused a slight effect on cane elongation as compared to the other two species. The lower mean dewlap height for *P. urvillei* was also linked to the relatively higher number of cane stalks. As the interaction between the number of shoots and mean height of each stalk may vary with weed species and weed densities; the use of the total dewlap heights to compare any effect of weed competition on cane growth appeared to be more appropriate.

The only adverse effect of competition from *B. pilosa* on the total dewlap height of sugar cane was observed at the four higher weed densities (120-197 plants m^{-2}) tested, the lower densities showed

no effect (Fig. 3.7). Similarly the two grasses which were transplanted at a maximum density of 70 plants m^{-2} showed only marginal competition effect on total dewlap height.

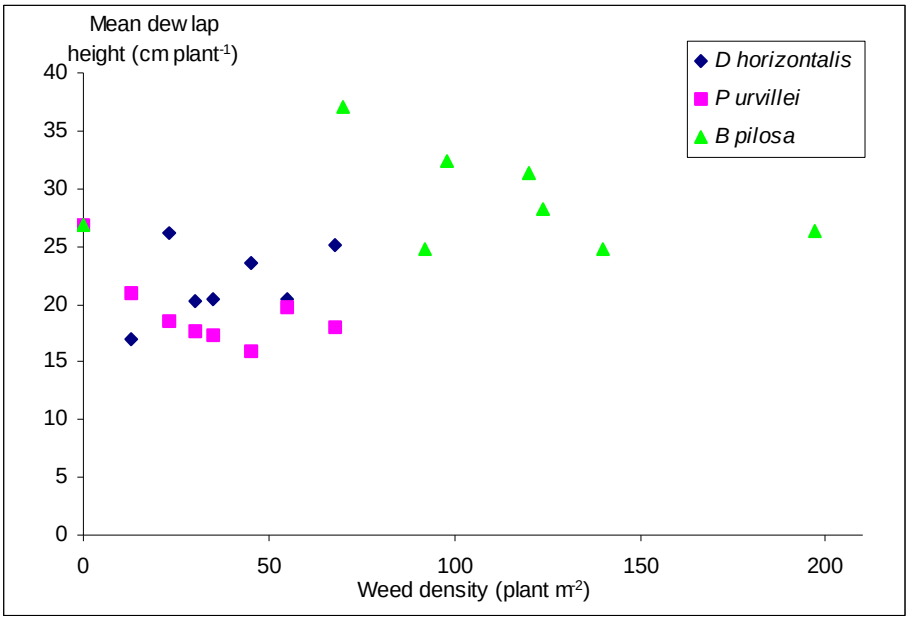


Fig. 3.6 Effect of different weed densities of *B. pilosa*, *D. horizontalis* and *P. urvillei* on the mean dewlap height (cm $shoot^{-1}$) of cane 14 WAT.

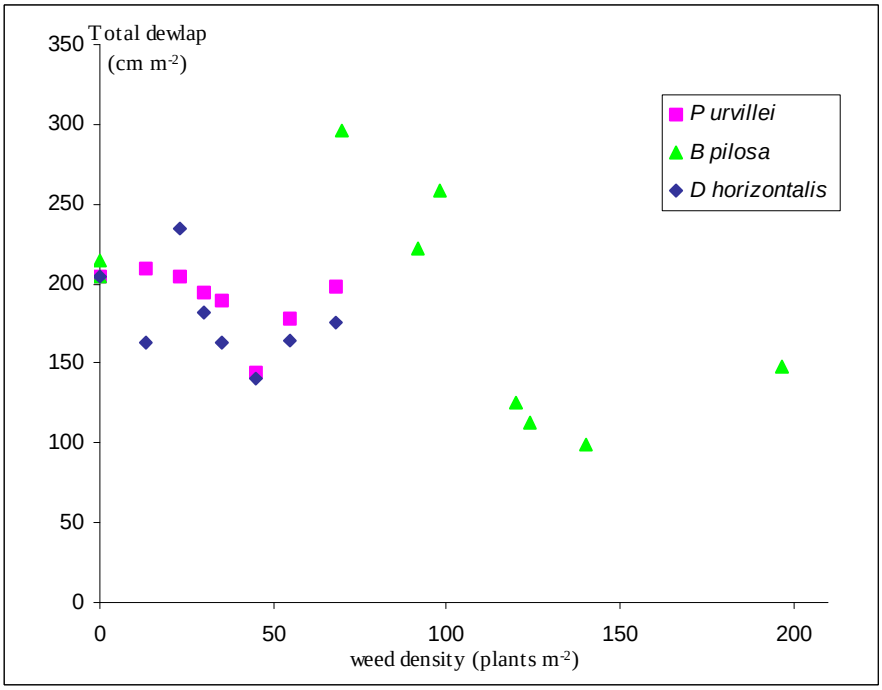


Fig. 3.7 Effect of different weed densities (plants m^{-2}) of *B. pilosa*, *D. horizontalis* and *P. urvillei* on total dewlap height (cm m^{-2}) of cane 14 WAT.

3.3.2.3 Effect of weed competition on leaf area of weed and cane

The densities of *B. pilosa* were higher than those of the two grasses and consequently produced more leaf area than the two grasses (Table 3.1). Although the leaf area of *B. pilosa* was three to four times higher than that of *P. urvillei*, its relative leaf area (L_w) was only twice that of *P. urvillei* (Table 3.1). This may be explained by a more important reduction in leaf area of cane when the latter was in competition with *P. urvillei*. The relative dry weights for *D. horizontalis* were also found to be lower than that of the broad-leaved weed.

Table 3.1 Effect of weed competition 14 WAT on leaf area (cm^2 m^{-2}) of cane and weeds for *B. pilosa* and *P. urvillei* and the relative leaf area (L_w) for *B. pilosa*, *P. urvillei* and *D. horizontalis*

Weed density (plants m^{-2})	Leaf area (cm^2 m^{-2})				Dry wt (g m-2)		L_w (relative leaf area)		
	B. pilosa		*P. urvillei*		*D.horzontalis*				
	weed	cane	weed	cane	weed	Cane	*B. pilosa*	*P. urvillei*	*D. horizontalis**
Weed-free	-	9148	-	9148	-	331	-	-	-
13			3648	9805	233	231		0.27	0.50
23			4550	8498	171	354		0.35	0.33
30			6934	7404	48	322		0.48	0.13
35			9166	5810	38	206		0.61	0.16
45			8061	5526	62	209		0.59	0.23
55			6783	7150	56	211		0.49	0.21
68			6014	7350	54	205		0.45	0.21
70	29550	6775					0.81		
92	12784	6536					0.66		
98	16553	7726					0.68		
120	16081	7092					0.69		
124	13403	4119					0.76		
140	11743	2460					0.82		
197	16640	5698					0.74		

* Based on dry weights for *D. horizontalis* and cane shoots

The regression model developed by Kropff and Spitters (1991) for early prediction of crop losses by weed competition and which relates yield loss (YL) to relative weed leaf area (L_w -expressed as weed leaf area over total leaf area of crop and weed) shortly after crop emergence, was used to compare the 'relative damage coefficient' of the weed species. Although the relative leaf area (L_w), mean height and dry weight of *B. pilosa* appeared higher than the two grasses; its q value (relative damage coefficient) seemed to be lower than the two grasses (Table 3.2). However, the variability in the data, particularly with respect to *D. horizontalis*, was high and the q values may not be statistically different. The q value for *D. horizontalis* may not be reliable as its estimation was based on the

assumption that the leaf areas of the weed and sugar cane were proportional to their dry weight. The higher competitiveness of *P. urvillei* compared to *B. pilosa* indicated that other mechanisms of competition to that for light may be involved with the grasses. This was emphasized for *D. horizontalis* which, irrespective of weed density, showed chlorosis of cane leaves (Fig. 3.8).

Table 3.2 Relative weed competitiveness of three weed species on early growth of sugar cane planted in trays

Weeds	Dry weight/tray (g)	Mean weed height (cm)	Lw (mean)	q value
B. pilosa	83- 236	60- 85	0.741	0.06 (0.063)
D. horizontalis	14- 80	50	0.235*	0.37 (0.245)
P. urvillei	17- 49	70	0.464	0.15 (0.039)

* estimated from relative dry weights, values in parentheses represent standard error of q values

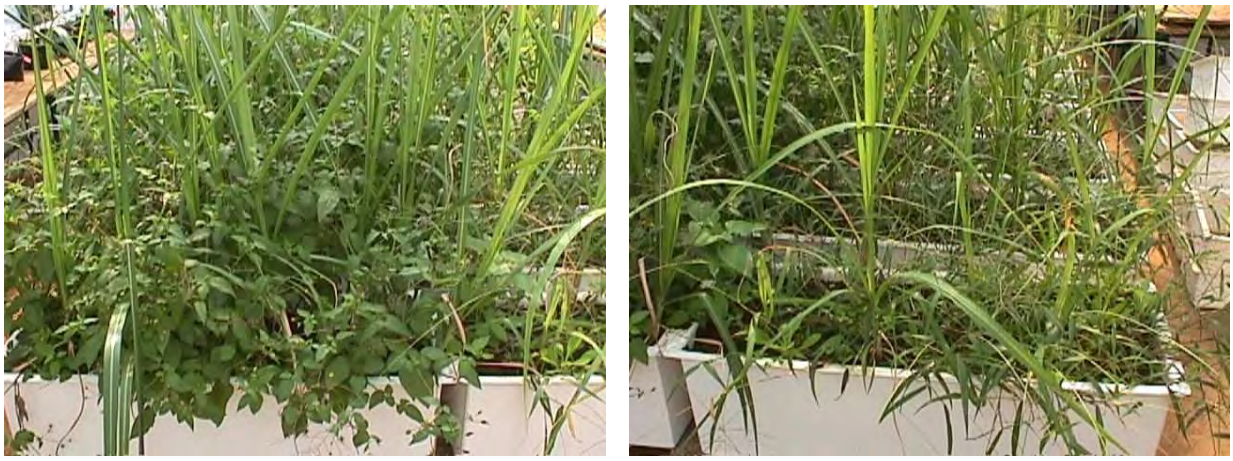


Fig. 3.8 Weed competition from *D. horizontalis* (right) causing cane leaf chlorosis compared to competition from *B. pilosa* (left).

3.3.3 Trial III - Weed competition from *Paspalum paniculatum* and *Paspalum urvillei* on sugar cane under field conditions

3.3.3.1 Effect of *P. paniculatum* and *P. urvillei* on cane growth (9 WAT)

The first cane measurement made at 9 WAT revealed that neither *P. paniculatum* nor *P. urvillei* had an effect on the mean dewlap height of the cane stalks. Similarly, no adverse effect, except a reduction in number of shoots at the highest density of *P. urvillei*, was noted on cane tillering (Table 3.3).

Table 3.3 Effect of *P. paniculatum* and *P. urvillei* on cane growth (9 WAT)

Weed densities (plants m^{-2})	*P. paniculatum*		*P. urvillei*	
	No. Shoots (shoot m^{-2})	Mean dewlap height (cm $shoot^{-1}$)	No. Shoots (shoot m^{-2})	Mean dewlap height (cm $shoot^{-1}$)
0	7.4	11.8	6.9	11.2
6.7	8.1	11.2	6.9	10.1
10	6.0	11.3	7.1	11.2
15	6.7	12.8	5.2	10.1
20	6.0	12.1	6.2	12.1
33.3	9.1	9.8	3.6	12.3

Values are means of three replications. Standard error (s.e.) of difference of means for number of shoots with same level of weed (d.f. = 20) = 1.51. Standard error (s.e.) of difference of means for mean dewlap with same level of weed (d.f. = 20) = 1.34.

3.3.3.2 Effect of *P. paniculatum* and *P. urvillei* on cane growth (16 WAT)

Cane dewlap height at 16 WAT was fitted against weed density of *P. paniculatum* and *P. urvillei* using the rectangular hyperbolic model (Fig. 3.9 & Table 3.4). *Paspalum urvillei* showed a relatively good fit and was found to cause a reduction in dewlap height with increasing weed density. The response by *P. paniculatum* was poor.

The reduction in cane growth by *P. urvillei* was caused by a reduction in cane shoot density with increasing weed density (Fig. 3.9). *Paspalum paniculatum* showed no effect on cane tillering. The difference between the two weed species may be due to a more consistent growth and establishment of *P. urvillei* after transplanting.

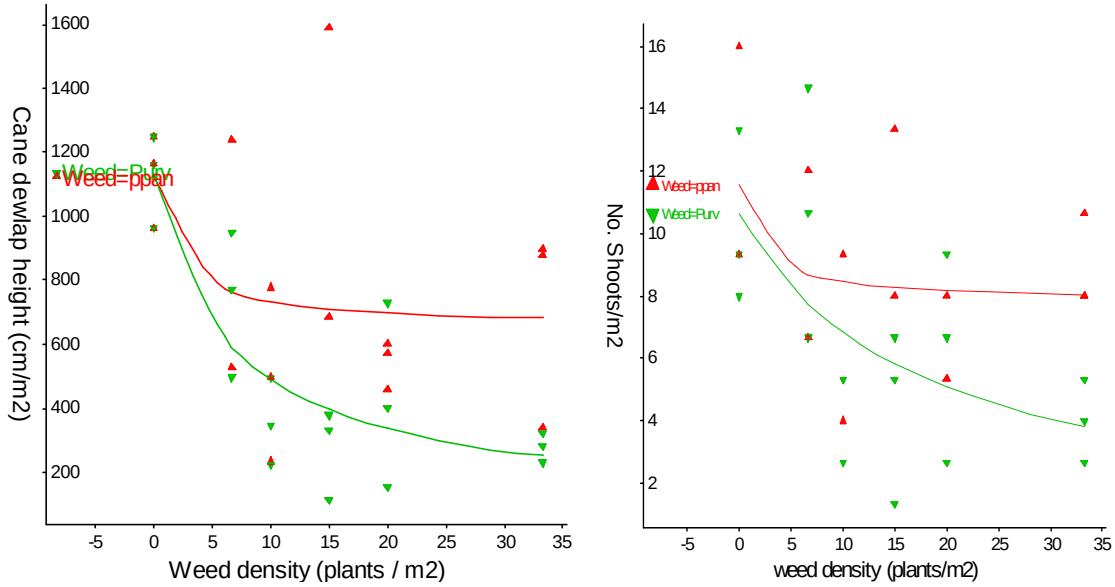


Fig. 3.9 Relationships between the density (plants m^{-2}) of *P. paniculatum* (red) and *P. urvillei* (green) and ***left***- total dewlap height (cm m^{-2}) and ***right***- tillering (no. of shoots m^{-2}) of sugar cane 16 WAT. Response curves are those from parameters given in Table 3.4.

Table 3.4 The parameters of the response curves showing relationship between weed density and total cane dewlap height and number of shoots using the rectangular hyperbola model (y= A + B/(1+D*x) where x= L_w. Values in parentheses are standard errors of parameter values.

	Weed	R^2	D	B	A
Dewlap height	*P. paniculatum*	0.08	0.51 (1.81)	468 (264)	657 (209)
	P. urvillei	0.68	0.16 (0.165)	1045 (324)	90 (297)
No of shoots	*P. paniculatum*	0.07	0.51 (2.40)	3.72 (2.83)	7.85 (2.24)
	P. urvillei	0.28	0.06 (0.089)	10.3 (6.64)	0.30 (6.93)

3.3.3.3 Effect of *P. paniculatum* and *P. urvillei* on leaf area development and relative competitiveness (16 WAT)

Paspalum urvillei produced a higher leaf area than *P. paniculatum* for the same densities (Table 3.5). The absence of any significant difference between the various densities was, most probably, due to the relatively high coefficient of variation and the inconsistency in the development of the weed infestations with respect to their initial densities. In general, it seemed that the leaf area of cane was lowered more when in competition with *P. urvillei* as compared to *P. paniculatum*. This may be due to greater competition for light as the mean height (top of leaves) of the *P. urvillei* was 100 cm while

those of *P. paniculatum* varied between 45 and 55 cm. Lower cane leaf area with *P. urvillei* may have also resulted from the relatively reduced number of tillers in those plots.

Table 3.5. Effect of *P. paniculatum* and *P. urvillei* on leaf area development of cane and weeds (16 WAT)

Weed densities (plants m^{-2})	Leaf area (cm^2 m^{-2})			
	P. paniculatum		*P. urvillei*	
	weed	cane	weed	cane
Weed-free		33512		31082
6.7 m^{-2}	9346	19589	22414	31622
10 m^{-2}	12568	17020	33092	15081
15 m^{-2}	8208	30647	32452	14349
20 m^{-2}	18014	15047	36284	19907
33.3 m^{-2}	25721	24509	31517	13754
S.e.d. (d.f.)	*5906.3(8)*	*9678.1(10)*	*11984(8)*	*7435(10)*

(Values are means of three replications)

The mean relative leaf area (L_w) of *P. urvillei* compared to sugar cane was 0.58 (s.e.= 0.063) and was greater than that of *P. paniculatum* (0.39 , s.e.= 0.065). Despite variability in the data, a reasonably good relationship between the dewlap height and the relative leaf area (L_w) was obtained for both weed species (Fig 3.10). The improvement in the relationship describing competition from the two *Paspalum* species with the L_w confirms that the densities at transplanting and development thereafter were not the same and so the link between weed density and dewlap height is likely to be compromised. The use of the L_w also considers any interaction between leaf area of the crop and the weed.

Fitting the relative leaf area and dewlap height reduction within each plot in the regression model developed by Kropff and Spitters (1991), a 'q' value of 0.20 (s.e.= 0.102) was obtained for *P. urvillei* compared to 'q' = 0.44 (s.e.= 0.262) for *P. paniculatum*. This showed *P. paniculatum* to be relatively more competitive than *P. urvillei* although the response curves in Fig. 3.10 showed the converse response. The greater competitiveness of *P. paniculatum* may be due to its lower leaf area having as much effect on dewlap height as the higher leaf area of *P. urvillei* or is due to the presence of a different mechanism of competition such as root effects. Both weeds proved to be a weaker competitor ($q < 1.0$) than sugar cane.

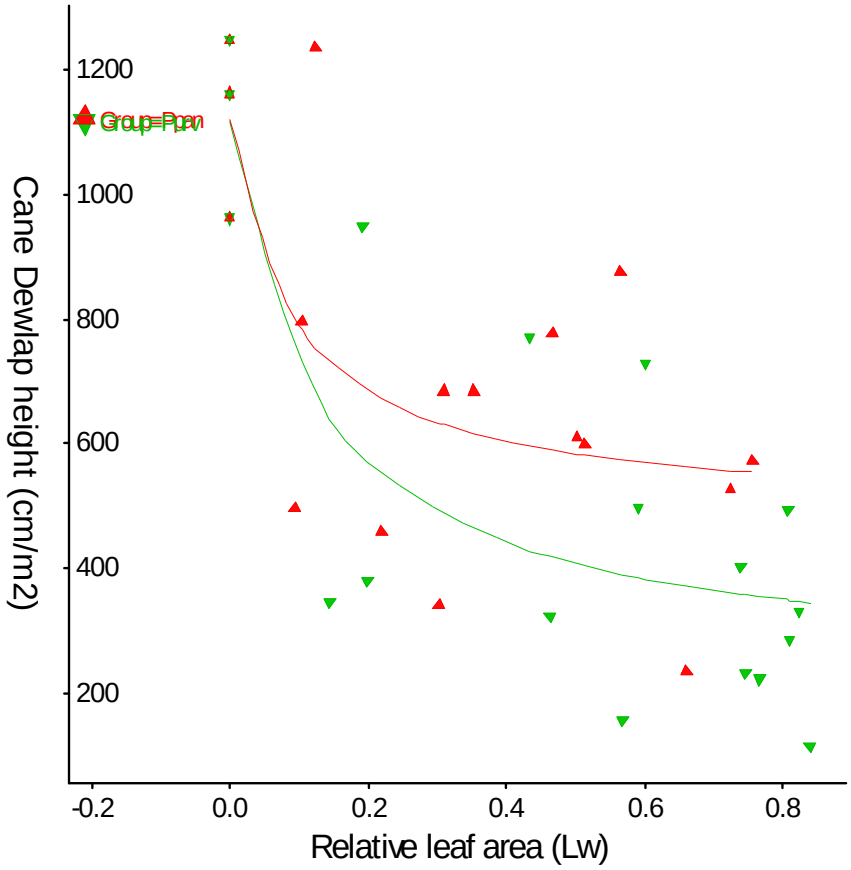


Fig. 3.10 Relationship between the total cane dewlap height (cm m^{-2}) and the relative leaf area of *P. paniculatum* (red) and *P. urvillei* (green) at 16 WAT. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density; for *P. paniculatum* R^2= 0.56 and parameter values D= 11.0 (13.9), B= 636 (202) and A= 487 (168), and for *P. urvillei* R^2= 0.60, D= 8.09 (8.27), B= 886 (210) and A= 231 (176). (Values in parentheses are standard error of the estimates).

3.3.4 Trial IV - Competition from *Bidens pilosa* on sugar cane grown in trays (glasshouse)

3.3.4.1 Effect of competition from *B. pilosa* on cane growth

The first three cane measurements showed no adverse effect of the various weed infestations on the total dewlap height of cane (Fig. 3.11). After the third measurement (12 WAT), the rate of growth of cane was higher and the weed-free treatment showed a significantly ($P< 0.05$) higher total dewlap height than some of the other treatments experiencing competition from *B. pilosa* at varying densities (Fig 3.11).

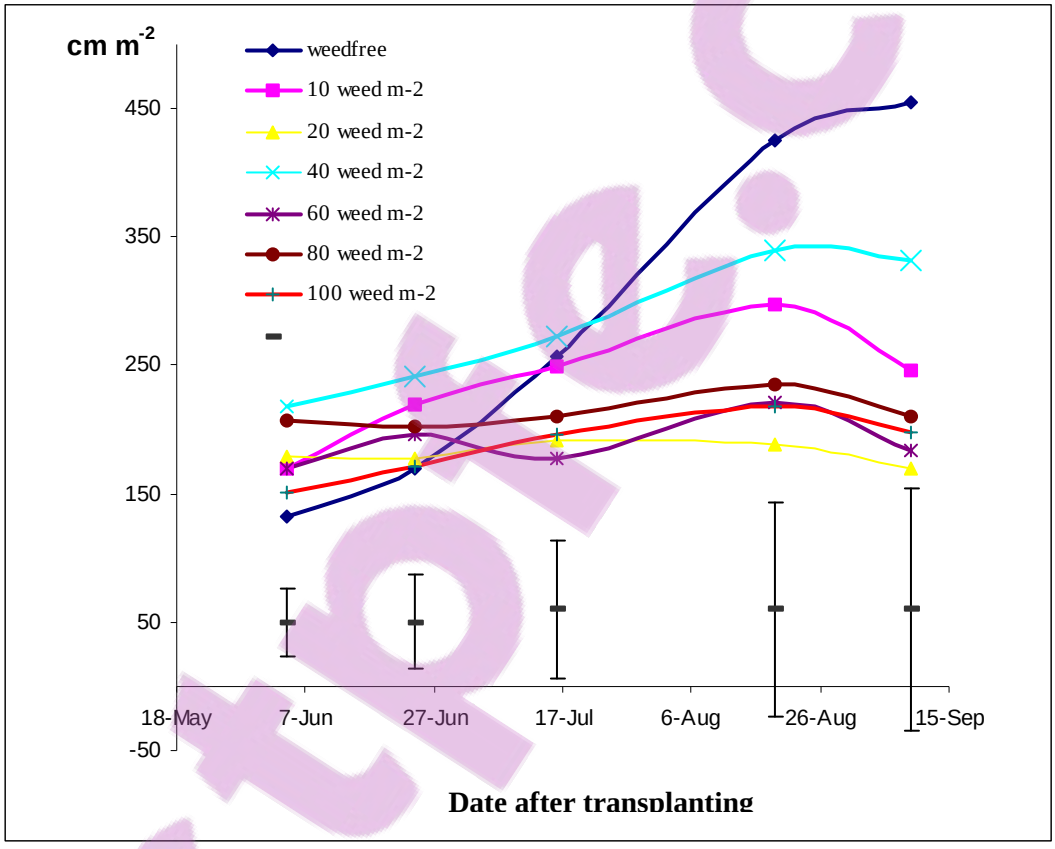


Fig. 3.11 The effect of different densities of *B. pilosa* on total dewlap height of cane stalks. The vertical error bars indicate 2 x s.e.d. of mean at each observation date.

Total dewlap height is the product of the number of cane shoots and the mean dewlap height of each stalk. Cane tillering was found to be the parameter most affected by weed density (Table 3.6). The number of tillers was found to increase with time in the weed-free treatment compared to the trays with weed infestations where no change in tiller density was observed during the same period of observation.

Table 3.6 Effect of weed competition from *B. pilosa* on cane tillering (shoots m^{-2})

Weed density (plants m^{-2})	No of shoots m^{-2}				
	4/6/02	24/6/02	16/7/02	19/8/02	9/9/02
0	17.9	17.0	16.6	21.6	25.0
10	20.0	20.0	19.3	19.3	20.0
20	20.8	20.0	19.3	18.3	20.0
40	21.8	21.8	20.0	20.8	21.8
60	19.3	20.0	15.8	19.3	19.3
80	21.8	20.8	18.3	17.5	18.3
100	16.8	15.0	15.0	15.0	15.8
Standard error (s.e.d.)	*2.3*	*2.1*	*2.4*	*3.9*	*4.6*

3.3.4.2 Effect of competition from *B. pilosa* on aboveground biomass (dry weight)

Weed biomass (aboveground) measured at the end of the trial showed no clear difference between the different densities, suggesting that the effects of the range of initial weed densities were not maintained throughout the trial period and intra-competition between weeds had occurred (Fig 3.12). The higher densities may have also caused greater competition earlier in cane growth as compared to the lower densities.

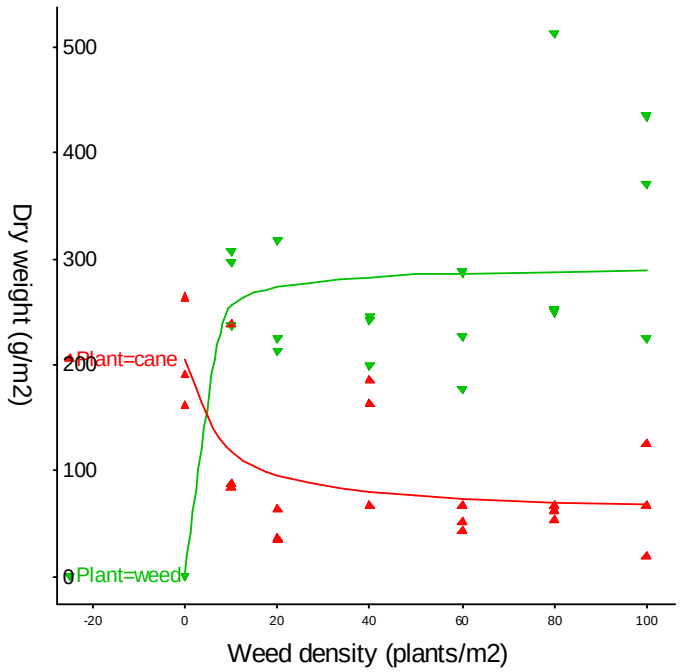


Fig. 3.12 Relationships between the dry weight (g m^{-2}) of cane (red) and *B. pilosa* (green) with weed density. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density; for cane R^2= 0.39 and parameter values D= 0.156 (0.175), B= 150.2 (40.7) and A= 58.6 (27.1), and for the weed R^2= 0.58, D= 0.69 (1.28), B= -292.7 (57.1) and A= 292.9 (31.6). (Values in parentheses are standard error of the estimates).

Competition from *B. pilosa* also reduced cane biomass as compared to the weed-free treatment; no significant difference between the various weed densities was observed (Fig. 3.12).

3.3.4.3 Relative competitiveness of *B. pilosa* with sugar cane

The relative leaf area (L_w) of *B. pilosa* estimated at the end of the trial period was found to vary between 0.57 and 0.97, thus showing that the weed produced more leaf area than the cane. A good relationship was obtained between the L_w and cane dewlap height (Fig. 3.13), this confirmed that the relative leaf area better described weed competition than density. However, the lack of differences in infestations between the different weed densities can again be seen by the grouping of most of the L_w values between 0.8 and 0.95.

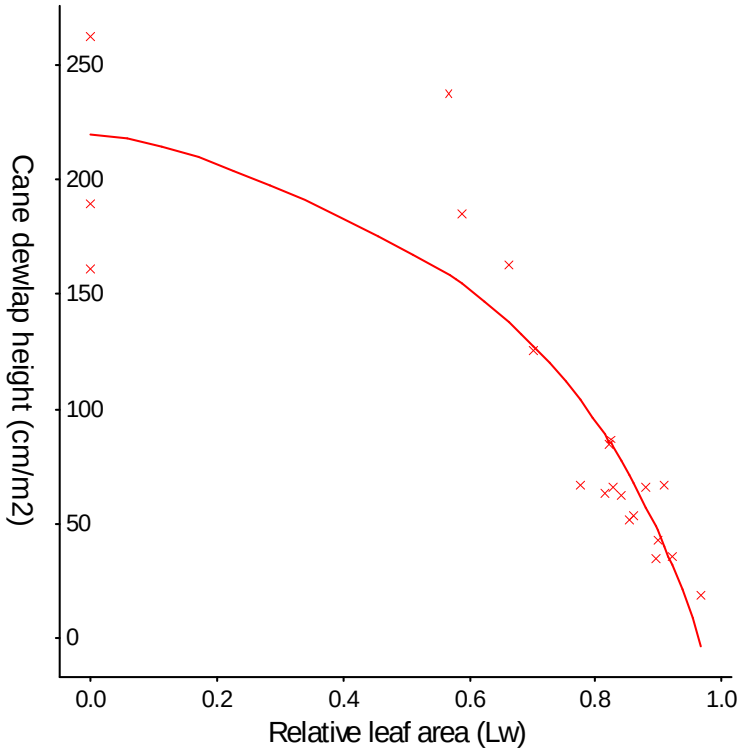


Fig. 3.13 Relationship between cane dewlap height (cm m^{-2}) and relative leaf area of *B. pilosa*. Response curve represents fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density; R^2= 0.79 and parameter values D= -0.756 (0.106), B= -81.6 (40.2) and A= 301.6 (54.0). (Values in parentheses are standard error of the estimates).

Fitting reduction in total dewlap height (compared to the weed-free control) to the relative leaf areas in the model developed by Kropff and Spitters (1991), a 'q' value of 0.23 (s.e. = 0.062) was obtained for *B. pilosa*. This also confirmed that sugar cane was a stronger competitor than this weed.

3.3.5 Trial V – Competition between sugar cane and *Paspalum paniculatum* and *Paspalum urvillei* under glasshouse conditions

3.3.5.1 Effect of *P. paniculatum* and *P. urvillei* on cane growth

The first two cane measurements made 4 WAT and 8 WAT showed no reduction (compared to weed-free control) in total dewlap height by weed competition, irrespective of weed species. From 14 WAT, a significant reduction in total dewlap height due to competition from the *Paspalum* species was observed (Fig. 3.14). *Paspalum paniculatum* showed a better relationship and caused a reduction in total dewlap height at all densities whereas *P. urvillei* showed no significant reduction at the lower densities.

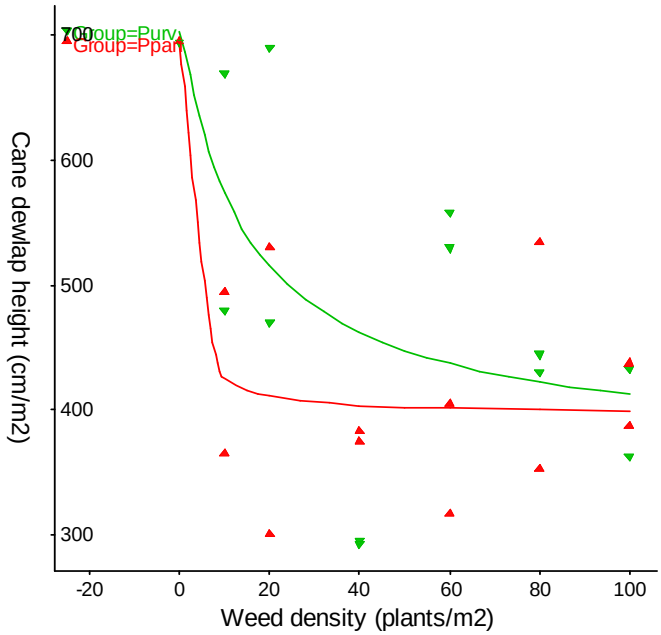


Fig. 3.14 Relationships between total cane dewlap height (cm m^{-2}) and the relative leaf area of *P. paniculatum* (red) and *P. urvillei* (green) at 14 WAT. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density; for *P. paniculatum* R^2= 0.45 and parameter values D= 0.94 (3.23), B= 299 (110) and A= 396.1 (45.9), and for *P. urvillei* R^2= 0.28, D= 0.06 (0.078), B= 337 (114) and A= 367 (91.0). (Values in parentheses are standard error of the estimates).

Irrespective of weed species and weed density, a significant reduction in the mean dewlap height of individual shoots was observed 14 WAT (Table 3.7). The main effect was from the presence of the weeds at 10 plants m^{-2} as increasing weed density failed to appreciably increase reduction in cane dewlap height. No difference between the various treatments and the control (weed-free) was observed for the number of shoots (tillering); the mean number of shoots m^{-2} for the weed-free treatment and the highest weed density were 15.1 and 13.8 (s.e. = 3.20) respectively. This implied that

the difference in the total dewlap height of cane observed should have been caused by an adverse effect of weed competition from the two grasses on stalk elongation.

Table 3.7 Effect of *P. paniculatum* and *P. urvillei* on mean cane dewlap height (14 WAT)

Weed density (plants m^{-2})	Mean dewlap height (cm per stalk)	
	P. paniculatum	*P. urvillei*
Weed-free	45.3	44.6
10	34.8	31.5
20	26.3	22.5
40	29.7	33.9
60	27.8	26.5
80	26.2	29.3
100	35.5	29.2

Values are means of two replications (except weed-free = means of 4 values). Standard error of difference (s.e.d) of means for subplot treatments (d.f. = 12) = 3.34; s.e.d for mean values of subplot treatments with same level of weed (d.f. = 12) = 4.72.

3.3.5.2 Effect of *P. paniculatum* and *P urvillei* on leaf area development and relative competitiveness

Leaf area of the weeds measured 14 WAT showed a poor correlation between initial weed densities and leaf area development of the weeds. Increasing weed leaf area decreased the leaf area of the crop in the case of *P. urvillei*, but not for *P. paniculatum* (Fig 3.15).

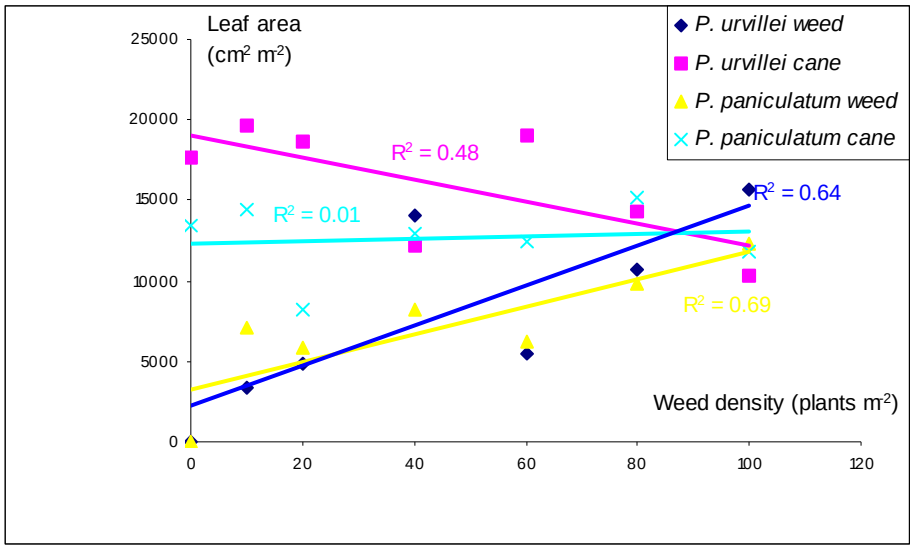


Fig. 3.15 Effect of increasing weed density of *P. paniculatum* and *P. urvillei* on weed and cane leaf areas (14 WAT)

Although *P. urvillei* produced a higher leaf area, the mean relative leaf area (L_w) of *P. paniculatum* was found to be 0.39 (s.e.= 0.045) and was similar to that of *P. urvillei* - 0.35 (s.e.= 0.056). The latter was due to less cane leaf area produced when sugar cane was in competition with *P. paniculatum*.

A reduction in cane dewlap height with increasing relative leaf area was observed with both weed species (Fig. 3.16). However, there was no clear difference between the two weed species.

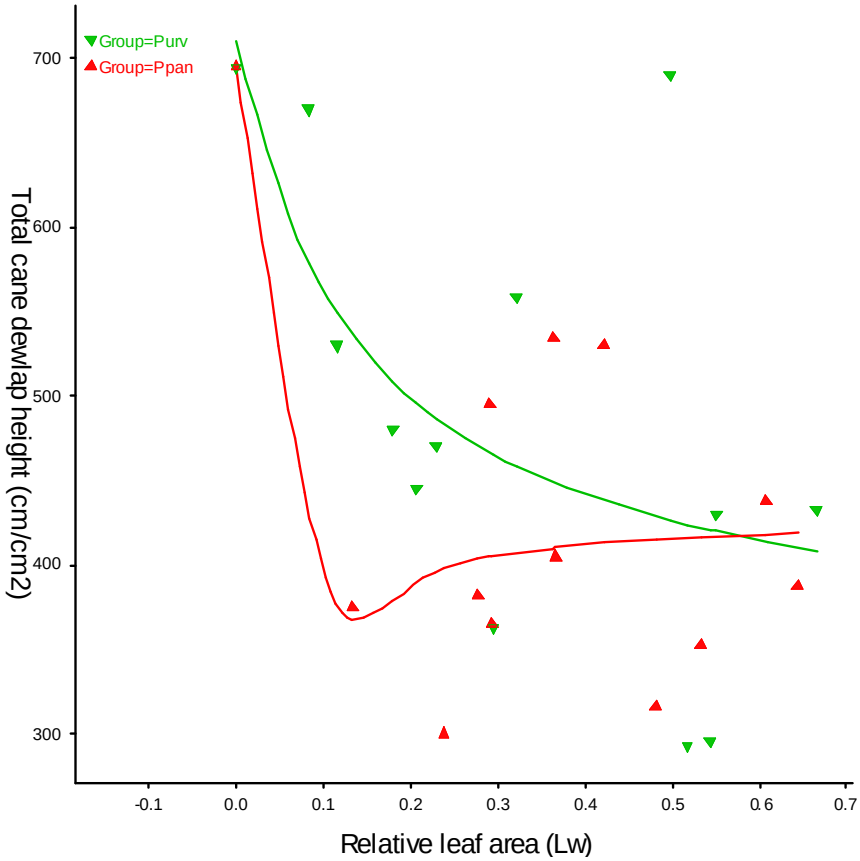


Fig. 3.16 Relationship between the loss in cane dewlap height and the relative leaf area of *P. paniculatum* (red) and *P. urvillei* (green) 14 WAT. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density; for *P. paniculatum* R^2= 0.46 and parameter values D= -39.6 (59.0), B= 265 (89.7) and A= 430 (41.7), and for *P. urvillei* R^2= 0.27, D= 6.7 (9.95), B= 370 (160) and A= 341 (146). (Values in parentheses are standard error of the estimates).

Fitting the relative leaf areas and reduction in total dewlap height for each weed species and density, in the regression model developed by Kropff and Spitters (1991), a 'q' value of 0.63 (s.e.= 0.171) was obtained for *P. urvillei* compared to 'q' = 0.89 (s.e.= 0.0.181) for *P. paniculatum*. This showed *P. paniculatum* to be slightly more competitive than *P. urvillei*.

3.3.6 Trial VI - Competition between sugar cane and *Paspalum commersonii* and *Paspalum conjugatum* under glasshouse conditions

3.3.6.1 Effect of *P. commersonii* and *P. conjugatum* on cane growth

Early cane measurements made at 3 WAT and 8 WAT revealed no difference, irrespective of weed species, between the weedfree control and the different weed infestation levels. At 13 WAT, a reduction in the dewlap height of sugar cane at some of the densities of *P. conjugatum* was observed; *P. commersonii* cause little effect on cane growth (Table 3.8).

Table 3.8 Effect of *P. commersonii* and *P. conjugatum* on cane growth 13 WAT

Weed density (plants m^{-2})	Mean total dewlap height of cane stalks (cm m^{-2})	
	P. commersonii	*P. conjugatum*
Weed-free	1024	
10	810	708
20	955	770
40	1004	1000
60	1013	766
80	910	691
*s.e.d.** (d.f.)	*83.9* (10)	

Values are means of two replications
* Standard error of difference (s.e.d.) of means compared at same level of weed

From measurements of cane shoot density and the mean dewlap height within the plots, there was no clear indication as to whether competition from these two weeds was acting through effects on stem height and/or through a reduction in tillering.

3.3.6.2 Effect of *P. commersonii* and *P. conjugatum* on sugar cane leaf area development and relative competitiveness

Leaf area of the weeds measured at 13 WAT showed that *P. conjugatum* produced more leaf area than *P. commersonii* for similar weed densities (Table 3.9). With *P. conjugatum*, increasing weed leaf area seemed to decrease the leaf area of the crop; this tendency was, however, not apparent with *P. commersonii*.

Table 3.9 Effect of *P. commersonii* and *P. conjugatum* on leaf area development of cane and weeds (13 WAT)

Weed densities (plants m^{-2})	Leaf area (cm^2 m^{-2})			
	P. commersonii		*P. conjugatum*	
	weed	cane	Weed	cane
Weed-free	-	20343	-	25302
10	4495	14797	9661	19955
20	9655	20034	13761	17246
40	8020	18122	18146	16764
60	7698	26097	18286	15767
80	27091	24461	34332	17664
*s.e.d.** (d.f.)	*6478.6* (10)	*4147.5* (10)	*6478.6* (10)	*4147.5* (10)

Values are means of two replications
* Standard error of difference (s.e.d.) of means compared at same level of weed, d.f. = degrees of freedom.

The mean relative leaf area (L_w) of *P. conjugatum* was found to be much higher than that of *P. commersonii* (0.50±0.12 v/s 0.32±0.04). Fitting the relative leaf areas (Lw) against the cane dewlap heights using the rectangular hyperbolic model, a relatively better relationship (combined R^2= 0.22) was obtained, as compared to that with density (Fig. 3.17). *Paspalum commersonii* showed no relationship between dewlap height and L_w; implying that *P. commersonii* had no effect on dewlap height at the densities tested.

The losses in total dewlap height by each weed species was fitted against the relative leaf areas in the regression model developed by Kropff and Spitters (1991). A 'q' value of 0.13 (s.e.= 0.063) was obtained for *P. commersonii* compared to 'q' = 0.25 (s.e.= 0.073) for *P. conjugatum*; thus confirming *P. conjugatum* to be relatively more competitive than *P. commersonii*. Because of the weak relationship between dewlap height and L_w especially for *P. commersonii*, the results must be treated with caution.

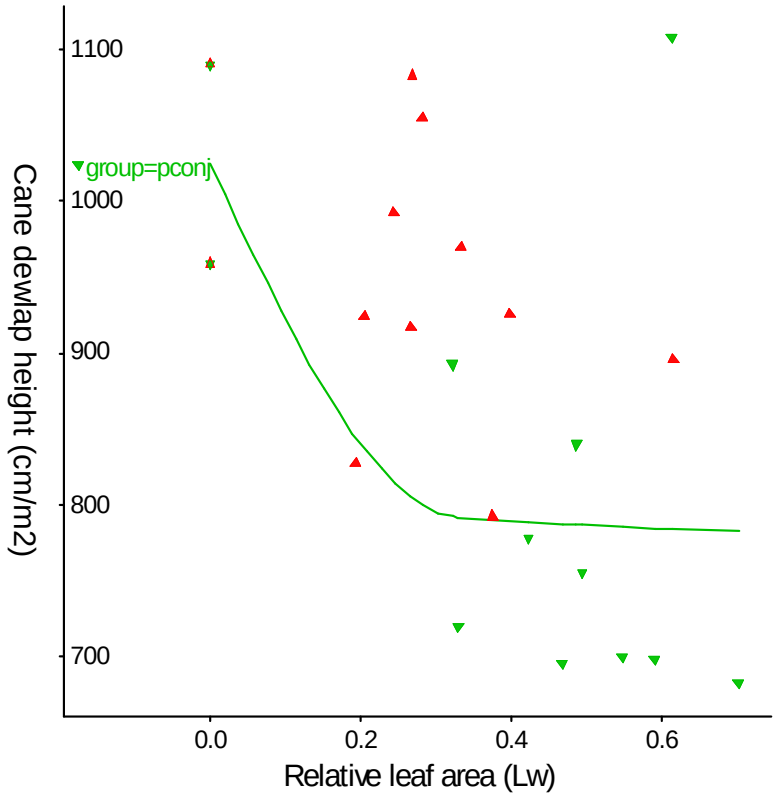


Fig. 3.17 Relationship between cane dewlap height (cm m^{-2}) and the relative leaf area of *P. commersonii* (red) and *P. conjugatum* (green). Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density; for *P. conjugatum* R^2= 0.22, D= 41 (543), B= 250 (188) and A= 774 (169) and no fit for *P. commersonii*. (Values in parentheses are standard error of the estimates).

3.3.7 Trial VII - Weed competition from *Ageratum conyzoides* and *Setaria barbata* on sugar cane grown in trays outdoors

3.3.7.1 Effect of *A. conyzoides* and *S. barbata* on cane growth

The first two cane measurements made 4 WAT and 9 WAT showed no reduction (compared to weedfree control) in the mean cane dewlap height by weed competition, irrespective of weed species (Table 3.10). However, the second measurement revealed a reduction in tillering (number of shoots) with the higher weed densities; compared to the control (weed-free), the number of shoots was reduced as from weed densities of 40 and 60 weeds m^{-2} for *A. conyzoides* and *S. barbata* respectively.

Table 3.10 Effect of *A. conyzoides* and *S. barbata* on cane growth 4 and 9 WAT

Weed density (plants m^{-2})	Mean cane dewlap height (cm/stalk)				Tillering (shoot m^{-2})	
	4 WAT		9 WAT		9 WAT	
	A. conyzoides	*S. barbata*	*A. conyzoides*	*S. barbata*	*A. conyzoides*	*S. barbata*
Weedfree	12.9	12.4	15.3	15.2	28.1	30.0
10	11.9	13.6	14.8	17.9	32.5	24.4
20	11.4	10.4	15.6	14.0	25.0	31.3
40	11.4	10.6	16.6	15.2	20.6	26.9
60	12.3	13.0	17.9	17.1	20.6	22.5
80	10.7	11.9	15.3	16.5	20.6	20.6
*s.e.d.** (d.f.)	*1.39* (30)		*1.49* (30)		*3.44* (30)	

Values are means of four replications.
* Standard error of difference (s.e.d.) of means compared at same level of weed, d.f.= degrees of freedom

3.3.7.2 Effect of *A. conyzoides* and *S. barbata* on final cane measurements (13 WAT)

Regressions fitted from cane dewlap heights measured 13 WAT against the respective weed densities showed that both weeds caused some reduction in cane growth but the relationship was relatively poor (Fig. 3.19). The reduction in cane dewlap by competition from *S. barbata* was almost similar for all the infestation levels whereas increasing density of *A. conyzoides* caused more reduction.

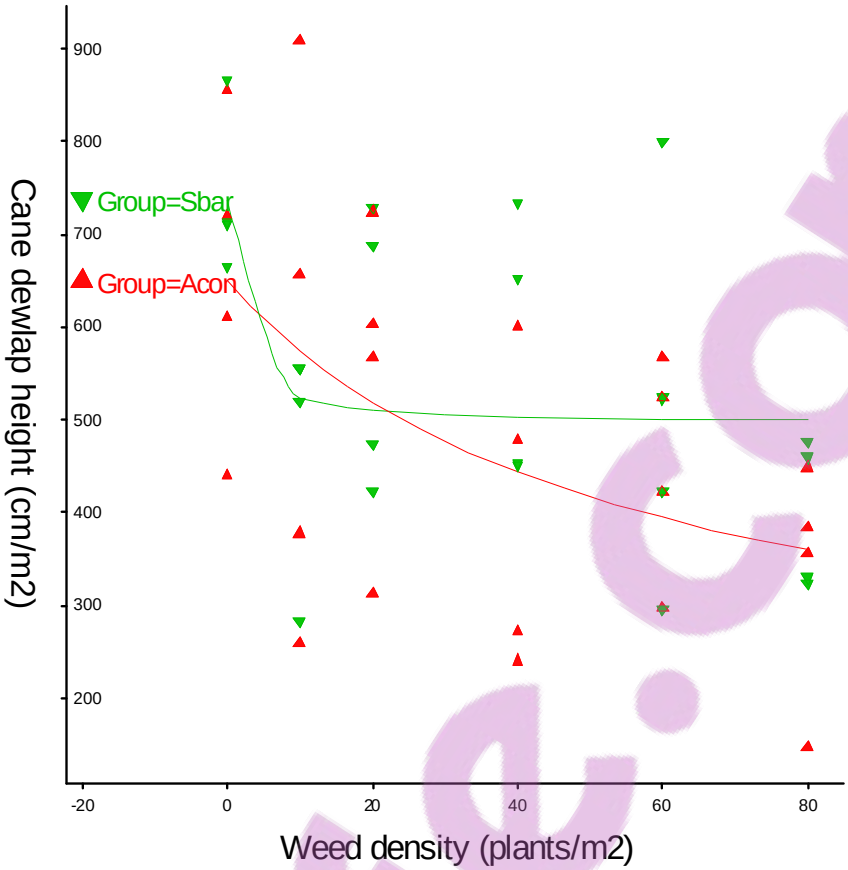


Fig. 3.19 Relationship between cane dewlap height (cm m^{-2}) and density of *A. conyzoides* (red) and *S. barbata* (green). Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density. For *A. conyzoides*, R^2= 0.21 and parameter values D= 0.019 (0.0392), B= 486 (440) and A= 164 (471), and for *S. barbata*, R^2= 0.22 and parameters D= 0.75 (2.97), B= 243 (92.6) and A= 495 (57.0). (Values in parentheses are standard error of the estimates).

3.3.7.3 Effect of *A. conyzoides* and *S. barbata* on leaf area development and relative competitiveness

The leaf area of the weeds measured 13 WAT increased at the lower densities to rapidly reach a maximum (asymptote) at around 8000–9000 cm^2 m^{-2} (Fig. 3.20). The response was relatively better with *A. conyzoides*. Similarly, the leaf area of cane was found to decrease with increasing density only at the lowest densities; the decrease was more pronounced with *A. conyzoides* (Fig. 3.20). The relationship between leaf area of cane and weed densities of *S. barbata* was poor (Table 3.11). These results indicated an interaction between weed leaf area and cane leaf area, particularly for *A. conyzoides*.

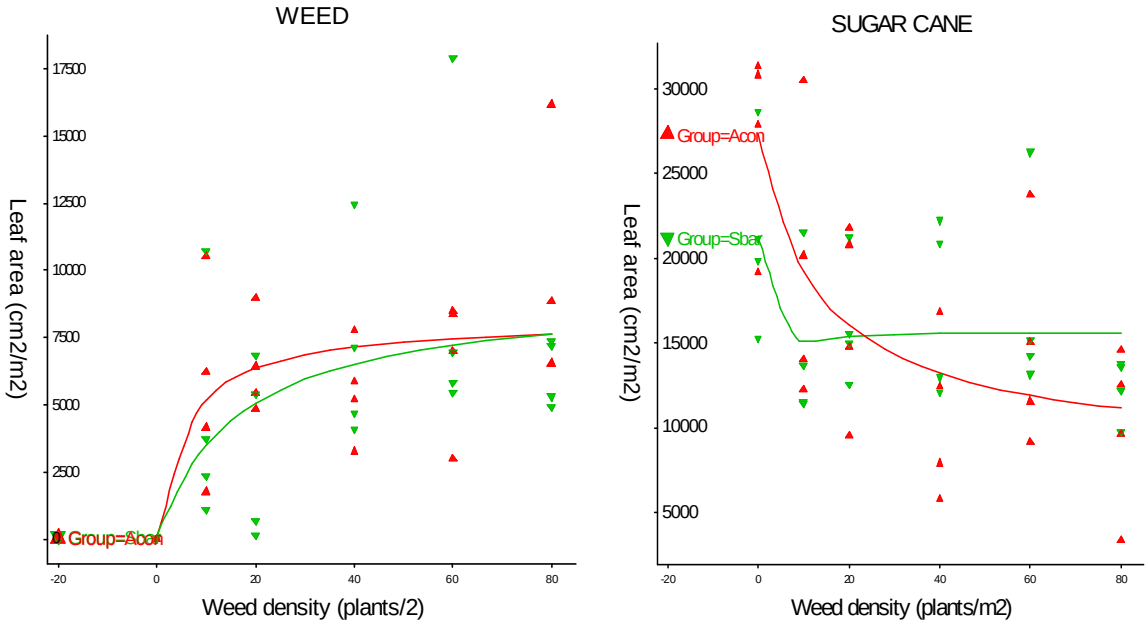


Fig. 3.20 Relationship between the density (plants m^{-2}) of *A. conyzoides* (red) and *S. barbata* (green) and leaf area (cm^2 m^{-2}) of weed (left) and cane (right). Response curves are those from parameters given in Table 3.11.

Table 3.11 The parameters of the response curves showing relationship between weed density and leaf area of weed and cane using the rectangular hyperbola model (y= A + B/(1+D*x) where x= L_w. Values in parentheses are standard errors of parameter values.

	Weed	R^2	D	B	A
Weed	*A. conyzoides*	0.44	0.17 (0.177)	-8139 (1961)	8183 (1419)
	S. barbata	0.30	0.06 (0.072)	-9119 (3191)	9219 (3028)
Cane	*A. conyzoides*	0.46	0.08 (0.066)	18862 (4703)	8482 (4186)
	S. barbata	0.12	-1.01 (5.03)	5543 (2867)	15686 (1614)

The mean relative leaf area (L_w) of *A. conyzoides* was found to be slightly higher than *S. barbata*. A lesser cane leaf area produced when sugar cane was in competition with *A. conyzoides* may explain this. A good relationship between cane dewlap height and the relative leaf area was again observed with *A. conyzoides.* The response *S. barbata* was much less clear (Fig. 3.21).

Fitting the losses in total dewlap height of cane stalks against their respective relative leaf areas in the regression model (Eqn 3) developed by Kropff and Spitters (1991) revealed a 'q' value of 1.09 (s.e.= 0.193) for *A. conyzoides* compared to 'q' = 0.92 (s.e.= 0.256) for *S. barbata*. This showed *A. conyzoides* to be slightly more competitive than *S. barbata*.

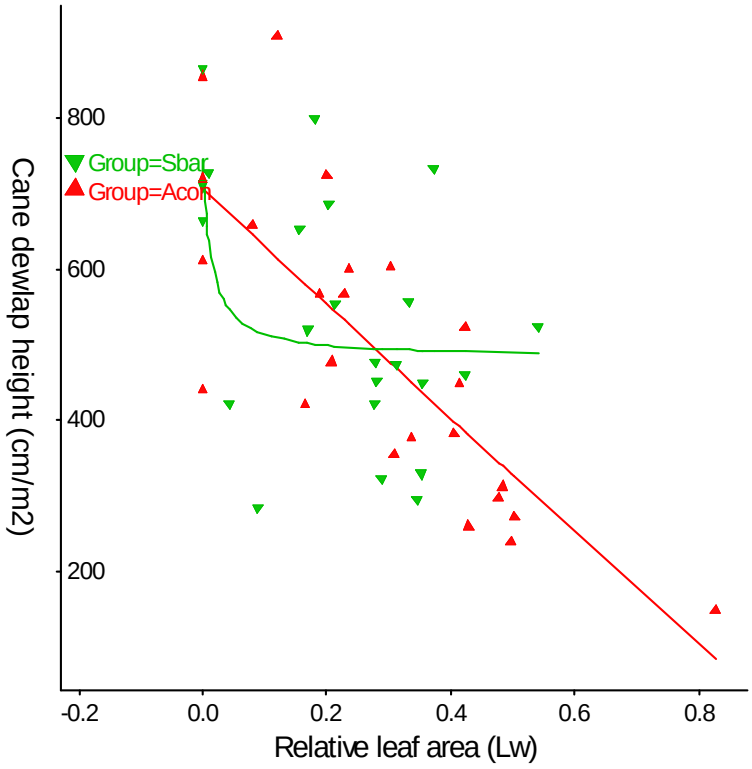


Fig. 3.21 Relationship between cane dewlap height (cm m^{-2}) and the relative leaf area of *A. conyzoides* (red) and *S. barbata* (green). Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density. For *A. conyzoides*, R^2= 0.58 and parameter values D= 0.028 (0.636), B= 27545 (617876) and A= -26838 (617907), and for *S. barbata*, R^2= 0.27, D= 75 (154), B= 260.9 (81.4) and A= 483.4 (47.1). (Values in parentheses are standard error of the estimates).

3.4 Discussion and conclusions

Time interval between start of infestation and effect on cane growth

The trials have demonstrated that the effect of competition from the different weed species on sugar cane was visible only several weeks (e.g. 12-14 weeks) after introducing the infestations although a few effects were observed earlier in some of the trials at the higher weed densities. This implied that there should be a minimum level of weed infestation and duration of interference to cause any adverse effect on cane growth; the higher densities reached that level of infestation earlier. The latter may be reached even earlier for quick growing species such as *B. pilosa* (in Trial II) where some effects were detected at the highest densities as from 3 WAT. The relative rate of growth of the same weed with respect to the crop may differ with growth conditions; *B. pilosa* was found to show an adverse effect on the total dewlap height as from 9 WAT in Trial IV. All the grasses tested took, more or less, the same time (between 13 and 16 WAT) to show their competitive effect.

Effect of weed competition on cane tillering v/s elongation

The effect on cane growth was, in most cases, due to a reduction in the number of shoots (tillering) but a reduction in cane elongation with similar tiller densities has also been noted (e.g. Trial IV). The total dewlap height which is the product of the number of shoots/stalks and mean dewlap height of each stalk gave a good comparison for the effect on cane growth and was also found to have a good correlation with the aboveground biomass. In Trials V and VI, a reduction in the total dewlap height was observed despite no effect on tillering, this may be explained by the fact that the cane had already reached its peak tillering phase at the time of observation and had started its elongation phase (mean dewlap height of stalks in the weedfree plots had reached 45 cm and 55 cm in Trials V and VI respectively). The latter was also observed for *P. urvillei* in Trial II where the cane stalks had reached more than 25 cm in height at the time of assessment. As the number of shoots reduces naturally after the peak of the tillering phase, this may partly mask the effect of any reduction due to competition which occurred prior to the peak tillering phase as compared to the weedfree control. In the other trials, the final assessments were made when the cane stalks in the weedfree plots had a mean dewlap height varying between 18 and 100 cm.

The effect of competition on tillering or cane elongation was sometimes difficult to separate as observed in Trial VI, or was even found to vary among the different weed species tested as in Trial II where only *D. horizontalis* showed a reduction in tillering.

Effect of weed density on weed competition

Increasing weed densities was found to influence weed competition but the relationship between cane dewlap height and weed density was generally poor, the R^2 exceeding 0.50 only once (0.68 for *P. urvillei* in Trial III). No response was also noted in Trials II and VI. Some of the trials also showed that beyond certain weed densities, there was intra-specific competition and sometimes even causing less damage than the lower densities. For example the relative growth of *D. horizontalis* was higher at the lower densities in Trial II. The intra-specific competition also influenced the weed infestation over the period of assessment as leaf area measurements showed a poor consistency between the initial densities at establishment and those maintained throughout the duration of the trials.

Relative leaf areas of cane and weeds

The leaf areas of the weeds were found to vary with species, density and growing conditions (temperature, time of observation, field v/s glasshouse, etc). Similarly, the leaf area of cane in the weed-free treatments was also found to differ with respect to cane variety and the growing conditions. Furthermore, the leaf area of cane was also found to decrease with the presence of weeds; the decrease was more pronounced with higher weed leaf areas.

The relative leaf area (L_w) varied with weed species and density. In general, the weed species with a higher leaf area were found to have a higher L_w; exception to that was observed in Trial V where *P. urvillei* showed higher leaf areas (for similar weed densities at establishment of infestations) than *P. paniculatum* but the mean relative leaf area (L_w) was found to be the same. The latter was caused by a more adverse effect of *P. paniculatum* on the leaf area of the crop.

The use of the relative leaf area instead of weed density to show effect of weed competition on cane growth was found to give better relationships (correlations). The better response with the relative leaf areas confirmed the variability in development of weed infestations following their transplanting. As the cane leaf area was also found to be adversely affected by increasing weed infestations (weed leaf area), the relative leaf catered for that and also for the difference in growth stages of both the cane and the weeds at time of transplanting.

Relative competitiveness of weeds in sugar cane

The relative competitiveness of the weeds was compared by applying the model by Kropff and Spitters (1991). This model has been developed to quantify the effect of weed competition on final yields. However as the cane growth period is very long and most of the comparisons were either very

small plots or carried out in trays, the effects of weed competition on the final yield would have not been possible. For comparisons done as in this chapter, it was assumed that the effects on cane growth parameters such as total dewlap heights could be used instead of final yields. In sugar cane experimentation, the use of those cane growth parameters is quite common; e.g. effect of herbicides on sugar cane has been assessed by measuring cane before spraying and 6-8 weeks later (Rochecouste, 1967).

The seven trials have shown that sugar cane was a stronger competitor than all the weeds tested except *Ageratum conyzoides* in Trial VII where the q value exceeded one (Table 3.12). However, *A. conyzoides* was also found to have a lower q value in Trial I which was carried out under field conditions.

Table 3. 12 Summary of relative competitiveness values of weeds in sugar cane

Trial	Weed species	Date of final assessment (WAT)	Mean L_w	Estimated q value (*standard error*)
I	*A. conyzoides*	21	0.47	0.88 (0.154)
II	*B. pilosa*		0.74	0.06 (0.063)
	D. horizontalis	14	0.24	0.37 (0.245)
	P. urvillei		0.45	0.15 (0.039)
III	*P. paniculatum*	16	0.39	0.44 (0.262)
	P. urvillei		0.58	0.20 (0.102)
IV	*B. pilosa*	12	0.77	0.23 (0.062)
V	*P. paniculatum*	14	0.39	0.89 (0.018)
	P. urvillei		0.35	0.63 (0.171)
VI	*P. commersonii*	14	0.32	0.13 (0.063)
	P. conjugatum		0.50	0.25 (0.073)
VII	*A. conyzoides*	13	0.34	1.09 (0.193)
	S. barbata		0.26	0.92 (0.256)

The relative competitiveness was found to vary with weed species and growing conditions. Among the broad-leaved weeds, *A. conyzoides* was found to be more competitive than *B. pilosa*. *Paspalum paniculatum* and *S. barbata* seemed to be more competitive than *P. urvillei*, *P. conjugatum* and *P. commersonii*. *Digitaria horizontalis* (q value estimated from dry weights) seemed to be more

competitive than *P. urvillei*. However, variations were observed in the q values for the same species tested under different trial conditions; this indicates that a single q value obtained from a single trial cannot be used for comparison of relative competitiveness and it would not predict weed competition correctly under all field conditions. Although more trials under different agro-climatic conditions may be required, indications on the relative competitiveness of some weeds were consistent; e.g. *A. conyzoides* and *B. pilosa* were both assessed in two trials and the higher competitiveness of the former weed was maintained.

The two trials (Trials III & V) comparing competition between *P. paniculatum* and *P. urvillei* showed almost the same tendency, i.e. *P. paniculatum* being more competitive than *P. urvillei* although the latter produced more leaf area and grew taller to intercept more light within the canopy. As both trials were conducted with the same cane variety, the relatively higher q values in Trial V may have resulted from a higher weed and cane development obtained under field conditions. The relative growth rate of the crop and weeds, which would be dependent on the agroclimatic conditions together with the time of weed emergence and observation, would influence the q value. The latter aspect and the mechanisms for light competition needs to be studied further to understand weed competition in sugar cane.

In general, the variability of the data was quite high and sometimes resulted in relatively poor relationships (low R^2 values). These were due to variability in cane growth within the trays, lack of repetitions in some of the trials and the difficulty in maintaining the weed infestations at their initial densities. The latter problem was partly resolved as the q values were calculated from the relative leaf areas and the loss in cane growth. The size of the trays limited the duration of the trials and the 'border effect' could have influenced the cane shoots growing near the end of the tray rows. Nevertheless, the main objectives were achieved and it was possible to show how the different weed species affected cane growth. But, some caution is needed in interpreting the relative ranking of the different weeds.

CHAPTER 4

EFFECT OF TIME AND LEAF AREA DISTRIBUTION ON WEED COMPETITION BETWEEN SUGAR CANE AND *PASPALUM PANICULATUM* OR *PASPALUM URVILLEI*

4.1 Introduction

In Mauritius, extremely high costs of weed control with herbicides and environmental concerns have necessitated the development of weed management strategies aimed at minimization of herbicide use and exploitation of alternative methods of control. An approach based on the critical periods of weed competition (Chapter 2) and upon the ability to predict the effects of weeds on cane yield is being developed. Damage relationships that quantify yield losses on the basis of early observations of weed infestations have been studied for some weed species in sugar cane (Chapter 3) and have revealed that sugar cane is a stronger competitor than most of the weeds tested. However, the effect on cane growth would depend on the level of infestation and the relative competitiveness of the weed species. The latter itself will depend on the time of weed emergence, its rate of growth and stage of growth of the cane. Lindquist (2001) showed that the relationship between crop yield loss and weed density also varies with the influence of management practices and environmental factors on crop-weed competition. A better understanding of competition processes is therefore required for development of sound weed management strategies.

Trials conducted under both field and glasshouse conditions (Chapter 3 - Trial III & Trial V respectively) have shown a higher relative competitiveness of *P. paniculatum* compared to *P. urvillei* despite the latter producing more leaf area and growing taller. The competitive difference between the two weeds may be due to their vertical leaf distribution, as the effects of weed height on reduction of light penetration through the crop canopy have been reported in weed competition studies (Massinga *et al*., 2003). As sugar cane takes a relatively longer time before canopy closure, the relative competitiveness (q) values obtained for the two weed species need to be examined more closely as this coefficient is dependent on time, either time after weed emergence or on growth stages when observations are made (Kropff & Spitters, 1991).

The model developed by Kropff and Spitters (1991) to express yield loss of the crop as a function of the relative leaf area of the weed is as follows:

$$YL = \frac{q\ L_w}{1 + (q-1)\ L_w} \qquad \text{(Eqn 1)}$$

where YL is the yield loss, L_w is the relative leaf area of a weed species (weed leaf area / crop + weed leaf area) , and q the 'relative damage coefficient'. Parameter q is a measure of the competitiveness of the weed species with respect to the crop and is thus species specific. The competitive strength of a species is strongly determined by its share in leaf area at the moment when canopy closes and interplant competition starts (Spitters & Aerts, 1983; Kropff, 1988). Generally, this model has been developed to assess yield loss caused by the weeds as early as possible after crop emergence. In sugar cane where the critical period of weed competition starts a few weeks after crop emergence or ratooning, and the canopy closure period is relatively long, the ratio of the leaf area per plant of the crop and the weed is expected to change and it is important to know how the relative leaf area (L_w) of weeds changes up to canopy closure.

In the early growth phase, when the observations on weed infestation have to be made, the canopy is not closed and the crop and weed plants generally grow exponentially according to the function (Kropff & van Laar, 1993):

$$LA_t = LA_0 \times e^{(R_1 \times t)} \qquad \text{(Eqn 2)}$$

where LA_t represents the leaf area per plant at time t, LA_0 the leaf area at the reference time 0 (the moment of observation for which the relative competitiveness q has been determined from experimental data), R_1 is the relative growth rate of leaf area ($^0C^{-1}\ d^{-1}$), and t is the time expressed in degree days ($^0C\ d$). The relative growth rate of the leaf area R_1 is only relevant in early growth phases when plants grow exponentially and can be determined by growth analysis of free growing plants.

From the above two equations, Kropff and Spitters (1991) and Kropff and van Laar (1993) derived an equation relating the change in time of the relative competitiveness value q in the period of exponential growth when the canopy is not closed as follows:

$$q = q_0 \times e^{((R_{1(c)} - R_{1(w)}) \times t)} \qquad \text{(Eqn 3)}$$

where q_0 is the value of q when L_w is observed at t = 0 (the moment of observation for which the relative damage coefficient q has been determined from experimental data) and t indicates the period between t = 0 and the moment of observation (in degree days) for which the relative competitiveness q will characterize the effects. $R_{1(c)}$ and $R_{1(w)}$ are the relative growth rate of leaf area of the crop and the

weed respectively. When q_0 is determined for a given crop - weed combination at a certain time period after crop emergence, the value of the relative competitiveness q value at other dates of observations can be estimated using this equation.

Under adequate water and soil nitrogen, competition for light is thought to be the primary cause of yield loss from weeds (Munger *et al*., 1987). Competition for light is an instantaneous process that depends on the relative share of light absorbed by a species in a mixed canopy and the efficiency of energy use in dry matter production (Lawlor, 1995). Light absorption in mixed canopies is determined by the leaf area index (LAI) of the species, plant height, vertical leaf area distribution and leaf angle distribution (Lindquist & Mortensen, 1999). The effects of weed height on reduction of light penetration through the crop canopy have been reported in competition studies between velvetleaf (*Abutilon theophrasti* Medikus) and soybean (Akey *et al*., 1990), tomato and black nightshade (*Solanum ptycanthum* Dun.) (McGiffen *et al*., 1992), and wild oats (*Avena fatua* L.) and wheat (Cudney *et al*., 1991). Massinga *et al*. (2003) emphasized the importance of evaluating the vertical distribution of light through the canopy to assess the effect of weed height on light competition, after showing that in a mixed canopy of corn and *Amaranthus palmeri* S. Watson more than 60% of light was intercepted 1 m above ground where 80% of the weed leaf area was concentrated compared to a weed-free corn situation where 60% of the light was intercepted from 0.5 to 1.5 m above the ground.

For a better understanding of the mechanisms of weed competition in sugar cane, particularly for light, and the relative competitiveness of weed species with different morphological characteristics, three field trials comparing competition from *P. paniculatum* and *P. urvillei* on sugar cane have been conducted between 2003 and 2006. The main objectives of the trials were:

- to compare the relative competitiveness q values for the two weed species at different time of observations after transplanting;
- to study the competition and compare q values of the two weeds with respect to two transplanting dates;
- to assess the effect of leaf area distribution (vertical) of cane and weeds at different times after transplanting on weed competition.

4.2 Materials and methods

4.2.1 Trial I – Effect of time of observation and two transplanting dates on the relative competitiveness (q value) of *Paspalum paniculatum* and *Paspalum urvillei* in competition with sugar cane

Trial site and plant material

A field experiment was initiated in November 2003 at Réduit Experiment Station, L soil group (Parish & Feillafé, 1965), to compare competition from *P. paniculatum* and *P. urvillei* on sugar cane. The field was planted on 24 November 2003 using three-eyed cuttings of cane variety R 575 obtained from a plant cane field on the station and adopting all other cultural practices as per normal recommendations. Young plants of the two weeds were collected from abandoned fields in the Belle-Rive region and transplanted after pruning of the upper part of the leaves to reduce transpiration.

Treatments and experimental layout

The weeds were transplanted at two dates, the first on 23 and 24 January 2004 (9 WAP) and the second on 17-19 March 2004 (17 WAP). At each date, *P. urvillei* and *P. paniculatum* were both manually transplanted at densities of 6, 10, 15, 20 and 33 plants m^{-2}; a weed-free plot was also included. Each plot consisted of three cane rows of 1.5 m long and cane planted at a row spacing of 1.5 m; the effective competition area was 1.2 x 1.5 (1.8 m^2) for each row of cane, with a walking path of 0.3 m in the centre of the interrows. The statistical design used was a split-split plot with the two transplanting dates as main-plots, weed species (*P. paniculatum* v/s *P. urvillei*) as sub-plot and six weed densities as sub-sub-plot treatments. Each treatment was replicated three times. The middle row within each plot was kept for cane measurement at end of the treatment period whereas the two border rows were used for destructive sampling for cane and weed dry weight and leaf area data. The field was irrigated regularly and all emerging weeds other than those transplanted were hand-weeded.

Data collection and analysis

Data on cane and weed (fresh/dry weights, leaf areas, average cane dewlap heights) were collected on 4 March 2004 (5 WAT), 30 March 2004 (9 WAT), 4 May 2004 (14 WAT) and 3 June 2004 (18 WAT) with respect to the first transplanting date (TD1). For the second transplanting date (TD2), similar data were collected three times, namely on 7 May 2004 (7 WAT), 8 June 2004 (11 WAT) and 12 July 2004

(16 WAT). At each data collection date, a quadrat of 0.5 m X 1.0 m was placed on the external rows with the longer side across the cane row. Fresh weights of the sampled material were determined immediately after harvesting, and sub-samples were then dried for 48 hours at 105^{o}C for dry matter estimation. The trial was harvested on 27 August 2004; all millable stalks in the middle row of each plot were hand-cut and weighed (fresh weight).

Data collection on leaf area of cane and weeds was done with the CID portable leaf area meter (see details in Chapter 3 - Trial I); sub-samples representing 10 to 50% of the total fresh weight were used for this estimation. Daily minimum and maximum temperatures were available from the station's records; the mean daily temperature was calculated to estimate the growing degree day (GDD) for the duration of the trial.

Statistical and regression analysis

The relative leaf area (L_w) was calculated from the cane and weed leaf area data. The effect of competition from the two *Paspalum* species were compared by fitting regression curves of their cane dewlap (total) heights against the relative leaf area using the rectangular hyperbola (linear-by-linear) function in Genstat (Genstat, 2005) which is similar to the equation proposed by Cousens (1985) (see details in Chapter 3 – Trial I). Only regressions that were statistically significant ($P< 0.05$) were presented, even though the R^2 values were sometimes low (where fits were not statistically significant the regressions lines were not presented). The relative leaf area and cane yield data were subjected to non-linear regression analysis according to the weed competition model (Eqn 1) developed by Kropff and Spitters (1991) using Genstat (Genstat, 2005) to estimate the relative competitiveness q values for the two weed species at each observation and transplanting date.

4.2.2 Trial II – Relative competitiveness of *Paspalum paniculatum* and *Paspalum urvillei* on sugar cane at two observation dates and effect of leaf area distribution on competition

Trial site and plant material

The field experiment to study weed competition from *P. paniculatum* and *P. urvillei* on sugar cane was established in March 2005 at Réduit Experiment Station, L soil group (Parish & Feillafé, 1965). Sugar cane, variety R 570, was initially planted in November 2004 using three-eyed cuttings obtained from a plant cane field on the station and using recommended local cultural practices. Young plants of the two weeds were collected from abandoned fields in the Belle-Rive and Ebène regions and were

transplanted on 20 January 2005 after pruning of the upper part of the leaves to reduce transpiration. At the start of this experiment, on 10 March 2005, the now vigorous cane shoots were stubble-shaved, to equalise the initial size of the weeds and cane, and to allow new shoots to sprout (ratooning) again from all plots. The weed infestation were maintained and restored by recruiting some gaps within the first week of April 2005.

Treatments and experimental layout

The two weeds were transplanted at densities of 12, 16, 24, 28 and 36 plants m^{-2} manually in each plot; a weedfree plot was also included. Each plot consisted of three cane rows of 1.5 m long and cane planted at a row spacing of 1.5 m; the effective competition area was 1.2 x 1.5 (1.8 m^2) for each cane row with a walking path of 0.3 m in the centre of the interrows. The statistical design used was a split-plot with the two weeds as main-plots and weed density as sub-plot treatments. Each treatment was replicated four times. The middle row was kept for cane measurement at end of the treatment period whereas the two border rows were used for destructive sampling for dry weight and leaf area estimation for both cane and the weeds. The field was irrigated regularly and all emerging weeds other than those transplanted were hand-weeded.

Data collection and analysis

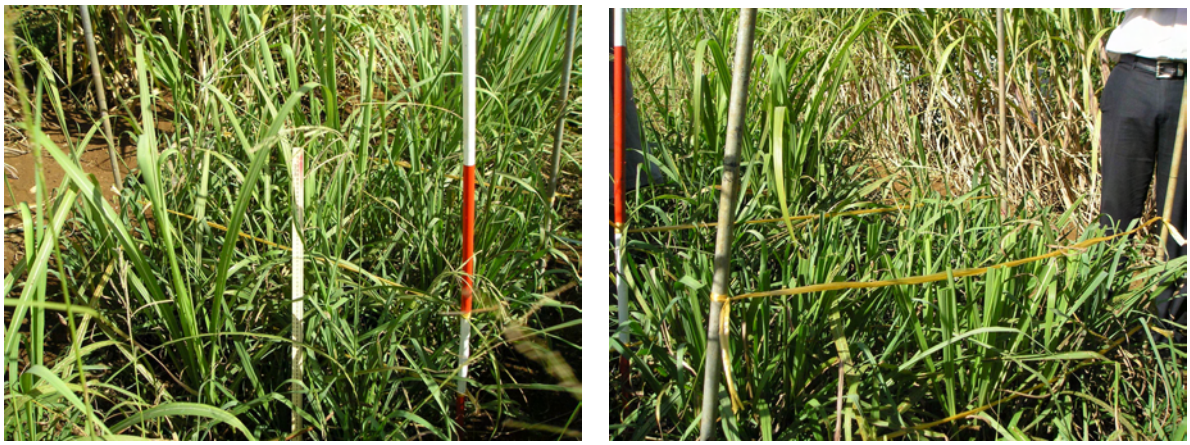
Data on weed and cane (fresh/dry weights, leaf areas, average cane dewlap heights) were collected at two dates; the first one on 13 May 2005 (8 WAH) and a second one during the first week of August 2005 (20 WAH). At each data collection date, a quadrat of 0.5 m x 1.0 m was placed on the external rows with the longer side across the centre of the cane row. On the second observation date, leaves of cane and weeds were collected separately in different layers representing horizontal layers of 0 to 30 cm from ground, between 30 to 60 cm, and a layer with all leaves above 60 cm (Fig. 4.1).

Fresh weights and dried weights were determined as in Trial I. Data collection on leaf area of cane and weeds was done with a portable leaf area meter as in Trial 1.

Statistical and regression analysis

All cane measurements and leaf area data were subjected to ANOVA. The relative leaf area (L_w) was calculated from the cane and weed leaf area data. The effect of competition from the two *Paspalum* species were compared by fitting regression curves of the loss in cane dewlap (total) height compared to the weed-free mean against the relative leaf area using the rectangular hyperbola (linear-by-linear)

function in Genstat (Genstat, 2005). Only regressions that were statistically significant ($P< 0.05$) were presented, even though the R^2 values were sometimes low (where fits were not statistically significant the regressions lines were not presented).



(a) **(b)**

Fig. 4.1 Weed competition between *P. urvillei* and sugar cane. Quadrat placed across cane row and different colours on peg show 30 cm marks for different layers (a) and leaves cut from top to lower layers (b).

4.2.3 Trial III – Relative competitiveness of *Paspalum paniculatum* and *Paspalum urvillei* on sugar cane at two transplanting dates and effect of leaf area distribution on competition

Trial site and plant material

The third field trial was established in September 2005 at Réduit Experiment Station, L soil group (Parish & Feillafé, 1965), to compare competition from *P. paniculatum* and *P. urvillei*. Sugar cane, variety R 570, was planted on 28 September 2005 using three-eyed cuttings obtained from an 11 months plant cane field on the station and following standard recommended cultural practices. The cane setts were treated (cold dip) against 'pineapple' disease (caused by *Ceratocystis paradoxa*) with a solution of benomyl at 0.3 g per litre. Young plants of the two weeds were collected from abandoned fields in the Belle-Rive and Ebène regions and were transplanted after pruning of the upper part of the leaves to reduce transpiration.

Treatments and experimental layout

The weeds were transplanted at two dates, the first between 24 and 26 October 2005 (4 WAP) and the second on 5 and 6 December 2005 (10 WAP). At each date, *P. urvillei* and *P. paniculatum* were both

manually transplanted at densities of 4, 8, 16, 32 and 48 plants m^{-2} in each plot; a weed-free plot was also included. Each plot consisted of three cane rows of 2.0 m long and cane planted at a row spacing of 1.5 m. The statistical design used was a split-split plot with the two dates of transplanting weeds as main-plots, weed species (*P. paniculatum* v/s *P. urvillei*) as sub-plot and six weed densities as sub-sub-plot treatments. All treatments were replicated four times. The middle row in each plot was kept for regular cane measurements and was harvested at the end of the experimentation. The two border rows were used for destructive sampling for cane and weed dry weight and leaf area data at each observation date. The field was irrigated regularly and all emerging weeds other than those transplanted were hand-weeded.

Data collection and analysis

For the first transplanting date (TD1), data on weed and cane (fresh/dry weights, leaf areas, average cane dewlap heights) were collected on 7 December 2005(6 WAT), 26 December 2005 (9 WAT), 23 January 2006 (13 WAT) and 27 February 2006 (18 WAT). For the second transplanting date (TD2), similar data were collected three times, namely on 16 January 2006 (6 WAT), 9 February 2006 (9 WAT) and 20 March 2006 (15 WAT). At each data collection date, a quadrat of 0.5 m x 1.0 m was placed on the external rows with the longer side across the cane row. Mean dewlap height of each stalk found in the middle cane row were measured on 30 November 2005, 29 December 2005, 7 February 2006 and 25 April 2006. The cane stalks in the middle row of each treatment plot were harvested on 8 September 2006.

At each observation date, the vertical distribution of leaves was assessed by dividing the canopy into horizontal layers, fixed at 0 to 20 cm, 20 to 40 cm, 40 to 60 cm, 60 to 80 cm and >80 cm above ground (Fig. 4.1a). The cane and weed leaves found in each layer were hand-cut and separated for dry weight and leaf area analysis; the leaves from the topmost layer of the quadrat (0.5 x 1.0 m) were harvested first (Fig. 4.1b). Fresh and dry weights of sampled material were determined as in Trials I and II. Data collection on leaf area of cane and weeds was done with a portable leaf area meter as in the earlier trials.

Statistical and regression analysis

Data with respect to cane measurements (dewlap height, no of shoots), dry weight (aboveground biomass), leaf area and cane yields at harvest were subjected to ANOVA. The relative leaf area (L_w) was calculated from the cane and weed leaf area data. Cane yield data were fitted against the weed

densities using the rectangular hyperbola (linear-by-linear) function in Genstat (Genstat, 2005). Only regressions that were statistically significant ($P< 0.05$) were presented, even though the R^2 values were sometimes low (where fits were not statistically significant the regressions lines were not presented). Relative leaf area and cane yield loss data were subjected to non-linear regression analysis (weed competition model developed by Kropff and Spitters (1991)) using Genstat (Genstat, 2005) to estimate the relative competitiveness q values for the two weed species.

4.3 Results

4.3.1. Trial I - Effect of time of observation and two transplanting dates on the relative competitiveness of *Paspalum paniculatum and Paspalum urvillei* in competition with sugar cane

4.3.1.1 Effect of time of observation on the competitive effects of *P. paniculatum* and *P. urvillei* transplanted 9 WAP (first transplanting date – TD1)

Rate of growth of cane and weeds

Cane growth increased during the first three observation dates before slowing down at the fourth observation date (18 WAT of weeds or 27 WAP of cane) (Fig. 4.2). On three observation dates, namely 5, 14 and 18 WAT, the mean dry weight of cane (mean of all densities and three replicates) was higher for the plots under competition with *P. urvillei*, indicating that *P paniculatum* may have caused more competition. The biomass of weeds was also found to increase with time, a maximum dry weight was recorded for *P. urvillei* at 9 WAT compared to *P. paniculatum* which reached its peak at the third observation date.

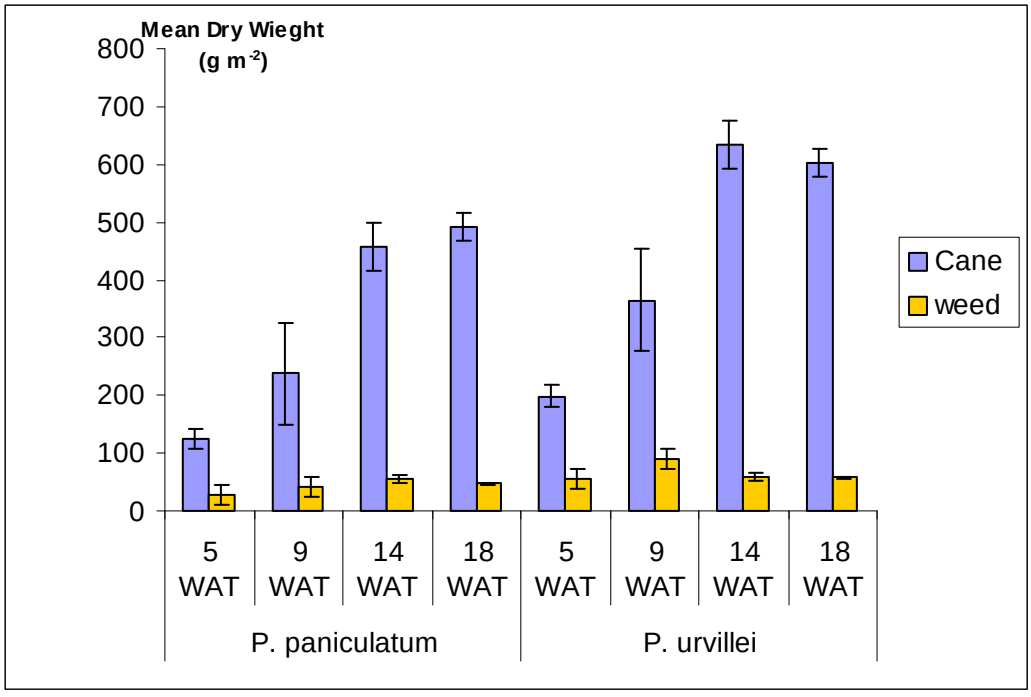


Fig. 4.2 Mean dry weight (g m^{-2}) of cane and weeds 5, 9, 14 and 18 weeks after the first transplanting (TD1) (mean of 6 weed densities for cane and 5 for weeds). Error bars show standard error of mean.

Relative dry weight of cane and weeds

In general, the aboveground biomass (dry weight) of weeds at each observation date confirmed a higher amount of weeds with increasing weed density (Figs. 4.3a & 4.3b). The relative biomass of weeds, irrespective of species, was almost similar at the first and second observation dates; these decreased later on to reach a ratio of cane to weed exceeding 85% of the total biomass at the last observation date.

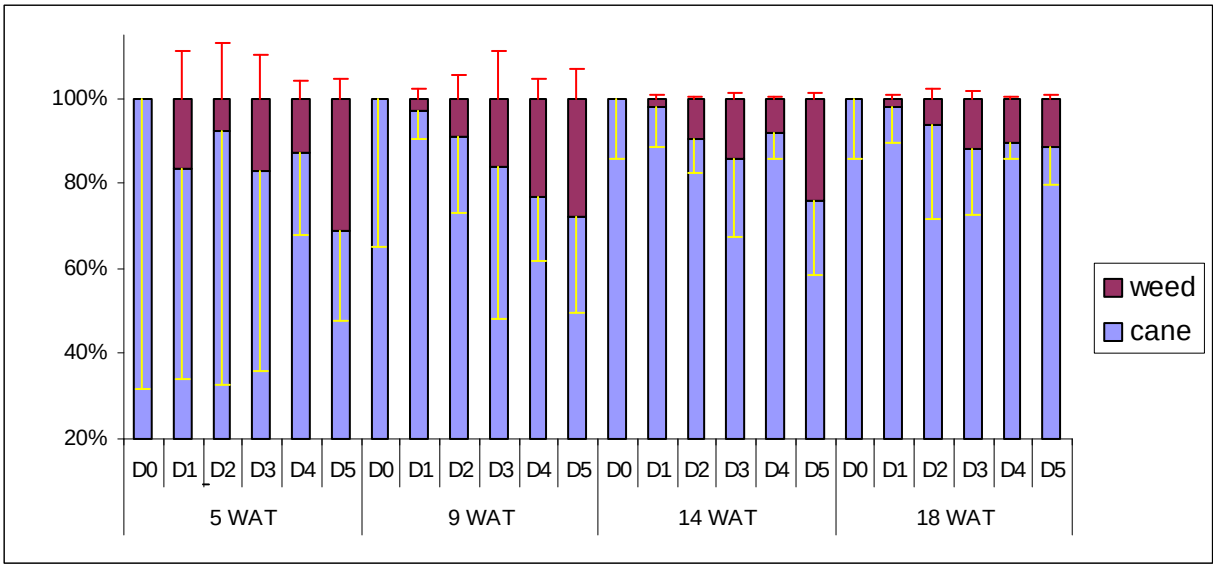


Fig. 4.3a Relative dry weight of cane and *P. paniculatum* at different weed densities (D0= 0, D1= 6, D2= 10, D3= 15, D4= 20 and D5= 33 plants m^{-2}) and observation dates. For each date of observation, the yellow error bars represent 1 x s.e.d. for cane and red error bars represent 1 x s.e.d. for weed.

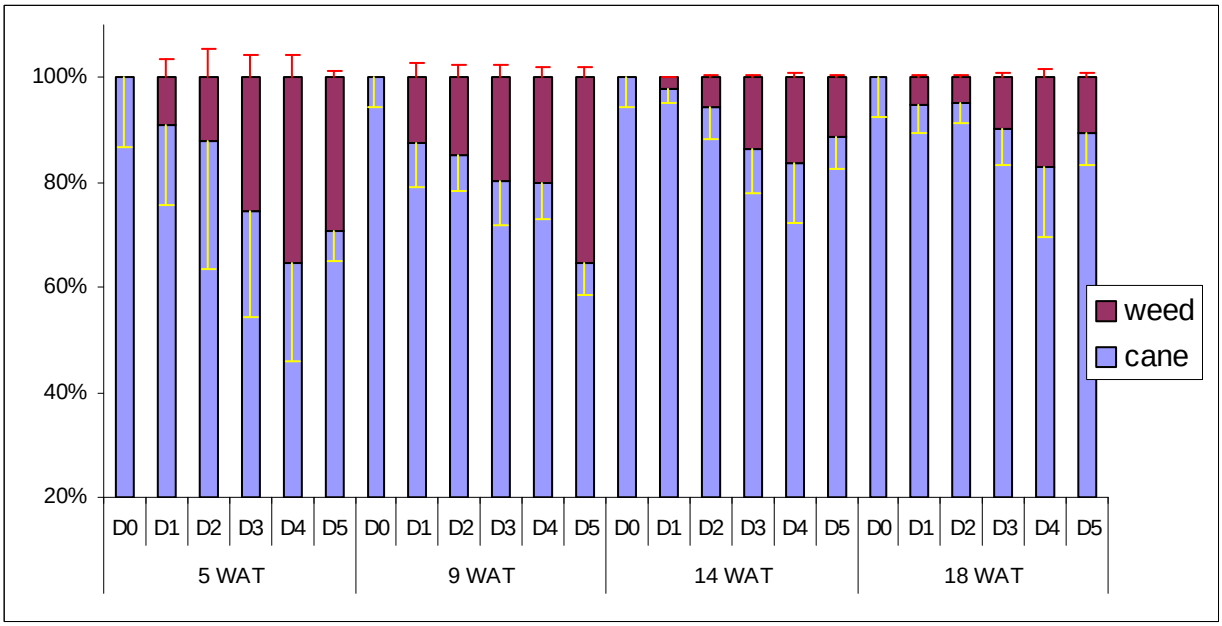


Fig. 4.3b Relative dry weight of cane and *P. urvillei* at different weed densities (D0= 0, D1= 6, D2= 10, D3= 15, D4= 20 and D5= 33 plants m^{-2}) and observation dates. For each date of observation, the yellow error bars represent 1 x s.e.d. for cane and red error bars represent 1 x s.e.d. for weed.

Leaf area of cane and weed

The mean cane leaf area in the weed-free treatment increased over the four observation dates (Figs. 4.4a & 4.4b). At all observation dates, there was no consistent adverse effect of weed competition on the leaf area of cane although a tendency for the cane leaf area to decrease with increasing weed leaf area was apparent in some assessments. Leaf area of *P. paniculatum* increased with weed density (Fig. 4.4a). Although increasing trends were apparent with *P. urvillei*, they were only rarely statistically superior. There was a lot of variability in the data, which is reflected in the standard errors, thus making it difficult to confirm any cane responses.

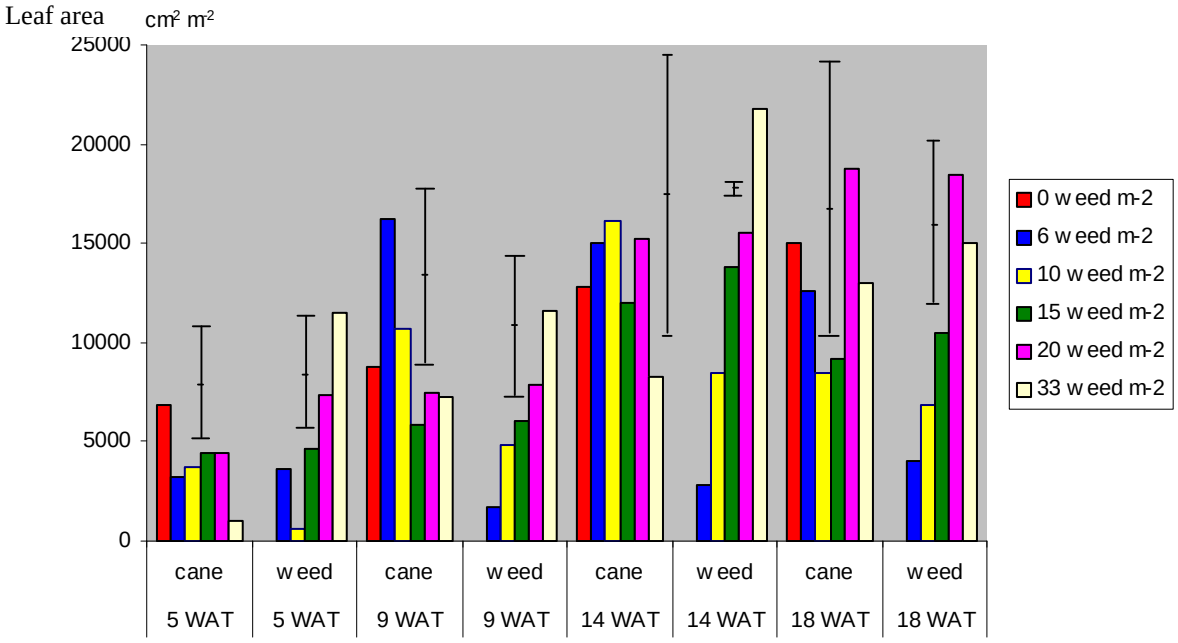


Fig. 4.4a Leaf area of cane and *P. paniculatum* at different weed densities and observation dates. Error bars represent 2 x s.e.d.

In general, the differences in leaf area between cane and weed at the respective weed densities and dates of observation were lower than those observed for the total dry weight (aboveground biomass) (see Figs 4.3 & 4.4). This may be explained by the fact that the dry weight of the cane is constituted of both stalks and leaves; the dry weight of cane stalk increased with cane elongation and time.

The mean (of five densities) relative leaf area of *P. paniculatum* was 0.55 (s.e.= 0.125), 0.41 (s.e.= 0.063), 0.48 (s.e.= 0.058) and 0.47 (s.e.= 0.054) at 5, 9, 14 and 18 WAT respectively. For *P. urvillei*, it was 0.45 (s.e.= 0.046), 0.39 (s.e.= 0.049), 0.38 (s.e.= 0.052) and 0.46 (s.e.= 0.053) at 5, 9,

14 and 18 WAT respectively. These results suggest no major drift in the relative growth of cane and the two weeds with time.

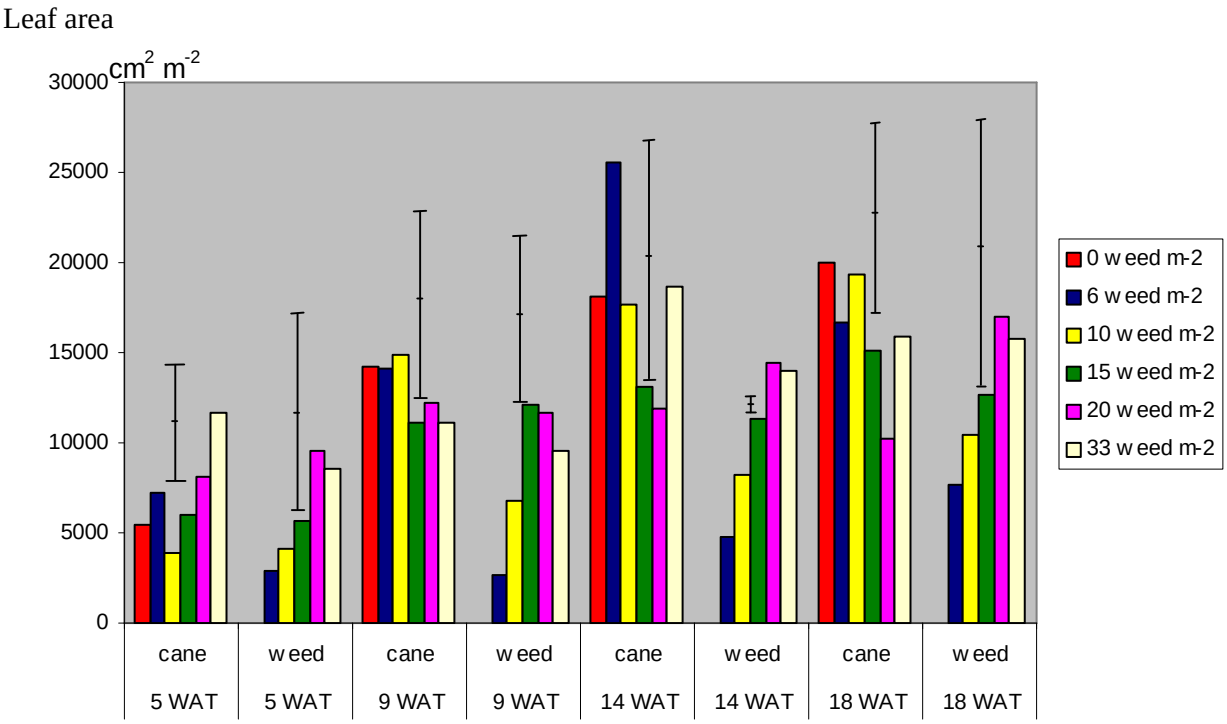


Fig. 4.4b Leaf area of cane and *P. urvillei* at different weed densities and observation dates. Error bars represent 2 x s.e.d.

Effect of weed competition on total dewlap height

The mean total dewlap height of cane measured at each of observation dates showed no significant differences in most of the comparisons (Table 4.1). This is explained by the high coefficient of variation (CV%) observed, as the weeds may have developed differently with time compared to their respective initial densities at transplanting.

Table 4.1 Effect of different weed densities of *P. paniculatum* and *P. urvillei* on total dewlap height (cm m^{-2}) of cane observed at four dates

Weed density (plants m^{-2})	Total dewlap height (cm m^{-2})							
	5 WAT		9 WAT		14 WAT		18 WAT	
	P. pan	*P. urv*	*P. pan*	*P. urv*	*P. pan*	*P. urv*	*P. pan*	*P. urv*
Weed-free	268		471		536		530	
6	190	309	449	435	518	849	433	638
10	223	231	277	408	608	606	347	663
15	183	239	216	406	441	521	377	575
20	286	262	267	294	569	432	737	444
33	278	294	255	350	353	798	467	515
S.e.d. (d.f.)	*86.8 (19)*		*114.9 (20)*		*217.5 (18)*		*191.1 (20)*	
CV %	*42.0*		*39.3*		*47.0*		*44.9*	

Effect of relative leaf area and time of observation on cane dewlap height

The relationships between cane dewlap height and the relative leaf area (L_w) between *P. paniculatum* or *P. urvillei* and cane at each observation date (e.g. 9 & 18 WAT in Fig. 4.5) showed a better correlation from 9 WAT (Table 4.2). The poor relationship at 5 WAT may suggest that weed competition between cane and the weeds was not apparent as they were still developing and, may be, there needs to be a minimum period of exposure before any effect on cane can be observed.

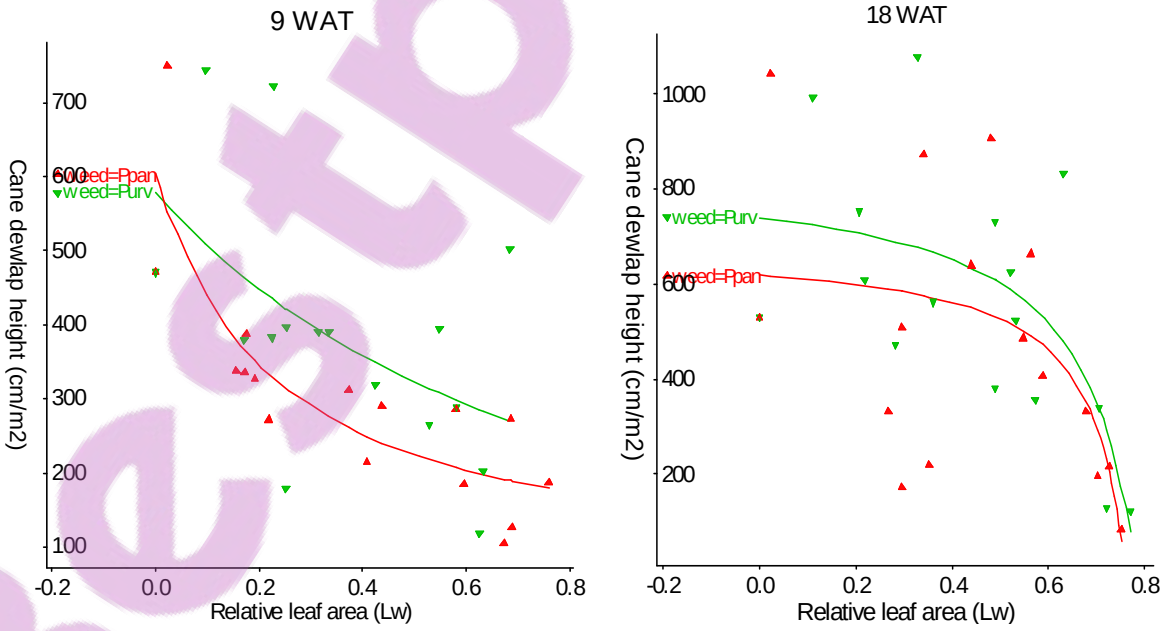


Fig 4.5 Relationship between the relative leaf area (L_w) of *P. paniculatum* or *P. urvillei* transplanted 4 WAP and dewlap height of cane (cm m^{-2}) observed at 9 WAT (left) and 18 WAT (right). Response curve are those from parameters given in Table 4.2.

At 9 WAT, the effect of competition increased with increasing relative leaf area (L_w) while for the 3rd and 4th observation dates, very little reduction in dewlap height occurred at lower L_w and was followed with a rapid reduction thereafter. The reasons for this difference in response are unclear, partly because of the variability in the data sets but may be explained by a reduction in cane leaf areas with some of the higher weed densities, which may have impaired photosynthesis and cane development. The competitive effect at the higher relative leaf areas may also indicate that, with time, the vertical distribution of the leaves within the canopy may have changed.

Paspalum paniculatum seemed to cause more reduction in dewlap height as compared to *P. urvillei* at all observation dates; however the standard errors of the various parameters did not confirm that difference in relative competitiveness (Table 4.2).

Table 4.2 The parameters of the response curves showing relationship between cane dewlap height and relative leaf area (L_w) of weeds using the rectangular hyperbola model (y= A + B/(1+D*x) where x= L_w. Values in parentheses are standard errors of parameter values.

Observation date	Weed	R^2	D	B	A
5 WAT	*P. paniculatum*	0.17	-1.32 (0.274)	-19.7 (42.1)	319 (86.0)
	P. urvillei	-	-1.21 (0.337)	-0.87 (3.32)	284 (28.2)
9 WAT	*P. paniculatum*	0.68	4.41 (3.19)	551 (114)	53 (118)
	P. urvillei	0.16	1.13 (3.81)	707 (1260)	-129 (1343)
14 WAT	*P. paniculatum*	0.27	-0.17 (1.35)	-3313 (30374)	4105 (30492)
	P. urvillei	0.35	-0.85 (0.39)	-270 (381)	1044 (460)
18 WAT	*P. paniculatum*	0.22	-1.20 (0.194)	-61.1 (94.7)	680 (192)
	P. urvillei	0.37	-1.11 (0.193)	-110 (128)	851 (217)

Effect of weed competition on cane yield (TD1)

The cane yield recorded in the weed-free plot was much lower than those usually obtained for plant cane in Réduit because the trial was planted very late in the season and was harvested only forty weeks later. Planting cane by the end of August is the recommended practice while plant cane is normally harvested between 12 and 14 months after planting. However, it is assumed that the lower yields do not preclude completely comparisons for the relative competition from the two weeds. The relationship between cane yield and weed density of the two weeds was poor, only *P. paniculatum* showing a decrease in yield as compared to the weed-free treatment (Fig 4.6). *Paspalum urvillei* showed no effect on cane yield.

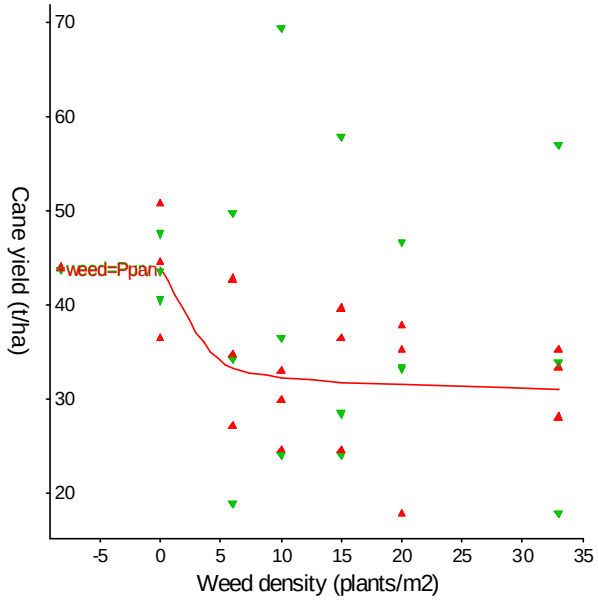


Fig. 4.6 Relationship between cane yield and weed density of *P. paniculatum* and *P. urvillei* transplanted 9 WAP. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where R^2= 0.25 and parameter values D= 0.64 (1.77), B= 13.45 (5.82) and A= 30.44 (4.33) for *P. paniculatum*; for *P. urvillei* there was no fit. (Values in parentheses are standard error of the estimates).

A relatively better relationship was observed between cane yield and the relative leaf areas of the weeds, cane yields decreased with increasing relative leaf areas (Fig. 4.7).

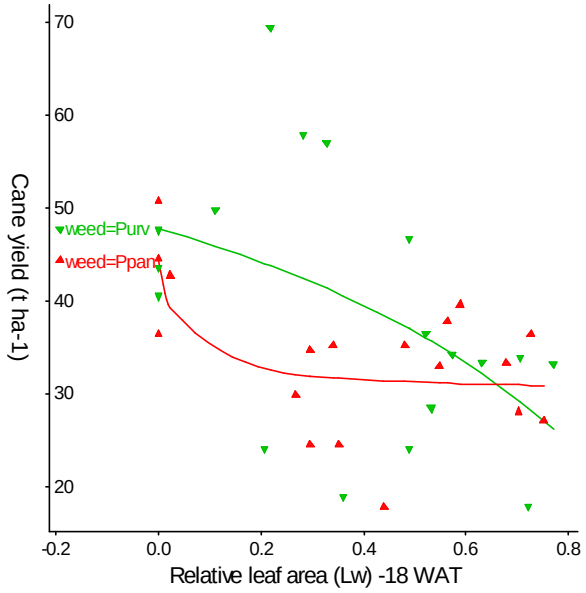


Fig. 4.7 Relationship between cane yield and relative leaf areas (L_w) of *P. paniculatum* and *P. urvillei* transplanted 9 WAP. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where R^2= 0.34 and parameter values D= 23.4 (51.3), B= 14.2 (4.57) and A= 30.1 (3.31) for *P. paniculatum*; and for *P. urvillei*, R^2 was 0.14 and parameter values D= -0.55 (1.18), B= -29.0 (105) and A= 76.8 (110). (Values in parentheses are standard error of the estimates).

Relative competitiveness (q value) of P. paniculatum and P. urvillei and time of observation

The loss in cane yield (compared to means of the weed-free treatment) within individual plots with the same weed species and at the same date of observation was fitted with the corresponding relative leaf area (L_w) values to determine the relative competitiveness 'q' values. At all dates, there was a tendency for the q value for *P. paniculatum* to be higher (although differences not significant at $P< 0.05$) than that of *P. urvillei* (Table 4.3), as comparisons reported in Chapter 3.

Table 4.3 Relative competitiveness 'q' values for *P. paniculatum* and *P. urvillei* at different observation dates after transplanting weeds

	Relative competitiveness q value			
Date of observation	5 WAT	9 WAT	14 WAT	18 WAT
P. paniculatum	0.31 (0.078)	0.28 (0.099)	0.28 (0.081)	0.27 (0.083)
P. urvillei	0.16 (0.073)	0.17 (0.136)	0.13 (0.123)	0.20 (0.109)

Values in parentheses represent standard errors (s.e.) of the estimated q value.

The relative competitiveness of both weed species did not change with the time of observations as discussed by Kropff and Spitters (1991) and Kropff and van Laar (1993). A calculation of the relative competitiveness q value with time was attempted using the values at 5 WAT as q_0 (closer to weed emergence). The relative growth rate of the leaf areas of cane and weed were calculated using 16.0^{o}C as the base temperature for estimation of growing degree days (^{o}C d) for sugar cane (Inman-Bamber, 1994) and weed species (assumed to be similar to cane as data for weeds are not available). Data were fitted into equation 3 (Eqn 3).

The estimated values showed that the observed q values were lower than the expected ones (Table 4.4). According to the estimated values, the q value for both weed species should have increased to a peak at the second observation date due to a relatively higher growth rate of the leaf area of cane as compared the weed. The relatively lower q values recorded may have arisen due to the difference in vertical distribution of the cane leaves compared to those of the weeds with time. The difference in competitiveness between the two *Paspalum* species was maintained.

Table 4.4 Estimation of relative competitiveness q values with time and relative rate of growth of cane and leaf area ($^{o}C^{-1}$ d^{-1}).

	9 WAT		14 WAT		18 WAT	
	P. pan	*P. urv*	*P. pan*	*P. urv*	*P. pan*	*P. urv*
Time (^{o}C d)	236		483		613	
Mean rate of growth of cane leaf area ($^{o}C^{-1}$ d^{-1})	0.010	0.005	0.007	0.008	0.006	0.007
Mean rate of growth of weed leaf area ($^{o}C^{-1}$ d^{-1})	0.005	0.002	0.007	0.003	0.004	0.005
Estimated q value	0.54	0.29	0.35	0.18	0.34	0.23

P. pan = P. paniculatum; P. urv = P. urvillei

4.3.1.2 Effect of time of observation on the competitive effects of *P. paniculatum* and *P. urvillei* transplanted 17 WAP (second transplanting date – TD2)

Rate of growth of cane and weeds

The increase in mean cane dry weight (mean of all weed densities), which was attained in the presence of both weed species, between the three observation dates was not significant ($P< 0.05$) (Fig. 4.8). Although transplanting was carried out 17 WAP, the results showed that weed growth was not affected by the relatively more advanced stage of the cane, particularly with *P. urvillei* (see Fig. 4.2).

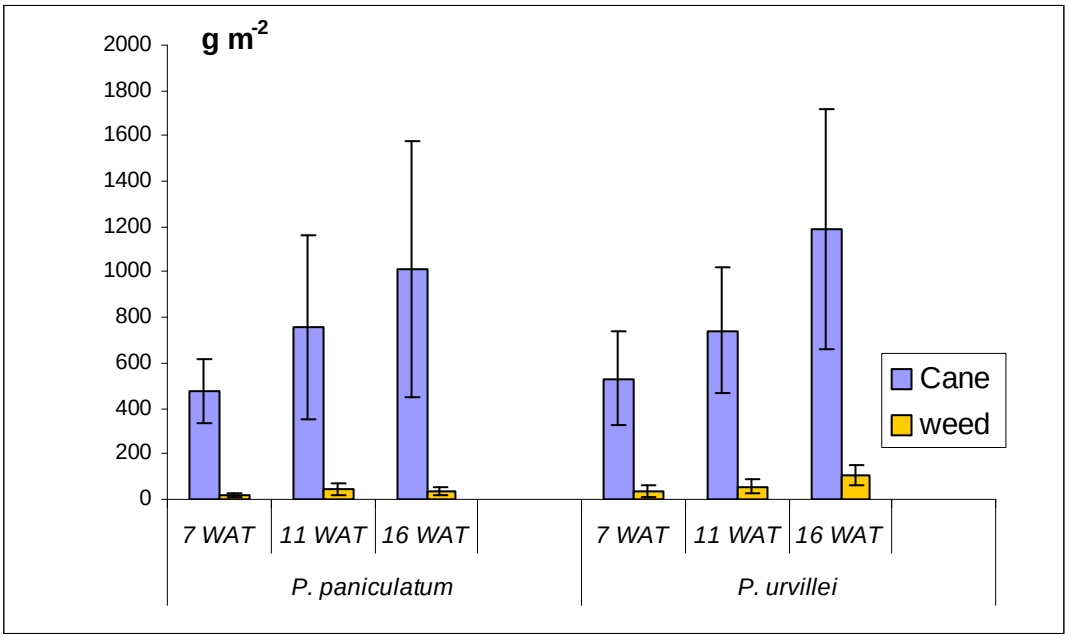


Fig. 4.8 Mean dry weight (g m^{-2}) of cane and weeds 7, 11 and 16 WAT weeds (made 17 WAP - TD2). Error bars show standard error of mean.

Relative dry weight of cane and weeds

The dry weight analysis of weeds showed that the proportions of weeds at the three dates were not consistent and seemed to reach a plateau at the higher densities at 11 and 16 WAT, particularly for *P. urvillei* (Figs. 4.9a & 4.9b). Sugar cane gained biomass with time and the relative amount of weeds, irrespective of species, remained similar for the next two observation dates; this implied that the weeds had also developed and built up biomass within those periods. The latter was more visible within the *P. urvillei* plots. The ratio of sugar cane in the total biomass represented 90% in nearly all plots which is somewhat higher than in the first transplanting date experiment.

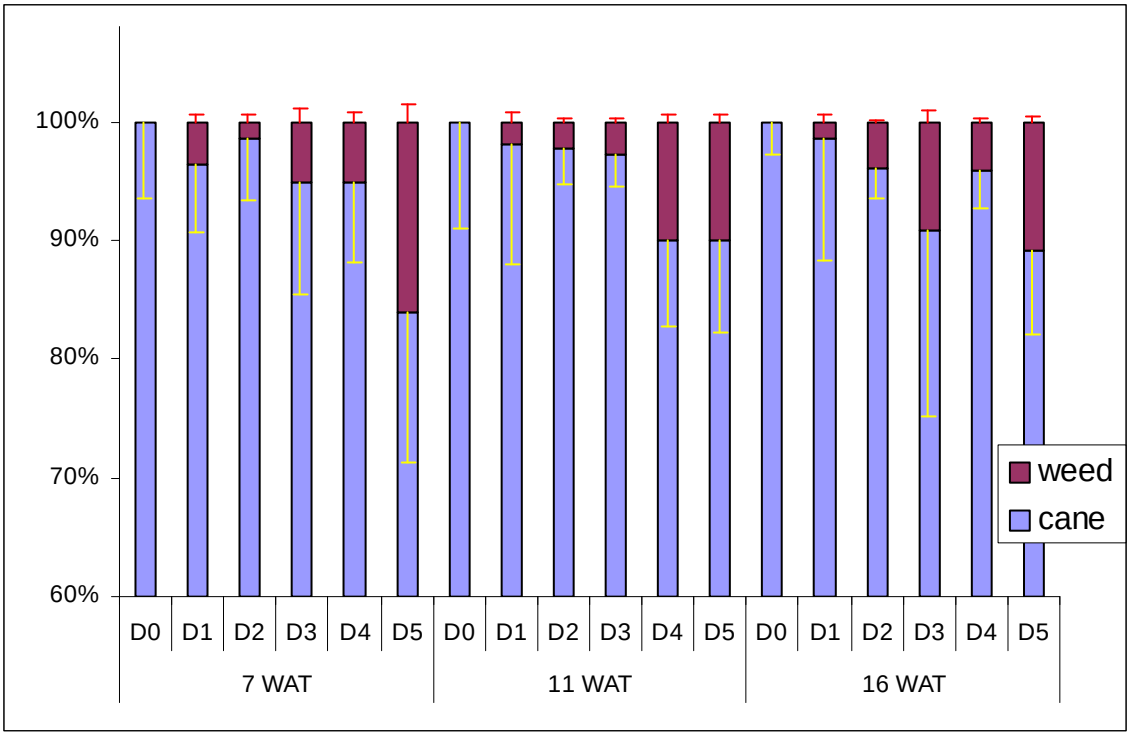


Fig. 4.9a Relative dry weight of cane and *P. paniculatum* at different weed densities (D0= weedfree, D1= 6, D2= 10, D3= 15, D4= 20 and D5= 33 plants m^{-2}) and observation dates. For each date of observation, the yellow error bars represent 1 x s.e.d. for cane and red error bars represent 1 x s.e.d. for weed.

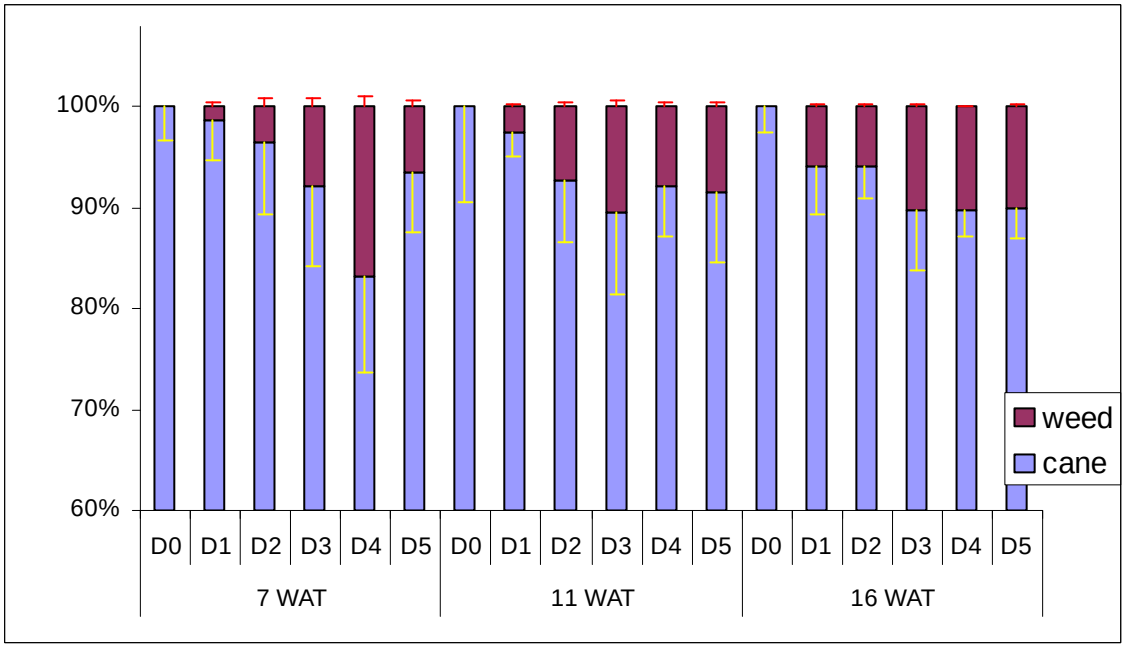


Fig. 4.9b Relative dry weight of cane and *P. urvillei* at different weed densities (D0= weedfree, D1= 6, D2= 10, D3= 15, D4= 20 and D5= 33 plants m^{-2}) and observation dates. For each date of observation, the yellow error bars represent 1 x s.e.d. for cane and red error bars represent 1 x s.e.d. for weed.

Leaf area of cane and weed

The mean cane leaf area in the weed-free treatment did not clearly increase over the three observation dates (after transplanting) (Figs. 4.10a & 4.10b). Irrespective of weed species and observation dates, no decrease in the leaf area of cane was observed with increasing weed density (increasing weed leaf area). Weed leaf area tended to increase with increasing density.

The mean (of all densities) relative leaf areas (L_w) of the weeds were slightly lower at the first observation date; the cane was at a more developed stage and the weeds grew relatively faster thereafter. The mean (of all weed densities) relative leaf areas with *P. paniculatum* were 0.29 (s.e.= 0.038), 0.33 (s.e.= 0.054) and 0.32 (s.e.= 0.062) at 7, 11 WAT and 16 WAT respectively; they were 0.26 (s.e.= 0.042), 0.36 (s.e.= 0.051) and 0.44 (s.e.= 0.059) for *P. urvillei* at the same dates. Thus there was a tendency for L_w to increase with time. Also L_w for this second date of transplanting was lower, especially for *P. paniculatum* than at the first transplanting date.

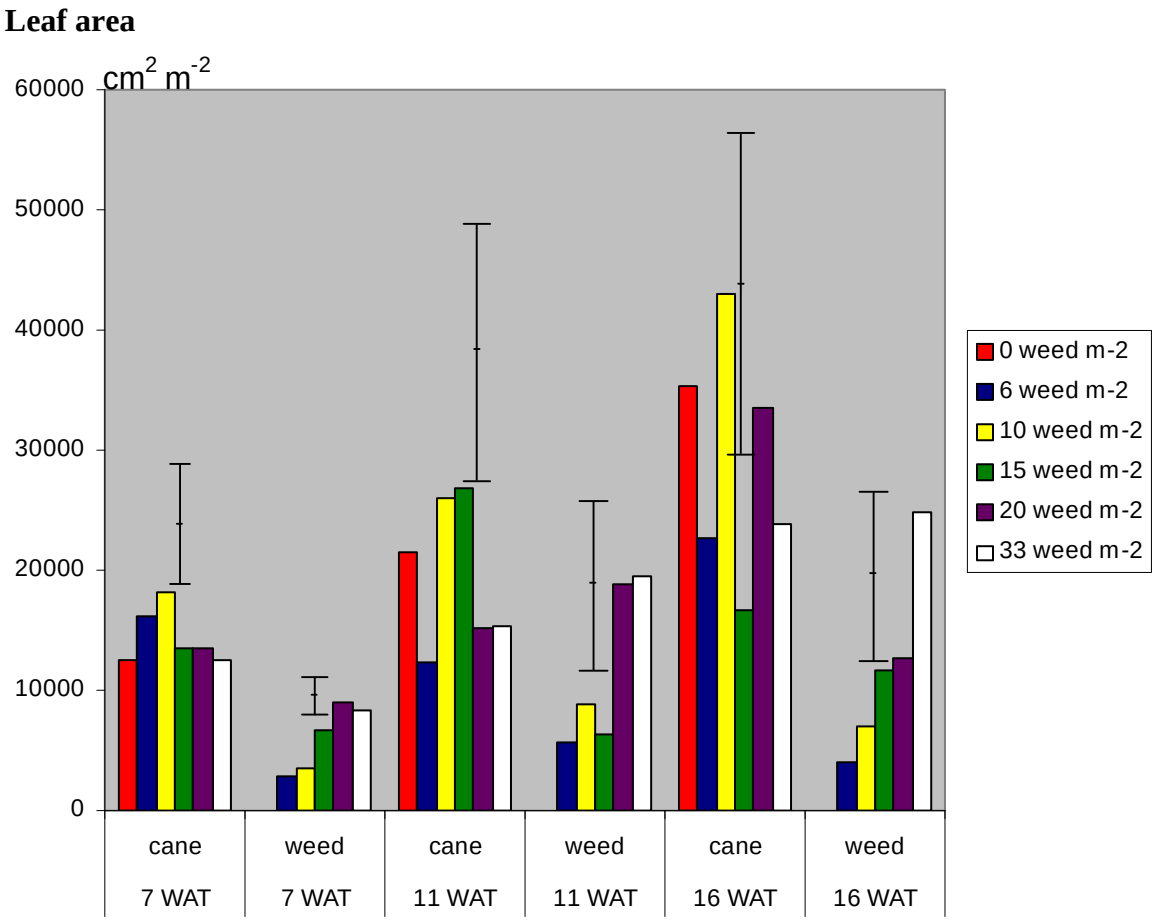


Fig. 4.10a Leaf area of cane and *P. paniculatum* at different weed densities and observation dates (TD2). Error bars represent 2 x s.e.d.

Leaf area

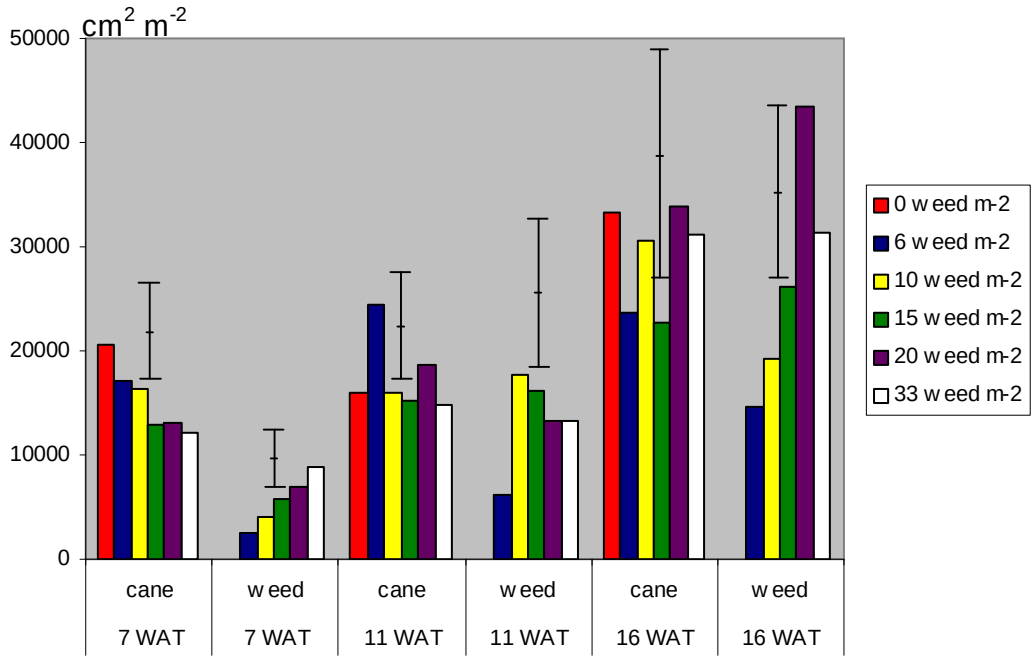


Fig. 4.10b Leaf area of cane and *P. urvillei* at different weed densities and observation dates (TD2). Error bars represent 2 x s.e.d.

Effect of weed competition on total dewlap height

For the second transplanting date, the mean dewlap height of cane measured at the three observation dates showed no significant differences due to the high CVs resulting from variability in the level of infestations between the repetitions and the treatments several weeks after transplanting. However, a general trend of a reduction in the total dewlap height due to the presence of the two weed species was observed within the data collected (Table 4.5). But no clear link was detectable between weed density and dewlap height

Table 4.5 Effect of different weed densities of *P. paniculatum* and *P. urvillei* on total dewlap height (cm m^{-2}) of cane observed at three dates after TD2

Weed density (plants m^{-2})	Total dewlap height (cm m^{-2})					
	7 WAT		11 WAT		16 WAT	
	P. pan	*P. urv*	*P. pan*	*P. urv*	*P. pan*	*P. urv*
Weed-free	699		613		1014	
6	592	658	418	769	879	872
10	624	552	723	474	840	981
15	424	513	706	438	802	684
20	470	486	449	556	862	943
33	441	522	478	505	640	858
S.e.d. (d.f.)	*163.7 (20)*		*197.8 (20)*		*273.9 (20)*	
*CV % **	*36.0*		*43.1*		*38.8*	

* weed x density x rep

Effect of relative leaf area & time of observation on cane dewlap height

A reasonable relationship between cane dewlap height and the relative leaf area (L_w) between *P. paniculatum* or *P. urvillei* was observed at the first and third observation dates (Fig. 4.11 & Table 4.6). The relationship was better with *P. paniculatum* (Table 4.6).

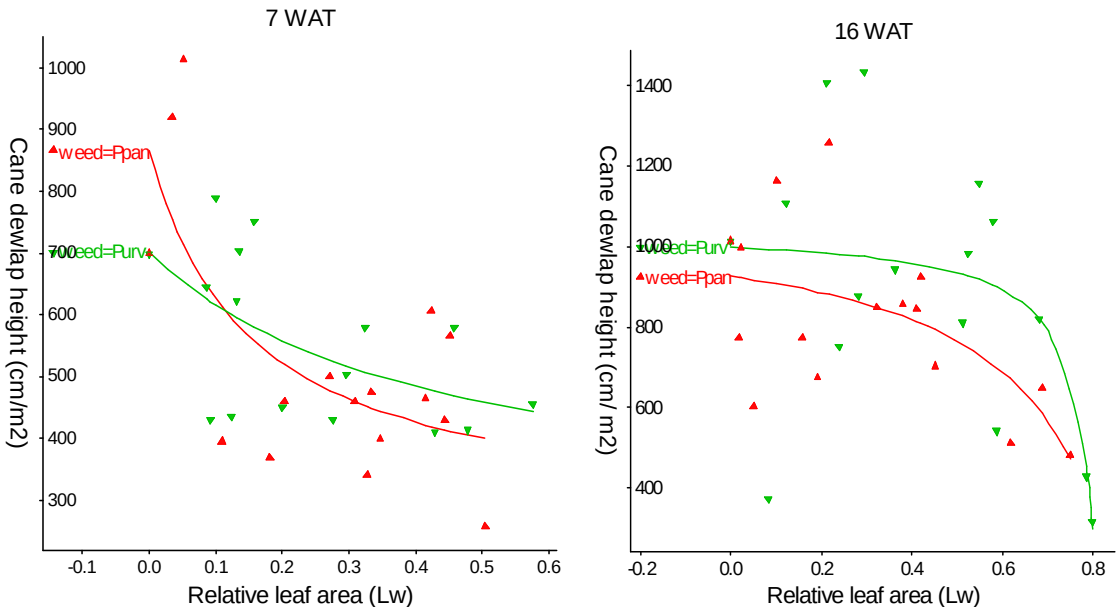


Fig 4.11 Relationship between the relative leaf area (L_w) of *P. paniculatum* or *P. urvillei* transplanted 17 WAP and dewlap height of cane (cm m^{-2}) observed 7 WAT (left) and 16 WAT (right). Response curves are those from parameters given in Table 4.6.

Table 4.6 The parameters of the response curves showing relationship between cane dewlap height and relative leaf area (L_w) of weeds using the rectangular hyperbola model (y= A + B/(1+D*x) where x= L_w. Values in parentheses are standard errors of parameter values.

Observation date	Weed	R^2	D	B	A
7 WAT	*P. paniculatum*	0.40	6.48 (8.46)	610 (201)	256 (225)
	P. urvillei	0.20	2.39 (6.95)	444 (518)	257 (588)
11 WAT	*P. paniculatum*	0.18	5.6 (10.6)	605 (304)	286 (326)
	P. urvillei	No fit	-	-	-
16 WAT	*P. paniculatum*	0.27	-0.98 (0.613)	-167 (371)	1093 (447)
	P. urvillei	0.26	-1.18 (0.112)	-43.8 (68.4)	1043 (149)

The response was again (as for TD1) found to change with time. There was little competition at relative leaf areas below 0.5 at the last date of observation but the dewlap heights decreased significantly thereafter (Fig. 4.11).

Effect of weed competition on cane yield (TD2)

The subplots for the second transplanting (TD2) date were harvested on the same day as for the TD1 plots and recorded low cane yields for the same reasons explained for first transplanting date. No significant relationship between cane yield and weed density, irrespective of weed species, was observed for the second transplanting date (Fig. 4.12).

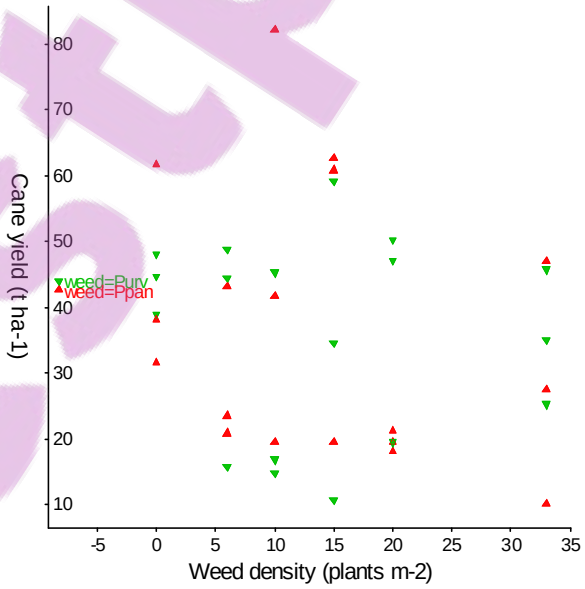


Fig 4.12 Relationship between weed density (plants m^{-2}) of *P. paniculatum* or *P. urvillei* transplanted 17 WAP and cane yield (t ha^{-1}). No fit for both response curves was obtained.

A poor relationship between the cane yields and the relative leaf areas, particularly that for the last observation date, was also noted. The lack of difference observed in the final yields as compared to the effects observed on total dewlap heights at the respective observation dates may imply that the cane recovered partly later. In absence of any relationship, the relative competitiveness factor 'q' was not estimated for the different observation dates as for the first transplanting date (TD1).

4.3.1.3 Effect of date of transplanting on the competitive effects of *P. paniculatum* and *P. urvillei*

Stage of cane growth at transplanting of weeds

The first transplanting (TD1) was carried out during the tillering phase while the second one (TD2) was done just after the peak within the tillering phase had been reached (Fig 4.13). Similarly, the mean cane stalk height at TD1 was approximately 20 cm compared to the second one when the stalks had reached some 50 cm (Fig. 4.14). These conditions would render the cane within the first transplanting plots more susceptible to weed competition.

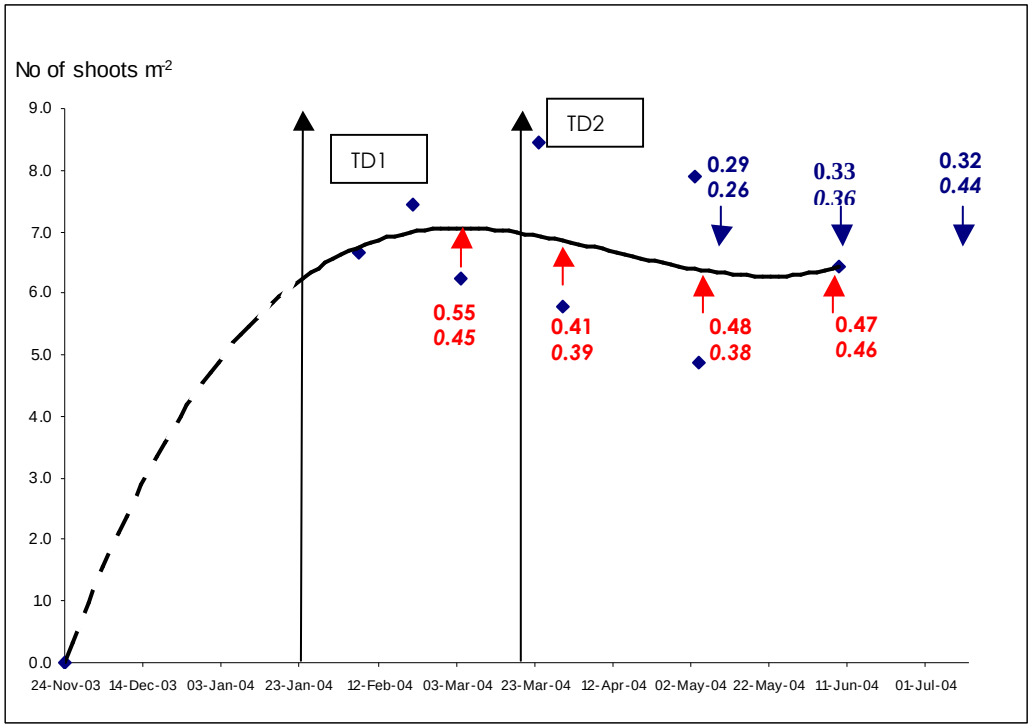


Fig. 4.13 Cane tillering in the weed-free plots and arrows showing first (TD1) and second (TD2) dates of transplanting of weeds (black), date of observations after 1st transplanting (red arrow) and date of observation after 2nd transplanting (blue arrow). The relative leaf areas (L_w) for *P. paniculatum* (normal) and *P. urvillei* (italic) at each observation date are shown in same colours as for the transplanting date.

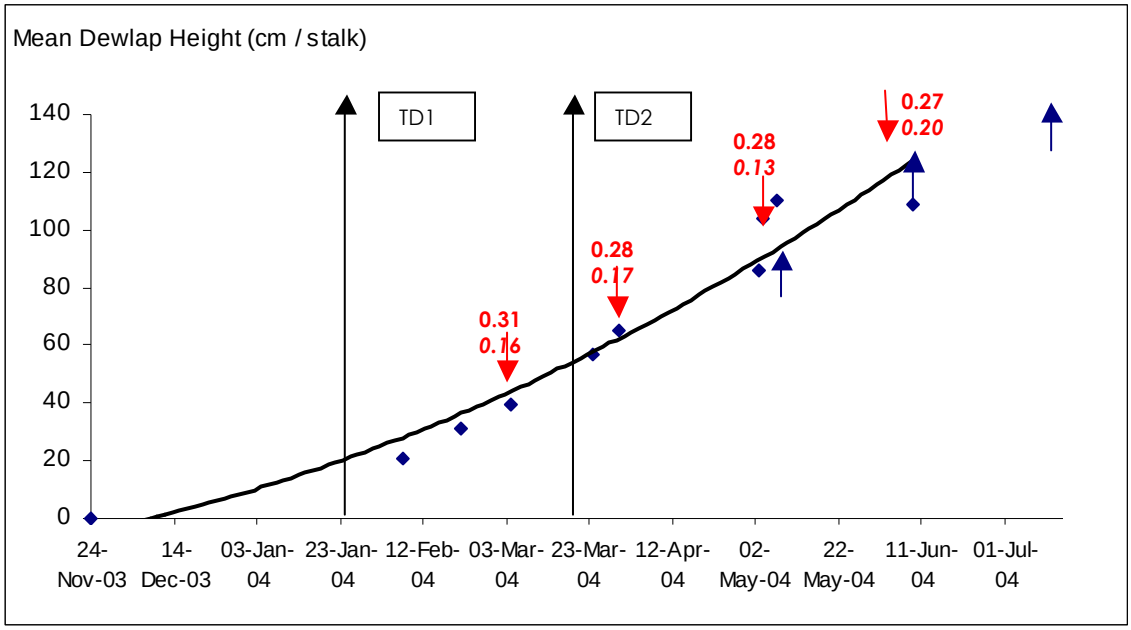


Fig. 4.14 Mean dewlap height of cane stalks in the weedfree plots and arrows showing first (TD1) and second (TD2) dates of transplanting of weeds (black), date of observations after 1st transplanting (red arrow) and date of observation after 2nd transplanting (blue arrow). The q values for *P. paniculatum* (normal) and *P. urvillei* (italic) at each observation date after TD1 are shown.

If weed competition was solely caused by competition for light, the presence of weeds at an earlier stage when the cane stalks were shorter would cause more competition and the weeds would have shown higher relative competitiveness values. The relative leaf areas (L_w) after the second transplanting date were not much lower than those of the first transplanting date; therefore competition should have been more or less similar. If the lack of difference in cane yields for the second transplanting date was due to some recovery or compensation later in the growth period as the cane approached maturity; this should have also happened for the first transplanting date. The difference between these two dates is related to the height of the cane and weeds, and their distribution in the canopy. The distribution of the leaf areas of the two crops may have differed with time and less competition for light would be expected at the later transplanting date. The results may also indicate that modelling of weed competition in sugar cane using the model of Kropff and Spitters (1991) at an advanced stage of growth is not appropriate. Another possible explanation would be that weed competition between the two *Paspalums* and sugar cane is also due to mechanisms of competition other than that for light.

4.3.2 Trial II – Relative competitiveness of *Paspalum paniculatum* and *Paspalum urvillei* on sugar cane at two observation dates and effect of leaf area distribution on competition

4.3.2.1 Effect of time of observation on the competitive effects of *P. paniculatum* and *P. urvillei*

Effect on cane growth

Cane measurements made at the first observation date on 13 May 2005 (8 WAH) revealed no difference in tillering (Table 4.7) and total dewlap height (Table 4.8) between the various weed densities of both weed species. The mean dewlap height of cane stalks in the weed-free treatments at the first observation date was 15.6 cm.

Table 4.7 Effect of weed competition from *P. paniculatum* and *P. urvillei* on tillering of sugarcane at two observation dates

Weed density (plants m^{-2})	No of shoots m^{-2}			
	May 2005		August 2005	
	P. paniculatum	*P. urvillei*	*P. paniculatum*	*P. urvillei*
0	18.3		20.6	
12	17.8	17.3	13.0	12.5
16	22.3	21.5	18.0	12.8
24	20.3	12.5	18.5	7.8
28	16.0	17.0	15.0	10.5
36	15.0	20.0	12.5	7.8
S.e.d. (d.f.)	*4.22 (30)*		*2.70 (30)*	
CV% *	33.2		27.0	

* rep x weed x density; values are mean of four replications

At the second observation date in August (20 WAH), weed competition had an adverse effect on cane tillering; the number of shoots was reduced compared to the first observation date and most of the weed densities, irrespective of weed species, showed a significant ($P < 0.05$) reduction in shoot number (Table 4.7). The reduction seemed to be more severe with *P. urvillei*. This reduction in cane stalk density resulted in a significantly lower total dewlap height in several treatments, particularly in the *P. urvillei* sub-plots (Table 4.8). The mean dewlap height of cane stalks in the weed-free treatments was 28.6 cm.

Table 4.8 Effect of weed competition from *P. paniculatum* and *P. urvillei* on total dewlap height of sugar cane at two observation dates

Weed density (plants m^{-2})	Total dewlap height (cm m^{-2})			
	May 2005		August 2005	
	P. paniculatum	*P. urvillei*	*P. paniculatum*	*P. urvillei*
0	375		589	
12	311	294	350	364
16	395	370	553	373
24	379	241	590	256
28	283	299	478	315
36	281	398	407	247
S.e.d. (d.f.)	*83.9 (30)*		*87.8 (30)*	
CV% *	37.3		29.1	

* rep x weed x density; values are means of four replications

Leaf area of cane and weeds

At the first observation date (8 WAH), *P. urvillei* seemed to produce more leaf area than *P. paniculatum*, however the differences were not significant ($P< 0.05$) due to the high coefficient of variation observed between the treatments (Table 4.9). Cane leaf area appeared little affected by the presence of the weeds.

Table 4.9 Effect of weed competition from *P. paniculatum* and *P. urvillei* on leaf area of cane and weed at first observation date (8 WAH)

Weed density (plants m^{-2})	Leaf area (cm^2 m^{-2})			
	Cane		Weed	
	P. paniculatum	*P. urvillei*	*P. paniculatum*	*P. urvillei*
0	8915		-	
12	12714	10045	3327	16279
16	15525	10816	5844	14500
24	14720	8050	8037	23533
28	8176	9992	15143	21843
36	9316	11564	10875	17757
S.e.d. (d.f.)	*3402.6 (30)*		*4942.8 (24)*	
CV% *	44.9		51.0	

* rep x weed x density; values are mean of four replications

Leaf area measurements made 20 WAH showed significantly higher weed leaf areas for *P. urvillei* than for *P. paniculatum* at several densities (Table 4.10). The relatively lower leaf area of cane recorded within the *P. urvillei* treatments may have resulted from the relatively higher weed leaf area in those plots.

Table 4.10 Effect of weed competition from *P. paniculatum* and *P. urvillei* on leaf area of cane and weed at second observation date (20 WAH)

Weed density (plants m^{-2})	Leaf area (cm^2 m^{-2})			
	Cane		Weed	
	P. paniculatum	*P. urvillei*	*P. paniculatum*	*P. urvillei*
0	20475		-	
12	16283	14945	9930	25587
16	29686	16366	10868	21273
24	23174	11085	7253	40874
28	22917	14242	9376	23649
36	18751	10899	8652	17290
S.e.d. (d.f.)	*4500.3 (30)*		*6213.8 (24)*	
CV% *	34.8		50.3	

* rep x weed x density; values are mean of four replications

Relative leaf area and reduction in dewlap height

The mean (of all densities) relative leaf area (L_w) of *P. paniculatum* was 0.39 (s.e.= 0.051) and 0.32 (s.e.= 0.021) for the first and second observation dates, respectively, compared to 0.63 (s.e.= 0.035) and 0.61 (s.e.= 0.031) for *P. urvillei*. Although the coefficient of variations for the cane measurements and leaf areas were high due to the weeds not establishing regularly and not maintaining their original densities as at establishment, the respective loss in cane dewlap height (compared to total dewlap height of weed-free) and the relative leaf areas of weed and cane of each individual plot were fitted using the rectangular hyperbolic model. For the first observation date (8 WAH), the relationship was very poor indicating that there was little or no effect of weed competition on cane dewlap height at that stage. Data for the second observation date (20 WAH) showed a relatively good relation between loss in cane dewlap and the relative leaf areas of *P. urvillei* (Fig 4.10). The relationship for *P. paniculatum* was less well defined.

There was an indication that the loss in cane dewlap height by *P. urvillei* was higher than that with *P. paniculatum* (Fig. 4.15)*;* this was partly shown by the parameter A (showing asymptotic loss)

in the response curves of the two weeds (Table 4.11). However, *P. paniculatum* exhibited lower L_w than *P. urvillei*.

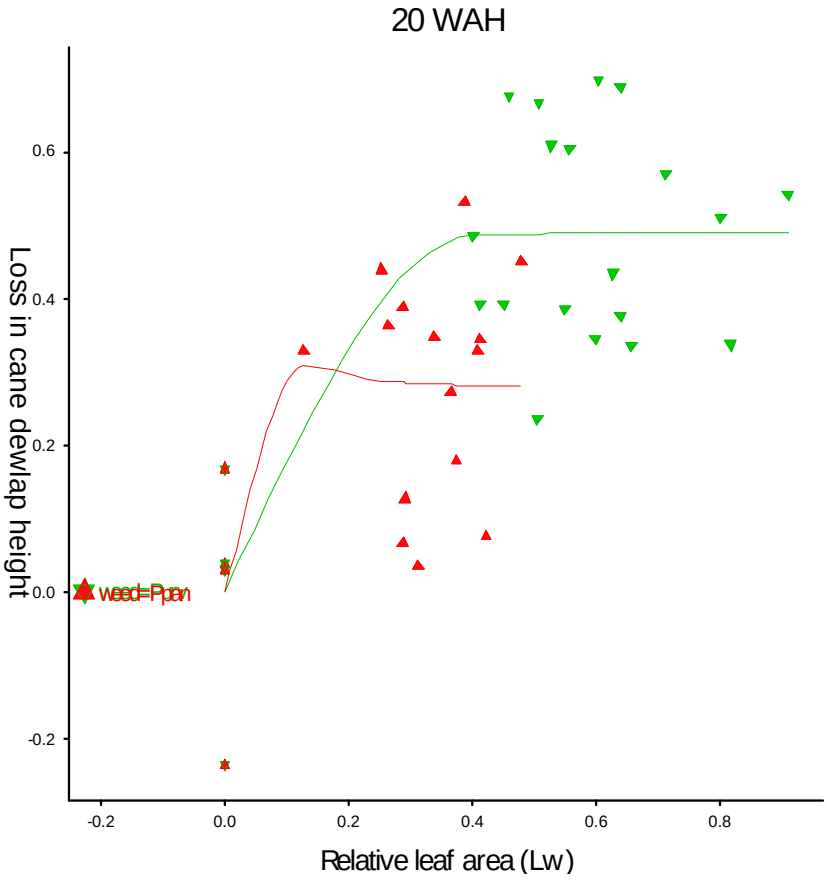


Fig 4.15 Relationship between the relative leaf area (L_w) of *P. paniculatum* (rin red) or *P. urvillei* (in green) and loss in cane dewlap height of cane observed 20 WAH. Response curve are those from parameters given in Table 4.11

Table 4.11 The parameters of the response curves showing relationship between cane dewlap height and relative leaf area (L_w) of weeds using the rectangular hyperbola model (y= A + B/(1+D*x) where x= L_w. Values in parentheses are standard errors of parameter values.

Weed	R^2	D	B	A
P. paniculatum	0.30	-66 (367)	-0.27 (0.119)	0.27 (0.090)
P. urvillei	0.60	117 (2667)	-0.50 (0.189)	0.50 (0.172)

However, the lower relative competitiveness of *P. paniculatum* in this trial may not only be due to its lower relative leaf areas, the difference in the vertical distribution of leaves (leaf area) of the two weeds within the canopy may have influenced the competition.

4.3.2.2 Effect of leaf area distribution on the competitive effects of *P. paniculatum* and *P. urvillei*

Leaf area distribution (vertical), measured at the second observation date, varied between the two weed species (Figs. 4.16a & 4.16b). The interaction between density and distribution was not significant for both weed species, thus enabling pooling of the different densities.

For *P. paniculatum,* all the leaves (weed) were found within the 0 to 30 cm and 30 to 60 cm strata and the interaction between leaf areas of the two cane and weed and their distribution was significant ($P< 0.01$) (Fig. 4.16a).

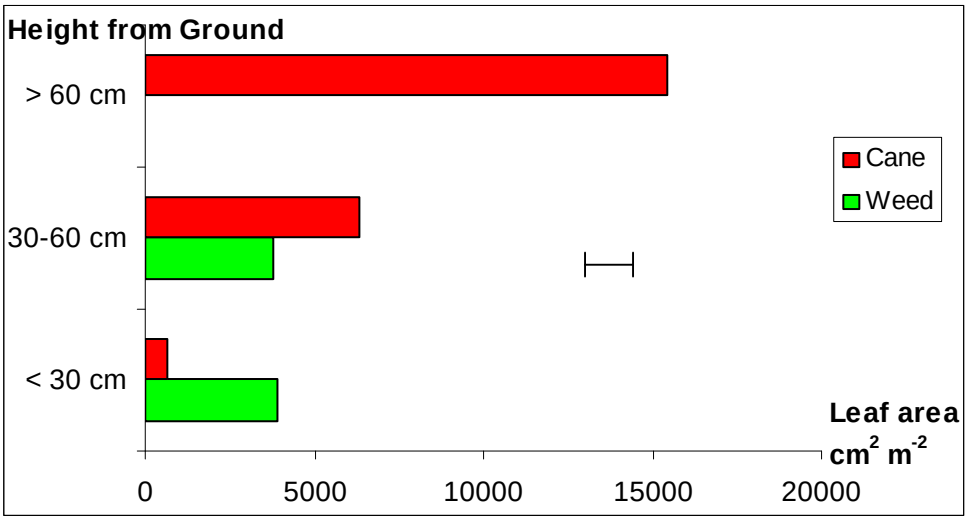


Fig. 4.16a Distribution of leaf area (cm^2 m^{-2}) of sugar cane and *P. paniculatum* at different plant heights measured 18 WAH. Columns are means of five weed densities and four replications. Error bar represents 2 x s.e.d.

For *P. urvillei*, the weed leaves were situated within all layers; the 30 to 60 cm layer had the highest weed leaf area among the three layers (Fig 4.16b). The interaction between leaf areas of the two plants and height distribution was not significant ($P<0.05$) for *P. urvillei*.

Absence of weed leaves above 60 cm would have favoured cane growth in the *P. paniculatum* main-plots as compared to *P. urvillei* where some competition occurred in that layer; thus supporting the conclusion that the former was less competitive in this experiment.

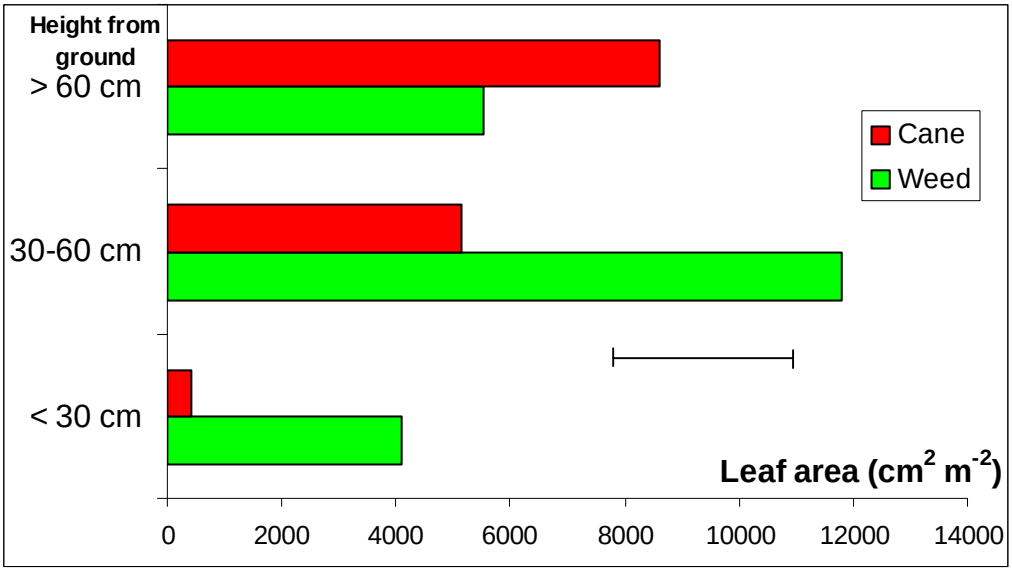


Fig. 4.16b Distribution of leaf area (cm^2 m^{-2}) of sugar cane and *P. urvillei* at different plant heights measured 18 WAH. Columns are means of five weed densities and four replications. Error bar represents 2 x s.e.d.

4.3.3 Trial III – Relative competitiveness of *Paspalum paniculatum* and *Paspalum urvillei* at two transplanting dates in sugar cane and effect of leaf area distribution on competition

4.3.3.1 Effect of time of observation on the competitive effects of *P. paniculatum* and *P. urvillei* transplanted 4 WAP (first transplanting date – TD1)

Increase in total cane dewlap height and effect of weed competition

The mean dewlap height of cane within the weed-free treatments increased exponentially up to the third observation date, with a peak of more than 50 cm m^{-2} per week increase between the 13th and 18th week after planting. The rate of increase in dewlap height slowed down between the third and fourth observation dates.

Total dewlap heights were not significantly ($P < 0.05$) affected by the different weed densities except for the highest density 6 WAT and the three more densely infested plots 13 WAT (Table 4.12). The lack of difference, particularly for observations made 9 WAT and 18 WAT, is explained by the high coefficients of variation (CV%) observed, as the weed infestations were not consistent and developed differently compared to their respective initial densities at transplanting.

Table 4.12 Effect of different weed densities of *P. paniculatum* and *P. urvillei* on total dewlap height (cm m^{-2}) of cane observed at four dates

Weed density (plants m^{-2})	Date of observation							
	6 WAT		9 WAT		13 WAT		18 WAT	
	P. pan	*P. urv*	*P. pan*	*P. urv*	*P. pan*	*P. urv*	*P. pan*	*P. urv*
Weed-free	57.4		100.4		314		406	
4	52.2	39.7	112.5	80.1	283	219	342	396
8	44.2	42.5	82.0	126.7	255	212	373	212
16	68.2	38.5	121.7	62.2	171	221	348	320
32	44.2	59.7	97.2	95.5	177	163	355	353
48	30.0	33.2	111.5	81.0	190	211	373	246
S.e.d. (d.f.)	*11.85 (30)*		*35.55 (28)*		*67.7 (30)*		*110.3 (30)*	
CV %	*35.4*		*51.5*		*42.1*		*45.4*	

P. pan = P. paniculatum; P. urv = P. urvillei

Effect of weed competition on tillering

Both *P. paniculatum* and *P. urvillei* caused a reduction in tillering as compared to the weed-free treatment; the effect was significant ($P< 0.05$) for several weed densities as from the second observation date (Table 4.13). Differences in tiller numbers were less pronounced between actual weed densities. The decrease in number of shoots within the weed-free plots at the last observation date may also be due to natural elimination of shoots known to occur after sugar cane has reached its peak of tillering.

Table 4.13 Effect of different weed densities of *P. paniculatum* and *P. urvillei* on tillering (number of stalk m^{-2}) of cane observed at four dates.

Weed density (Plants m^{-2})	Date of observation							
	6 WAT		9 WAT		13 WAT		18 WAT	
	P. pan	*P. urv*	*P. pan*	*P. urv*	*P. pan*	*P. urv*	*P. pan*	*P. urv*
Weed-free	15.5		14.6		19.1		12.4	
4	10.8	14.3	10.5	13.0	12.8	14.5	8.5	8.8
8	12.8	15.5	12.5	14.3	14.3	15.0	11.8	9.5
16	12.3	13.8	10.8	9.3	14.3	11.0	9.5	8.0
32	13.8	12.3	10.5	11.5	14.5	11.5	8.8	8.5
48	12.3	16.3	13.3	11.0	14.0	10.8	8.5	7.5
S.e.d. (d.f.)	*2.19 (30)*		*1.79 (30)*		*1.93 (30)*		*1.09 (30)*	
CV %	*22.5*		*20.8*		*19.1*		*16.2*	

P. pan – P. paniculatum; P. urv P. urvillei

Leaf area of cane and weed

The mean cane leaf area in the weed-free treatments, irrespective of weed species, did not differ between the first two observation dates but increased significantly later on (Figs. 4.17a & 4.17b). No adverse effect of weed competition on the leaf area of cane due to the presence of weeds was apparent for both species although a tendency of the cane leaf area being reduced by an increasing weed leaf area was observed as from 13 WAT, particularly for *P. paniculatum* (Figs. 4.17a & 4.17b). The mean weed leaf area was found to increase only after the second observation date; the highest leaf area for *P. urvillei* was recorded 13 WAT. There were clear increases in weed leaf area with increasing density.

Irrespective of the date of observation, the relative leaf area (L_w) of *P. urvillei* was higher than those of *P. paniculatum*. The mean (of all densities) L_w for *P. paniculatum* was found to be highest at 13 WAT; i.e. 0.36 (s.e.= 0.052), 0.34 (s.e.= 0.048), 0.52 (s.e.= 0.069) and 0.46 (s.e.= 0.068) at 6, 9, 13

and 18 WAT respectively. The same trend was observed for *P. urvillei;* the L_w was 0.47 (s.e.= 0.047), 0.52 (s.e.= 0.050), 0.73 (s.e.= 0.061) and 0.65 (s.e.= 0.040) respectively for 6, 9, 13 and 18 WAT. The relative leaf area (L_w) tended to be higher at the last two observation dates than at first two dates.

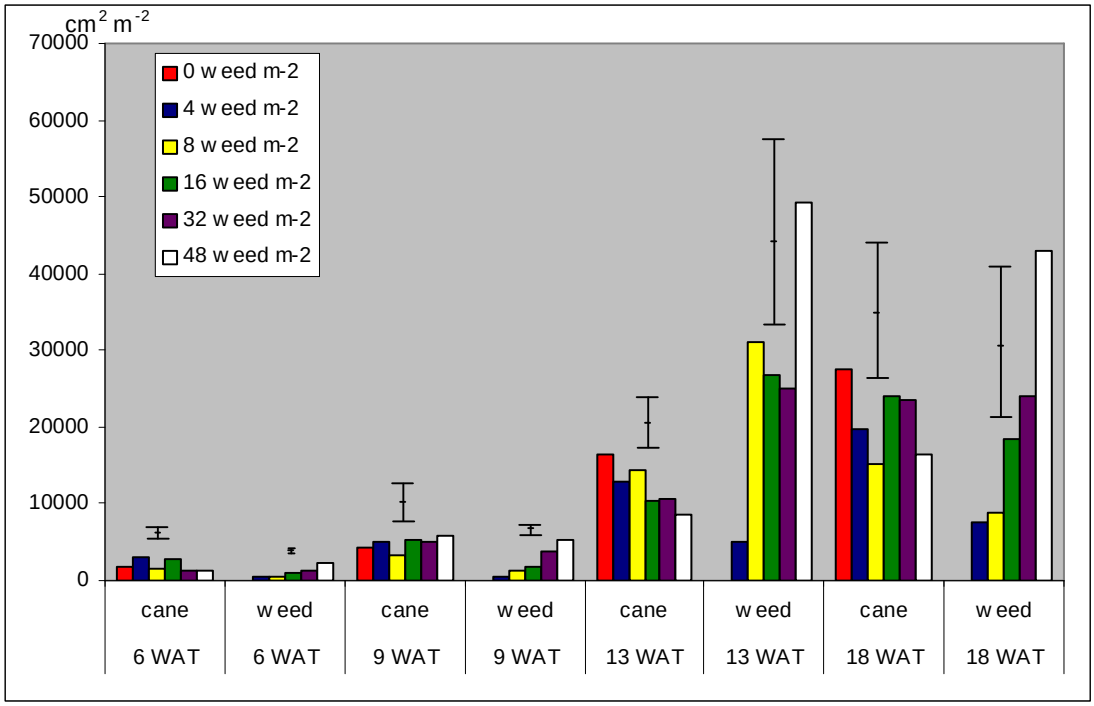


Fig. 4.17a Leaf area of cane and *P. paniculatum* at different weed densities and observation dates. Error bars represent 2 x s.e.d.

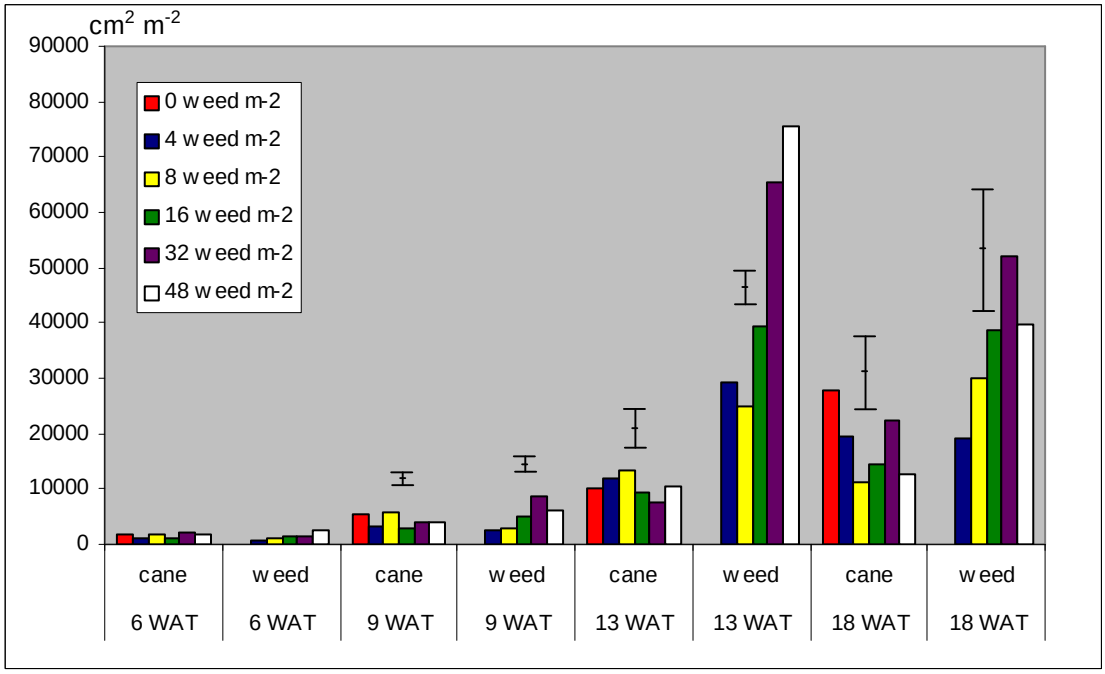


Fig. 4.17b Leaf area of cane and *P. urvillei* at different weed densities and observation dates. Error bars represent 2 x s.e.d.

Effect of weed competition on cane yield from P. paniculatum and P. urvillei transplanted 4 WAP

The trial was harvested 50 WAP and the mean yield in the weedfree treatments was 51.2 t ha^{-1}. This cane yield was relatively low because the trial was planted four weeks later than the end of the planting season, and it was also harvested before twelve months (plant cane established during the short-season planting are normally harvested after 13 to 14 months). Nevertheless, the results showed that weed competition from both *Paspalum* species caused a significant reduction in cane yield (Fig. 4.18). The relationship for *P. paniculatum* was better than that for *P. urvillei*; absence of significant differences in their parameter estimates indicated no difference in their responses.

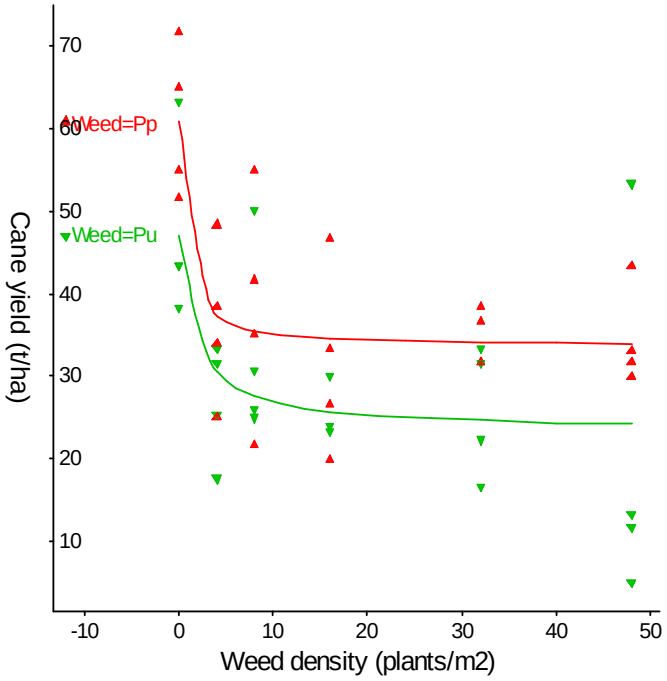


Fig. 4.18 Effect of weed competition on cane yield from *P. paniculatum* and *P. urvillei* transplanted 4 WAP. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where the R^2= 0.52 and parameter values D= 1.63 (3.05), B= 27.2 (5.60) and A= 33.62 (3.32) for *P. paniculatum* (in red), and R^2= 0.28, D= 0.58 (0.885), B= 23.5 (7.62) and A= 23.44 (4.97) for *P. urvillei* (in green). (values in parentheses are standard error of the estimates).

Relative competitiveness of P. paniculatum and P. urvillei and effect of time of observation

The loss in cane yields (compared to mean of the weed-free treatment) within individual plots with the same weed species and at the same observation date was fitted with their corresponding relative leaf area (L_w) values to determine the relative competitiveness 'q' values. The q value for *P. urvillei* was higher than that of *P. paniculatum* at 6 WAT and 18 WAT (Table 4.14).

Table 4.14 Relative competitiveness 'q' values for *P. paniculatum* and *P. urvillei* at different observation dates after transplanting weeds 4 WAP).

	Relative competitiveness q value			
Date of observation	6 WAT	9 WAT	13 WAT	18 WAT
P. paniculatum	0.41 (0.155)	0.56 (0.180)	0.11 (0.047)	0.09 (0.051)
P. urvillei	0.80 (0.243)	0.59 (0.194)	0.10 (0.040)	0.36 (0.093)

Values in parentheses represent standard errors (s.e.) of the estimated q value.

The relative competitiveness q value of *P. paniculatum* was higher at the two first observation dates than the last two observation dates. The higher q value for *P. urvillei* at the first observation date compared to *P. paniculatum* may suggest that the former developed quicker than *P. paniculatum* after transplanting. The data on leaf areas together with time expressed in growing degree days (^{o}C d) were fitted in the equation derived by Kropff and Spitters (1991) or Kropff and van Laar (1993) (Eqn 3) to express change in time of the relative damage (competitiveness) coefficient 'q' in the period of exponential growth, as for Trial I.

The increase in mean growth rate of leaf area of the weeds was higher than that of the crop at most of the observation dates. For all dates, irrespective of the weed species, the estimated q values for both weeds at 9, 13 and 18 WAT, calculated from the q values at 6 WAT and relative growth rates of leaf areas were higher than the measured ones (Table 4.15); the difference seemed to increase with time of observation. The latter change may have been caused by differences in height of the plants and the vertical distribution of leaves in the cane/weed canopy.

Table 4.15 Estimation of relative competitiveness q values with time and relative rate of growth of cane and leaf area ($^{o}C^{-1}$ d^{-1})

	Observation dates					
	9 WAT		13 WAT		18 WAT	
	P. pan	*P. urv*	*P. pan*	*P. urvi*	*P. pan*	*P. urv*
Time (^{o}C d)	161		405		712	
Mean rate of growth of cane leaf area ($^{o}C^{-1}$ d^{-1})	0.009	0.008	0.013	0.037	0.014	0.025
Mean rate of growth of weed leaf area ($^{o}C^{-1}$ d^{-1})	0.011	0.018	0.014	0.117	0.015	0.036
Estimated q value	0.72	1.44	0.46	0.88	0.45	1.15

P. pan = P. paniculatum; P. urv = P. urvillei

4.3.3.2 Effect of time of observation on the competitive effect of *P. paniculatum* and *P. urvillei* transplanted 10 WAP (second transplanting date – TD2)

Increase in total cane dewlap height and effect of weed competition

Cane measurements showed a slowing down in the growth rate (expressed as mean dewlap height) within the weedfree plots after the second observation date (9 WAT or 19 WAH).This was due to lower temperatures (growing degree days) prevailing from March and also a reduced number of shoots.

The differences in total dewlap heights observed between the weed-free treatment and the different weed densities were not significant ($P < 0.05$) at 6 WAT and 15 WAT (Table 4.16). The high coefficients of variation (CV%) confirmed the inconsistency in the establishment of weed infestations compared to initial densities at transplanting.

Table 4.16 Effect of different weed densities of *P. paniculatum* and *P. urvillei* on total dewlap height (cm m^{-2}) of cane observed at three dates

Weed density (plants m^{-2})	Date of observation					
	6 WAT		9 WAT		15 WAT	
	P. pan	*P. urv*	*P. pan*	*P. urv*	*P. pan*	*P. urv*
Weed-free	209		508		533	
4	203	251	458	550	523	721
8	315	102	388	224	685	611
16	213	215	445	339	520	580
32	333	212	242	403	645	550
48	241	221	456	303	573	661
S.e.d. (d.f.)	*75.3 (30)*		*124.6 (30)*		*181.0 (30)*	
CV %	*46.9*		*43.8*		*43.0*	

P. pan = P. paniculatum; P. urv = P. urvillei

Effect of weed competition on tillering

Irrespective of the weed species, weed competition had no adverse effect on cane tillering at the first observation date (6 WAT) and third date (15 WAT). A significant ($P < 0.05$) reduction in the number of shoots was recorded at 9 WAT when the cane was nearer to the peak of its tillering phase (Table 4.17). As the number of shoots reduced naturally after that period, weed competition had no further

impact on the tillering. But even at 9 WAT the pattern of responses did not produce a clear link between weed density and tillering.

Table 4.17 Effect of different weed densities of *P. paniculatum* and *P. urvillei* on tillering (number of stalk m^{-2}) of cane observed at three dates

Weed density (plants m^{-2})	Date of observation					
	6 WAT		9 WAT		15 WAT	
	P. pan	*P. urv*	*P. pan*	*P. urv*	*P. pan*	*P. urv*
Weed-free	12.2		16.0		9.8	
4	12.0	12.0	15.7	16.3	10.0	12.7
8	18.7	7.3	13.7	9.3	13.7	9.7
16	13.0	11.7	14.3	11.0	9.0	8.7
32	16.3	12.0	8.7	12.0	9.0	10.0
48	12.0	12.3	16.3	8.0	10.0	9.7
S.e.d. (d.f.)	*3.23(30)*		*2.94(30)*		*2.53(30)*	
CV %	*36.2*		*31.7*		*35.1*	

P. pan = P. paniculatum; P. urv = P. urvillei

Leaf area of cane and weed

For the second transplanting date (TD2), when the weeds were transplanted 10 WAP, the mean cane leaf area was much higher than the mean weed leaf areas in the subplots with *P. paniculatum* (Fig. 4.19a). This effect was not so marked with *P. urvillei*. The average leaf area of *P. paniculatum* increased to a maximum at the second observation date before reducing at 15 WAT. No adverse effect of weed competition on the leaf area of cane by the presence of either *P. paniculatum* or *P. urvillei* was observed. *Paspalum urvillei* produced more leaf area than *P. paniculatum* at all dates; the weed leaf area was much higher than the crop at weed densities of 32 weeds m^{-2} at 9 WAT and 15 WAT and and 48 weeds m^{-2} at 9 WAT (Fig. 4.19b).

The relative leaf areas (L_w) for both weed species were lower than those recorded at the same observation dates for the first transplanting date (TD1). Irrespective of the date of observation, the L_w of weed and cane was higher for *P. urvillei* than those for *P. paniculatum*. The L_w (mean of all densities) for *P. paniculatum* was highest 9 WAT and were 0.20 (s.e.= 0.047), 0.31 (s.e.= 0.053) and 0.17 (s.e.= 0.028) at 6 WAT, 9 WAT and 15 WAT respectively. For *P. urvillei*, the mean L_w at 6 WAT, 9 WAT and 15 WAT were respectively 0.45 (s.e.= 0.061), 0.42 (s.e.= 0.056) and 0.26 (s.e.= 0.033).

Leaf area

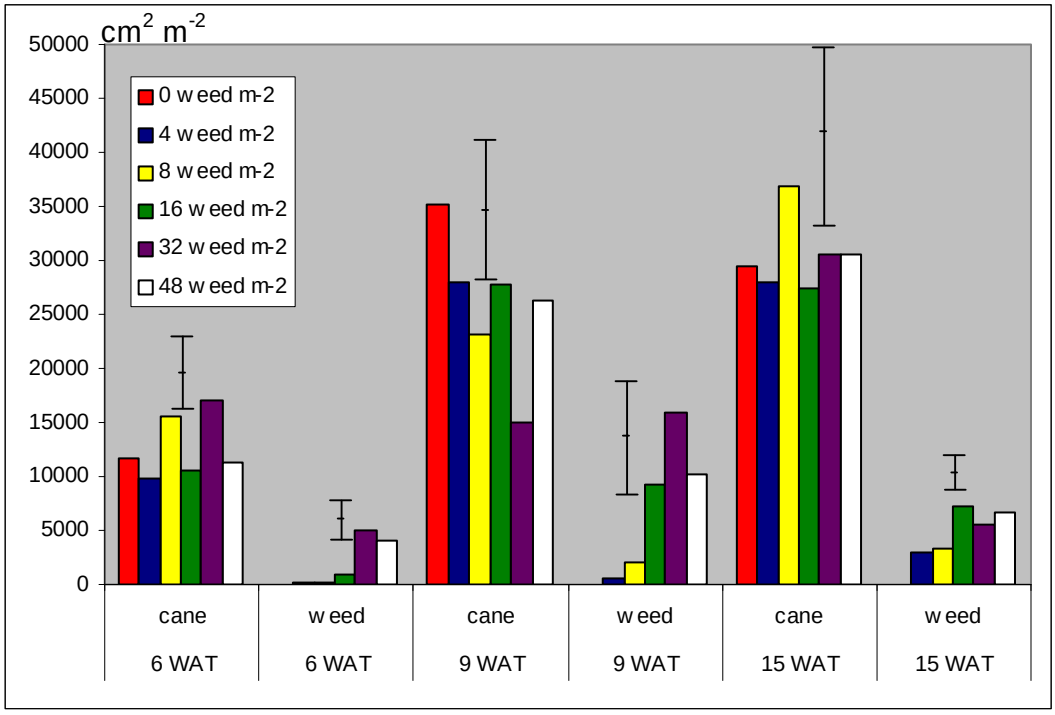


Fig. 4.19a Leaf area of cane and *P. paniculatum* at different weed densities and observation dates. Error bars represent 2 X s.e.d. (mean of all densities).

Leaf area

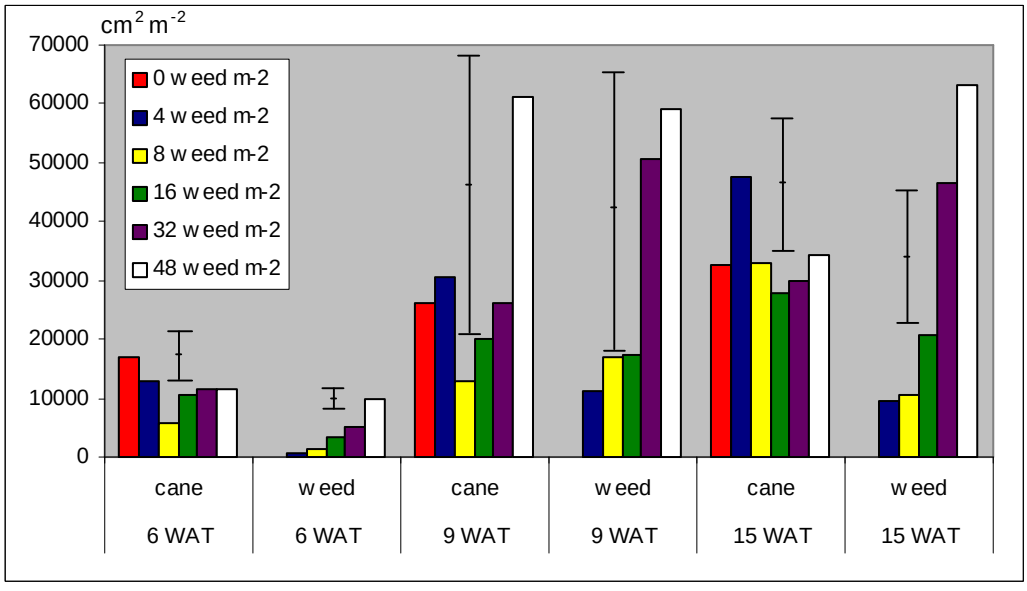


Fig. 4.19b Leaf area of cane and *P. urvillei* at different weed densities and observation dates. Error bars represent 2 x s.e.d. (mean of all densities).

Effect of weed competition on cane yield from P. paniculatum and P. urvillei transplanted 10 WAP

All experimental plots of the second transplanting date (TD2) were harvested on the same day as for TD1. The cane yields were relatively low as explained for the TD1. The relationship between the various weed densities and cane yield, fitted using the rectangular hyperbolic model, data was very poor for both weed species. No significant difference in cane yield between the various densities indicated that weed competition was not important when weed emergence or development was retarded (Fig. 4.20).

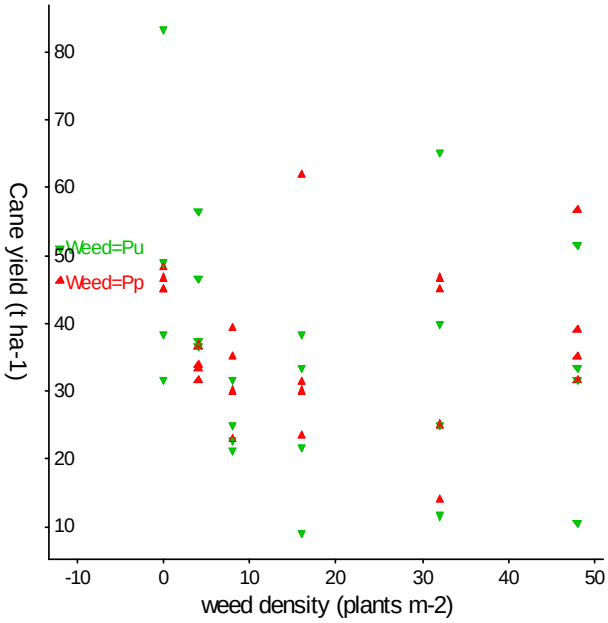


Fig 4.20 Relationship between weed density (plants m^{-2}) of *P. paniculatum* (in red) or *P. urvillei* (in green) transplanted 10 WAP and cane yield (t ha^{-1}). No fit for both response curves was obtained.

Relative competitiveness of P. paniculatum and P. urvillei & time of observation

No relationship was also obtained between cane yield and the relative leaf areas of the weeds. This lack of difference did not enable fitting of the relative competitiveness 'q' values to compare competition from the two weeds at the three dates of observation.

4.3.3.3 Effect of transplanting date on the competitive effect of *P. paniculatum* and *P. urvillei*

Effect of transplanting date of cane yields

No significant difference observed between the yields of the two transplanting dates (main plots) showing that the competition exerted at TD1 was not clearly greater than at TD2. Similarly neither the

interactions with the 'transplanting date' nor the difference between the two weed species was significant. Only the overall mean densities were found to differ significantly (Table 4.18); the yield of the weedfree treatment was significantly higher than those recorded in the infested plots.

Table 4.18 Effect of two transplanting dates of *P. paniculatum* and *P. urvillei* at different weed densities on yield of sugar cane

Weed densities (plants m^{-2})	Cane yields (t ha^{-1})				
	TD1 (4 WAP)		TD2 (10 WAP)		Mean
	P. paniculatum	*P. urvillei*	*P. paniculatum*	*P. urvillei*	
Weed-free	60.8	47.1	46.2	50.6	51.2
4	36.4	27.0	33.9	44.3	35.4
8	38.3	32.9	31.8	25.2	32.1
16	31.7	38.5	36.7	25.6	33.1
32	34.6	26.0	32.7	35.5	32.2
48	34.5	20.8	40.6	31.8	31.9
s.e.d. (d.f.)	6.25 (60)	6.25 (60)	6.25 (60)	6.25 (60)	4.42 (60)

Stage of cane growth at transplanting of weeds

The first transplanting (TD1) of weeds was carried out four weeks after planting when the cane was completing its germination and started its tillering phase, while the second one (TD2) was done a few weeks prior to the peak of the tillering phase (Fig 4.21). This may explain the reduction in cane tillering observed as from the second observation date after the first transplanting date and at 9 WAT for the second transplanting date. The mean cane stalk heights at both transplanting dates were below 20 cm (Fig. 4.22).

The relative competitiveness values recorded for the first transplanting date (Table 4.14) showed a relatively higher q value for the weeds at the first two observation dates because of their lower relative leaf areas (L_w). The q value is estimated from the relative leaf areas and a lower L_w would show a higher relative competitiveness for the same yield losses.

The relative leaf area after the second transplanting also increased after the first observation date but was unable to cause any significant effect on yield. This relatively higher L_w recorded at the second observation date (TD2) would be expected to have similar adverse effects on cane growth to those in TD1. However, similar L_w with different vertical distribution of leaves in the canopy may not result in same competitiveness.

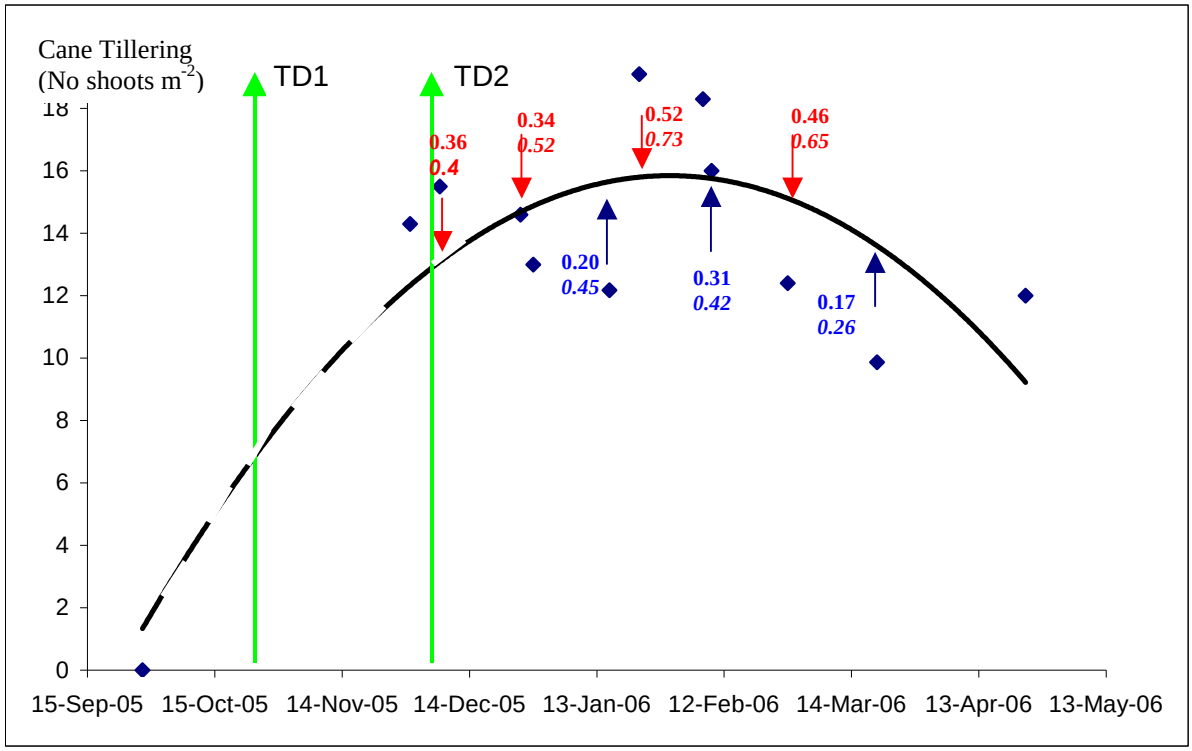


Fig. 4.21 Cane tillering in the weed-free plots and green arrows showing first (TD1) and second (TD2) dates of transplanting of weeds, small arrows show date of observations after 1st transplanting (red) and date of observation after 2nd transplanting (blue). The relative leaf areas (L_w) for *P. paniculatum* (normal) and *P. urvillei* (italic) are shown for each observation date.

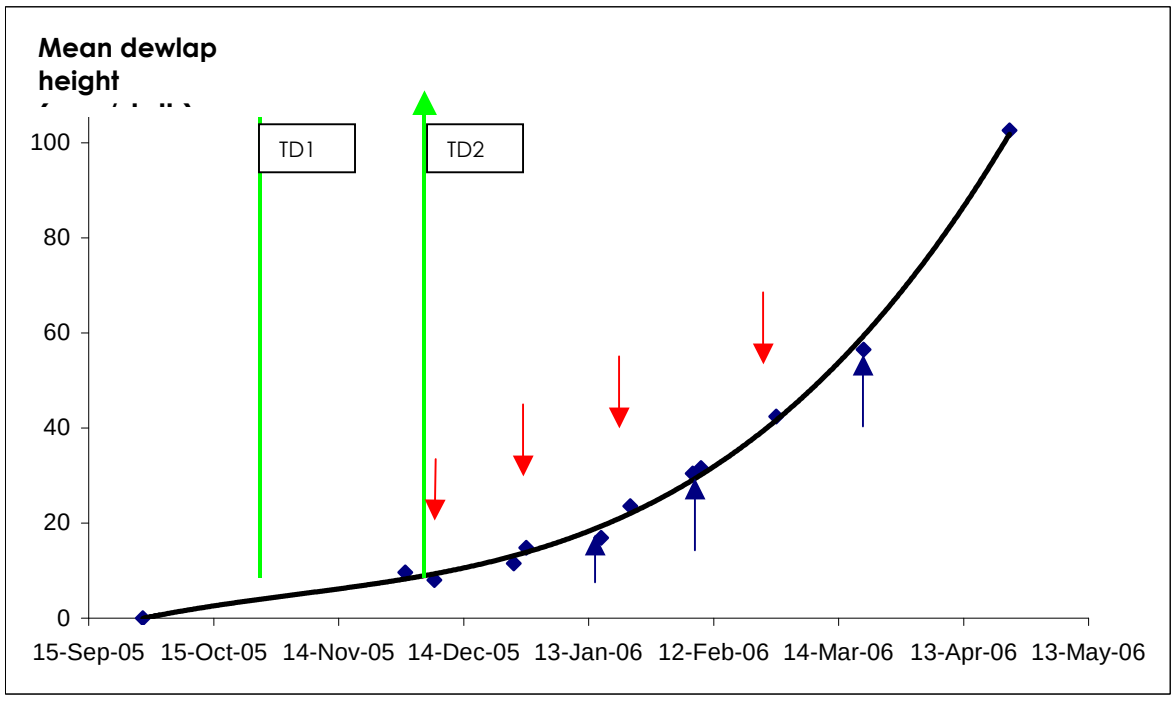


Fig. 4.22 Mean dewlap height of cane stalks in weed-free plots. Green arrows show two transplanting dates, red arrows show observation dates after 1st transplanting and blue arrows observation date after 2nd transplanting. Points show mean of four replications and two weed species.

Leaf area distribution between cane and weeds

Leaf area distribution (vertical) was measured at all observation dates for both TD1 and TD2. As the interaction between distribution and weed density was not significant, the mean leaf areas of cane and weeds within the different layers above ground are shown in Figs. 4.23, 4.24, 4.25 and 4.26. The distribution of cane leaves across the canopy changed with growth and increasing leaf area. At the earlier stage of growth, more leaves were found in the lower layers and increased to higher layers gradually through the observation dates; cane leaves were also recorded at 80 cm above ground at 18 WAT and 15 WAT in the TD1 and TD2 plots respectively.

For *P. paniculatum*, irrespective of transplanting date and weed density, the leaves were never found in layers above 60 cm from ground (Fig. 4.23 and Fig. 4.25).

Fig. 4.23 Distribution of leaf area (cm^2 m^{-2}) of sugar cane and *P. paniculatum* at different plant heights (cm from ground) measured at 6 WAT (top left), 9 WAT (top right), 13 WAT (bottom left) and 18 WAT (bottom right) weeds at the first date (TD1). Columns are means of five weed densities and four replications. Error bar represents 2 x s.e.d.

The bulk of *P. paniculatum* leaves competing with the cane leaves in the first 20 cm above ground at the first observation date in TD1 explains the adverse effect on tillering. Between the 5th and 9th WAT, the rate of growth of leaf area of *P. paniculatum* was almost similar to that of the crop and was able to maintain its competitiveness; in fact the competitiveness increased with more interference time. As from 13 WAT, despite its higher rate of growth of leaf area over that of the cane, *P. paniculatum* had most of its leaves with the two lower layers (0-20 cm & 20-40 cm) while most of the cane leaves were found at a higher level in the canopy. Competition for light should have been a minimum after that growth stage of cane; weed competition after that stage should therefore be due to the 'residual' effect on tillering and cane growth experienced earlier and due to other mechanisms of weed competition.

For *P urvillei*, the leaf distribution evolved with time as for *P. paniculatum* but, due to its morphological characteristics, grew taller than *P. paniculatum* and had leaves in the 40-60 and 60-80 cm layers at 18 WAT after the first transplanting date (Fig. 4.24). Transplanting *P. urvillei* 6 weeks later did not produce the same development of canopy (Fig. 4.26); it may have undergone competition from the cane. At the last two observation dates, irrespective of transplanting dates, most of the *P. urvillei* leaves were found in lower layers than cane leaves. This was also the case at 18 WAT in TD1 where the cane had sufficient leaves in a layer above (>80 cm), thus reducing competition for light interception by cane leaves.

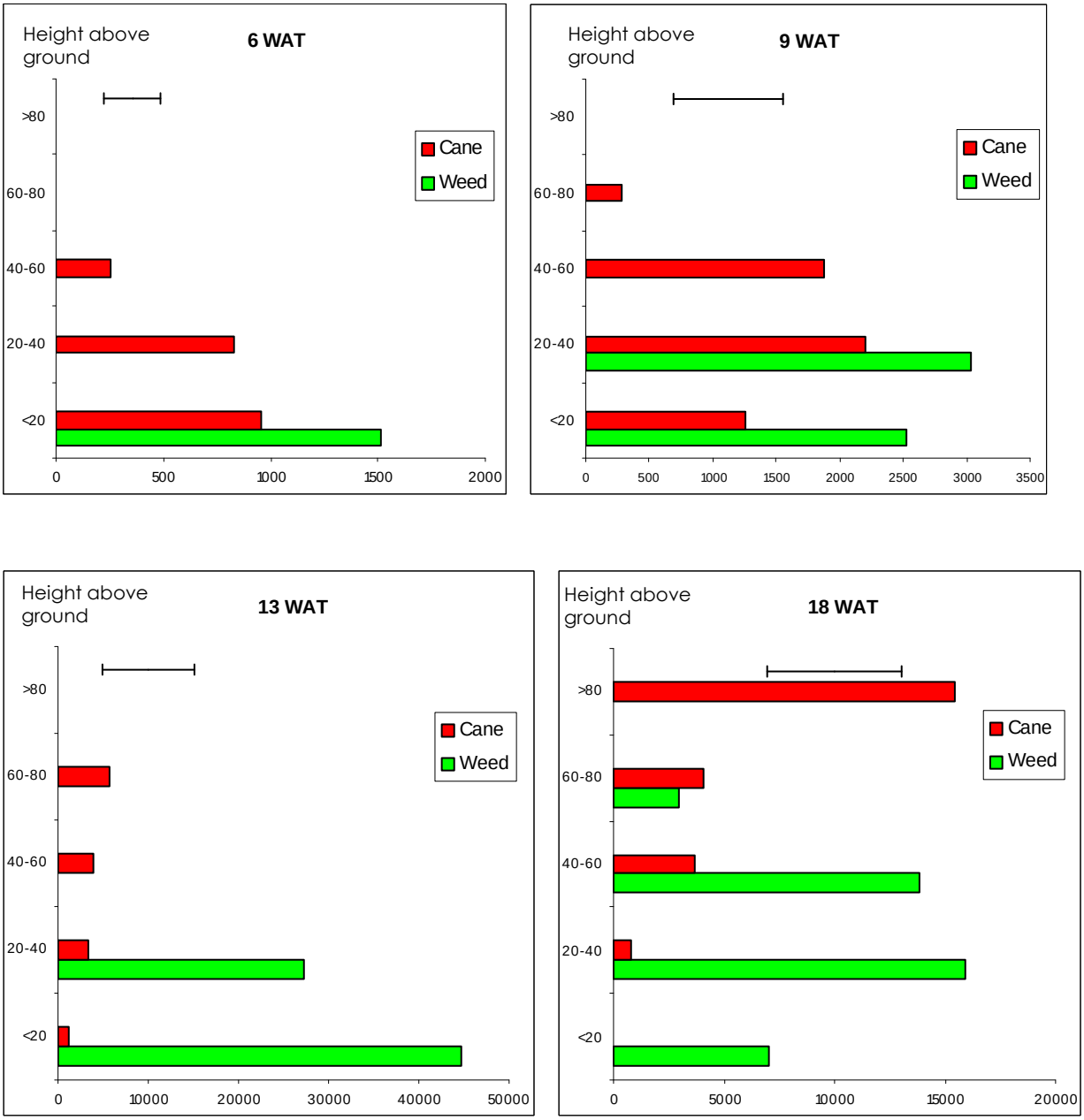


Fig. 4.24 Distribution of leaf area (cm^2 m^{-2}) of sugar cane and *P. urvillei* at different plant heights (cm from ground) measured at 6 WAT (top left), 9 WAT (top right), 13 WAT (bottom left) and 18 WAT (bottom right) weeds at the first date (TD1). Columns are means of five weed densities and four replications. Error bar represents 2 x s.e.d.

The second transplanting date showed that weeds developing later in the crop had leaves located at a lower height within the canopy (Figs 4.25 & 4.26). This would reduce competition for light and may explain the lack of adverse effects on cane yield after the second transplanting date.

If the five to eight top leaves contribute to more than 80% of photosynthesis in sugar cane, the competition recorded at the second and third observation dates after the 1st transplanting date should have partly been caused by other means of competition than that for light. The fact that *P. paniculatum*

maintains its higher competitiveness over *P. urvillei* despite the latter producing more leaf areas (higher L_w) and more in the higher layers within the crop canopy, adds to the possibility of other means of competition such as competition for underground resources.

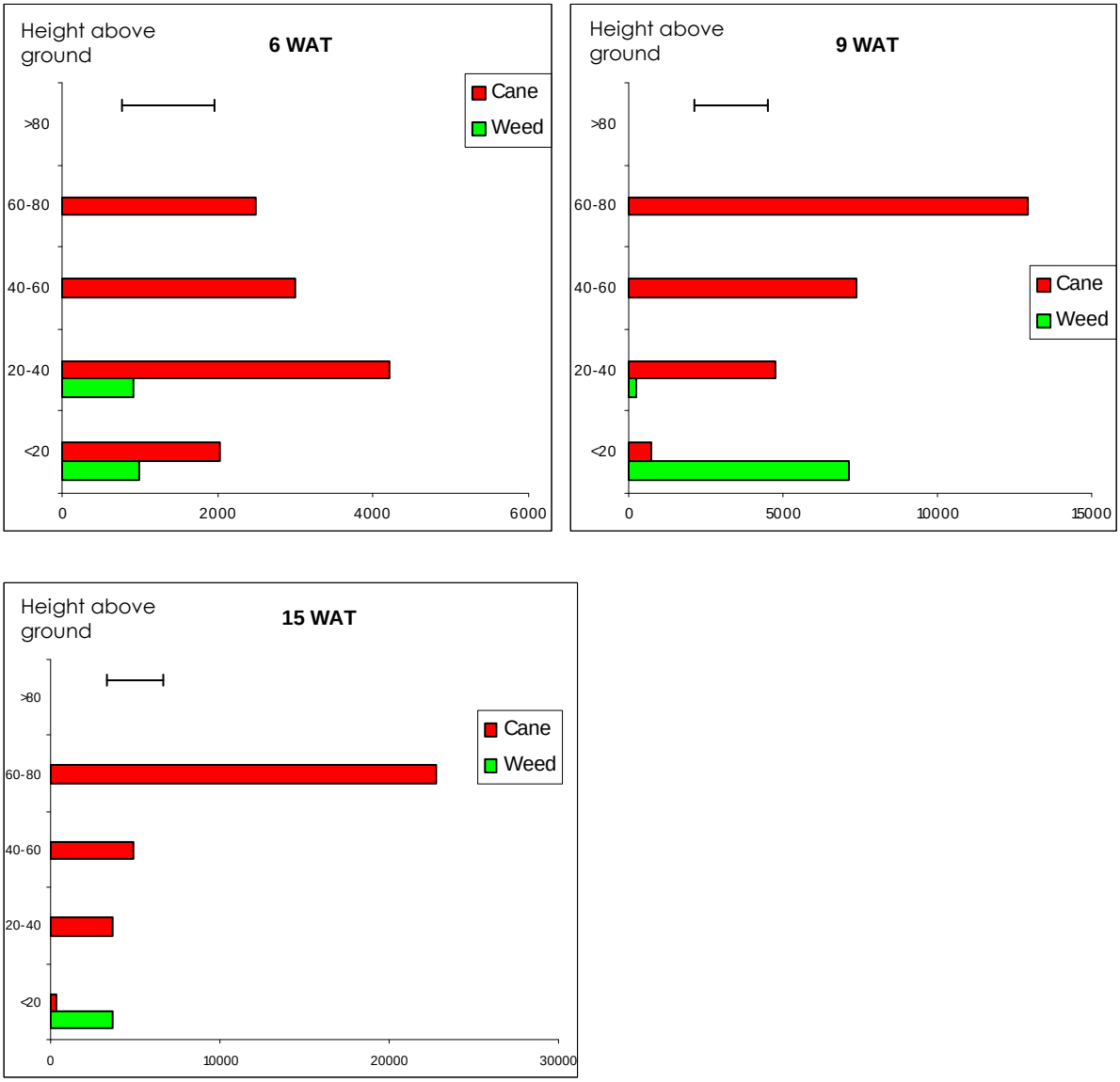


Fig. 4.25 Distribution of leaf area (cm^2 m^{-2}) of sugar cane and *P. paniculatum* at different plant heights (cm from ground) measured at 6 WAT (top left), 9 WAT (top right) and 15 WAT (bottom left) weeds at the second date (TD2). Columns are means of five weed densities and four replications. Error bar represents 2 x s.e.d.

Fig. 4.26 Distribution of leaf area (cm^2 m^{-2}) of sugar cane and *P. urvillei* at different plant heights (cm from ground) measured at 6 WAT (top left), 9 WAT (top right) and 15 WAT (bottom left) weeds at the second date (TD2). Columns are mean of five weed densities and four replications. Error bar represents 2 x s.e.d.

4.4 Discussion and conclusions

Relative competitiveness of P. paniculatum and P. urvillei

The three trials have shown sugar cane to be a stronger competitor than both *P. paniculatum* and *P. urvillei* in all comparisons. The relatively lower leaf areas and high standard errors associated with the estimates in the latter cases may explain such differences. *Paspalum paniculatum* seemed to have a higher relative competitiveness than *P. urvillei* in Trial I but this was not the case in the other two trials; *P. urvillei* caused greater reduction in cane dewlap heights in Trial II and was similar to *P. paniculatum* in Trial III.

Paspalum urvillei produced greater leaf area than *P. paniculatum* and it seemed that there was an interaction between weed leaf area and cane leaf area although significance was not shown in all the trials due to high variations in the data sets. *Paspalum urvillei* was found to have an equal or higher relative leaf area (L_w) to *P. paniculatum* and there were indications that *P. urvillei* was still growing at later observation dates and was thus able to maintain a relatively higher L_w at the last observation date. Early competition resulted in a reduction in tillering (number of shoots per unit area) and this was almost similar with both weed species although the much higher leaf areas of *P. urvillei* in Trial II seemed to have a greater adverse effect on tillering. Tillering rates in sugar cane has been reported to reduce sharply when tillers start experiencing light competition (Van Dillewijn, 1952) and this may explain the higher competition from *P. urvillei* on that parameter of cane growth.

With its relatively lower leaf areas, there may be a tendency to say that *P. paniculatum* leaves intercepted less light than *P. urvillei*. De Wit (1965) reported planophile leaves (horizontally oriented) to capture light with a higher efficiency than erectophile leaves (vertically oriented). Other work carried out in wheat shows planophile leaves to be more competitive (Seavers & Wright, 1999). *Paspalum paniculatum* leaves tend to have a slightly more planophile leaf structure compared to *P. urvillei*. (See Figs. 1.2 & 1.3 in Chapter 1). However, this would apply when leaves of both weeds and cane are at the same height in the canopy; the three trials showed *P. paniculatum* to maintain its relative competitiveness even when the cane leaves were much higher in the canopy. *Paspalum urvillei* developed more leaves in the higher layers of the canopy with time.

Relative competitiveness with time (duration of infestation)

The relative competitiveness (q value) of both *P. paniculatum* and *P. urvillei* did not change with time in Trial I while it seemed to decrease at later observation dates in Trial II after the first transplanting

date. This may have been due to the difference if the stage of growth at transplanting of weeds. Estimating q values with the equation developed by Kropff and Spitters (1991) or Kropff and van Laar (1993) at later growth stages showed higher values for the later q values. This change may partly be due to the base temperature of the weeds being different to that of cane. Furthermore, the equation by Kropff and Spitters (1991) or Kropff and van Laar (1993) is recommended up to canopy closure and when the rate of growth is exponential. This seemed to be different in sugar cane where canopy closure takes longer and there is a significant difference in the vertical distribution of leaf area between the period when cane starts elongation and canopy closure.

Effect of transplanting date on weed competition

The effect of time of weed emergence (transplanting weeds at two dates) on weed competition in sugar cane was well demonstrated in Trial III where the same time intervals were used between the first two observation dates. The adverse effect of weed competition on cane yield was reduced by transplanting the weeds later as this resulted in lower relative leaf areas (L_w) and to cane leaves being situated higher in the crop canopy. This implied that weeds emerging late in the season would cause less damage. This would, however, be dependent on the growth stage of cane, the relative growth rate of leaf area of the weed species and their morphological characteristics.

If the competition between sugar cane and weeds was linked to only one physiological process, e.g. light interception on tillering of cane, then the relative competitiveness for the second transplanting dates should have been lower than that observed from the earlier ones. This was demonstrated in both trials. It also seemed that there should be a minimum period of interference between the weeds and crop for the competition to build on; the reduction in the relative competitiveness after the peak q values was mainly due to the cane leaves growing higher in the canopy.

Competition for light and other resources

The three trials have demonstrated that competition in sugar cane is caused by interception of light by weed leaves. Although some of the effects of light interception occurring early in the growth of cane, e.g reduced tillering, may be sustained to later stages (cane yields in Trial III), weed competition for other resources or other mechanism of interference are also possible in sugar cane. Other mechanisms of competition may also be needed to explain the same (or relatively higher in Trial I) competitiveness of *P. paniculatum* compared to *P. urvillei* despite its lower relative leaf area.

CHAPTER 5

COMPARISON OF ROOT AND SHOOT COMPETITION BETWEEN SUGAR CANE AND *PASPALUM PANICULATUM* OR *PASPALUM URVILLEI*

5.1 Introduction

Weeds compete with crops for environmental resources available in limited supply, i.e. nutrients, water and light. Competition has been defined as the tendency of neighbouring plants to utilise the same quantum of light, ion of mineral nutrient, molecule of water, or volume of space (Grime, 1979). In sugar cane, it has been demonstrated that critical periods of weed competition with natural weed infestations started 12 WAH and ended 26 WAH, under normal growth conditions, in ratoon cane and control measures may need to be maintained up to 29 weeks after planting to keep yield losses below 5% in plant cane (Chapter 2; Seeruttun & Lutman, 2004). It was also shown that weed competition in plant cane starts earlier and this would depend on the rate of cane and weed growth, weed species, density of weed infestations, etc.

The success of weed management programmes which are directed towards minimization of herbicide use, largely depends upon the ability to predict the effects of weeds on crop yield (Kropff & Spitters, 1991). Weeds emerge in numerous flushes and the number of species present at any time in a sugar cane field may vary from 10 to more than 25; therefore the relative competitiveness of each individual weed is important for predicting impact on growth and yield. The simple descriptive regression model developed by Kropff and Spitters (1991), based on the hyperbolic yield loss – weed density model (Cousens, 1985), provides a good description of crop yield loss, expressed in total aboveground biomass, as a function of the relative leaf area of the weeds early in the development of the crop. Using this model, the 'relative damage coefficient' or relative competitiveness value q for several weed species in sugar cane has been derived (Chapter 3). However, in Chapters 3 and 4, the relative competitiveness of *P. urvillei*, a tussocky mostly erect perennial reaching 150-200 cm in height and leaves 12-50 cm long (Mc Intyre, 1991), was found to be lower than from the shorter *P. paniculatum* (reaching a maximum height of 100-150 cm with lanceolate leaves 20-40 cm long and 1.0-2.5 cm broad). The less competitive *P. urvillei* also produced relatively more leaf area per unit area. This result suggested that weed competition in sugar cane cannot be explained solely by

aboveground mechanisms (relative leaf area) and competition for belowground resources may also be a source of interference between the crop and the weeds.

The importance of root competition and the relationship between root and shoot growth have been demonstrated by many researchers in several crops including rice and cereals. Gibson *et al.* (1999) suggested that root competition may be the primary mechanism determining competitive outcomes between water-seeded rice and *Echinochloa phyllopogon* (Stapf) Koso-Pol, confirming similar conclusions in this crop published by Assemat *et al*. (1981) and Perera *et al*. (1992). In a comprehensive review of shoot and root competition, Wilson (1988) reported that in 33 out of 47 studies root competition had a greater effect on plant growth than shoot competition. For several cereal crops, including spring wheat, barley and oats, root competition was reported to be more important than competition for light (Aspinall, 1960; Irons & Burnside, 1982; Gamboa & Vandermeer, 1988; Satorre & Snaydon, 1992). Abdollahian and Froud-Williams (2005) showed that root competition by *Chenopodium album* L. caused greater reduction of shoot and root yield of sugar beet than shoot competition 16 weeks after transplanting. Root competition from an established grass sward was also demonstrated to affect shoot dry weight of *Rumex longifolius* DC. and *Taraxacum officinale* (Web.) Marss. much more than did shoot competition (Haugland, 1993). Using the divided box technique in an additive design, Tuor and Froud-Williams (2002) showed that root competition from purple nutsedge (*Cyperus rotundus* L.) for soil resources was more severe than competition for aerial resources in retarding the growth of maize and soyabean.

For a better understanding of the different mechanisms of competition between sugar cane and weeds, two experiments have been conducted to compare root and shoot competition between *P. paniculatum* and *P. urvillei* when grown with sugar cane. The objectives were to separate the effects of competition for aboveground and belowground resources by the two weed species and to elucidate the differences observed between the relative competitiveness of the two *Paspalum* species.

5.2 Materials and methods

Experimental method

The divided box technique of Schreiber (1967), as described by Satorre and Snaydon (1992), was used to separate the effects of aboveground (shoot) and belowground (root) competition between sugar cane and two *Paspalum* species. The technique provides conditions of no competition, shoot competition only, root competition only and both shoot and root competition between crop and weed (Fig. 5.1). The density of the crop (sugar cane) and weeds (*Paspalum* species) at planting were established according to the 1:1 additive design described by Satorre and Snaydon (1992). Keeping the number of buds on the cane stems per tray similar to the number of weeds transplanted would allow the effects of inter-specific competition between crop and weed to be measured without the confounding effects of intra-specific competition, as occurs in replacement designs (Firbank & Watkinson, 1985).

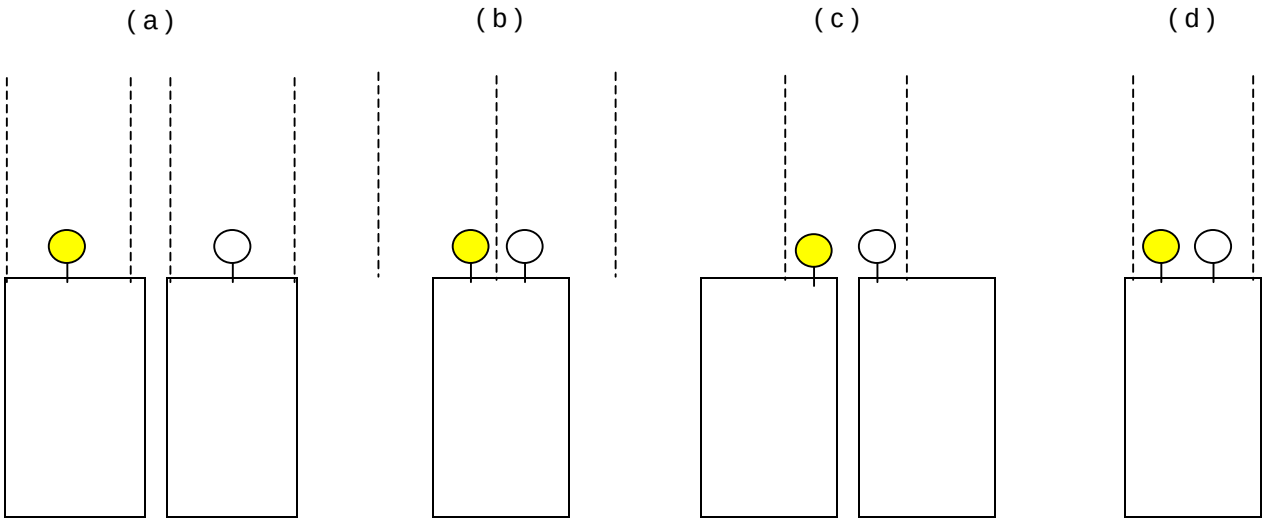


Fig. 5.1. The planting arrangement (side view) of sugar cane ( ) and *Paspalum* species ( ) to give (a) no competition; (b) root competition only; (c) shoot competition; and (d) both root and shoot competition (Satorre & Snaydon, 1992).

Trials site and plant material

Two trials/experiments were carried out, using the above technique, to compare root and shoot competition between sugar cane and two *Paspalum* species, namely *P. paniculatum* and *P. urvillei*. Trial I was carried out inside a glasshouse at Réduit experiment station whereas the second trial (Trial II) was established outside the glasshouse. The conditions inside the glasshouse were similar to those

prevailing outside as all openings (with a wire mesh to prevent insects, etc.) were left opened to maintain almost the same temperatures and natural light was used. Sugar cane was planted using two eyed-cuttings (cane setts with two buds each) obtained by cutting cane stems 9 to 11 months old (plant cane) from fields on the station or nearby nursery. The cane variety used in both trials was R 570. Seedlings or young plants of *P. paniculatum* and *P. urvillei* were uprooted and collected from an abandoned sugar cane field in the neighbourhood of the station.

Containers and growing medium

The sugar cane setts and weeds were planted in fibre glass containers 1.0 m long x 0.4 m wide X 0.3 m deep; an extension using iron sheets 0.3 m high was inserted on the top of each tray to increase the total planting depth to approximately 0.5 m (Fig. 5.2). For the treatments having root competition, only one tray was planted with both plants while for the other two treatments (no competition and shoot competition only) two trays were placed next to each other along the longer sides.

The trays were filled with topsoil collected from the fields on the station; the soil group at Réduit consists of Low Humic Latosols (L group according to Parish & Feillafé, 1965). Pre-experimentation soil analysis of the soil used as filling medium showed amounts of total N at 5100 kg ha^{-1}, 3900 kg ha^{-1} of total P and 2100 kg ha^{-1} of total K; the soil pH was 6.2, and CEC was 16.6 cmol kg^{-1}.

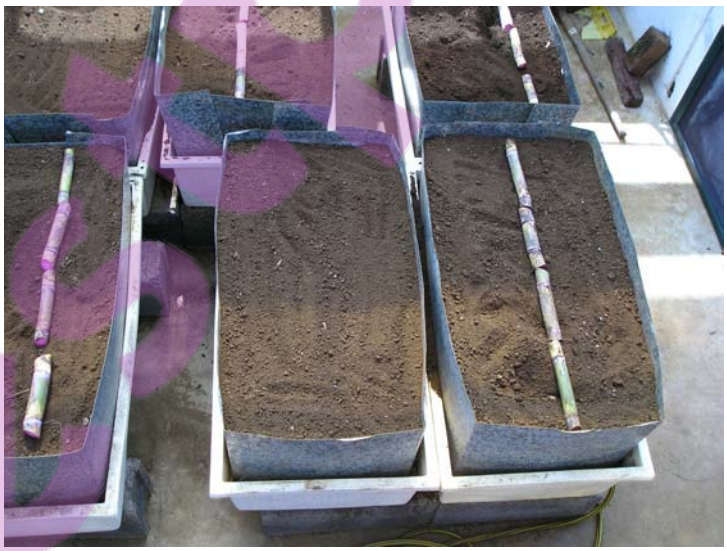


Fig. 5.2. Arrangement of trays (with iron sheet extensions placed on top of the trays to increase depth) for planting cane and weeds.

The aerial partitioning of the trays with respect to shoot competition was set by fixing black plastic sheets 1.0 m wide (giving a partitioning height of approximately 0.9 m) on 'bamboo' sticks placed at each corner of the trays (Fig. 5.3). The plastic sheets were placed along the longer side of the trays to limit the aerial space and assure same amount of light reaching the plants. The distance between the two sides for the control (no competition) and the treatment imposing root competition only were kept at approximately 0.8 m whereas the partitions for the two treatments having shoot competition were fixed at 0.4 m apart. The partitions were put into position four weeks after planting cane and provided a complete separation for most of the study period; a few sugar cane leaves grew above the top of the barriers for the last three to four weeks but were considered to have negligible effect on the results.

Fig. 5.3. Arrangement of trays with aerial partitions showing no competition (right picture at back); shoot competition only (left picture in front); and root + shoot competition (right picture – in front).

Planting sugar cane and transplanting of weeds

Sugar cane was planted at a density of four cuttings per tray in a single row either at the centre of the tray or side depending on the treatment; each two-eyed cane sett was pre-treated (cold dip) against 'pineapple' disease (caused by *Ceratocystis paradoxa*) with a solution of benomyl at 0.3 g per litre.

The weeds were transplanted one or two weeks after planting when the cane setts had started germination; the weed density used was eight plants/stools per container and they were evenly distributed and planted in a single row parallel to the cane. The weed leaves were partly pruned to reduce transpiration at transplanting and both cane and weeds were irrigated regularly to field capacity. The trays were kept free of other weed species by regular manual weeding which were carried out at the seedlings stage to avoid any additional competition. The dates of planting and transplanting of cane and weeds respectively are given in Table 5.1.

Table 5.1 Treatment dates in trials assessing root and shoot competition between sugar cane and two *Paspalum* species.

Trial	Dates			
	Cane planted	Weeds transplanted	Start of cane measurements	End of trial
Trial I	15 April 2006	28 April 2006	15 May 2006	6 October 2006
Trial II	16 November 2006	29 November 2006	30 December 2006	10 June 2007

Experimental layout and data collection

Treatments in Trial I were unreplicated because of the limited space inside the glasshouse, therefore, this is a preliminary trial in which treatment effects should be regarded as tendencies. In Trial II each treatment was replicated four times. In both trials the trays were disposed in a split-plot design with main-plots consisting of the two weed species. Data collection consisted of measuring dewlap heights of the primary cane shoots in each treatment at regular intervals; the dates of the first and last measurements are shown in Table 5.1. At the end of the experiments, all cane shoots were cut and measurements were taken for stalk height and dry weight separately for all cane shoots from each tray. In both trials, the aboveground biomass was collected and samples taken for dry weight measurements. The plant material was weighed before and after being oven-dried at 105^{o}C for 48 hours. Root biomass of cane and weeds were also measured in both trials after the trays were emptied and roots of cane and weeds separated, washed and dried.

Statistical design and analysis

Genstat (Discovery Edition 2) was used for all the statistical analyses with respect to Trial II. Data for cane dewlap height, aboveground and root biomass were subjected to analysis of variance (ANOVA) by using a split-plot design, and main effects and interactions were tested for significance. The two weeds were the main-plots and the sub-plot treatments consisted of the four combinations of root and shoot competition. Treatment means obtained by ANOVA were compared using LSD procedures at $P < 0.05$ level of significance.

5.3 Results

5.3.1 Trial I

5.3.1.1 Effect of root and shoot competition on shoot elongation and mean cane dewlap height

Cane growth was slower in Trial I, as it was conducted mostly through the winter period and shoot elongation was less than 2 cm per week between the periods early June to mid-August. When a relatively faster cane elongation resumed with higher temperatures as from the end of August, root competition between *P. paniculatum* and sugar cane apparently caused an adverse effect on cane growth (Fig 5.4). Shoot competition was found to have no effect on shoot elongation. This was also confirmed with the treatment where the cane shoots were exposed to both root and shoot competition and its effect being similar to that of root competition alone.

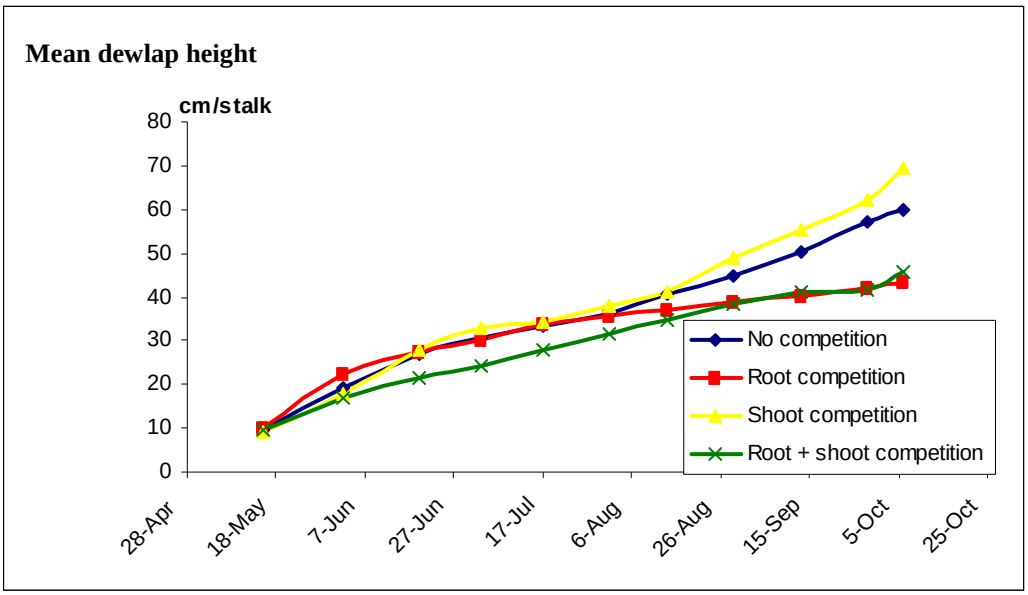


Fig. 5.4 Tendencies in root and shoot competition effects from *P. paniculatum* on elongation and mean dewlap height of cane shoots (mean of three primary shoots) in Trial I.

Data from this preliminary trial indicated that root competition between *P. urvillei* and sugar cane caused a reduction in shoot elongation of the crop (Fig 5.5); the effect was more apparent when cane shoots in the control (no competition) treatment had reached a mean dewlap height of 35 cm. Like *P. paniculatum*, shoot competition between *P. urvillei* and sugar cane did not cause any reduction

in cane elongation. Similarly, combining shoot competition with root competition appeared not to be more damaging than root competition alone.

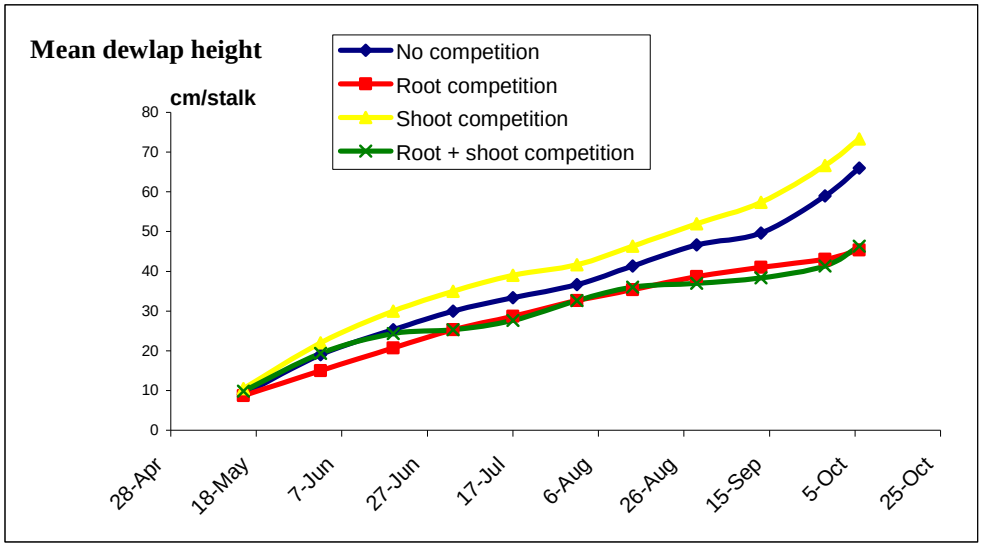


Fig. 5.5 Tendencies in root and shoot competition effects from *P. urvillei* on elongation and mean dewlap height of cane shoots (mean of three primary shoots) in Trial I.

5.3.1.2 Effect of root and shoot competition on aboveground biomass

The apparent effect of root and shoot competitions on cane elongation and dewlap height was confirmed with data obtained from the dry weight analysis of aboveground biomass. Root competition appeared to cause an adverse effect on cane development (Table 5.2). The dry weight of sugar cane biomass seemed to show a slightly more pronounced effect of root competition when it occurred in combination with shoot competition. The reduction in cane biomass with root and shoot competition also seemed to be greater with *P. urvillei*.

Table 5.2 Tendencies in shoot and root competition effects from *P. paniculatum* and *P. urvillei* on total aboveground biomass of weeds and sugar cane 25 WAP (Trial I)

	Aboveground biomass (dry weight - g m^{-2})			
	P. paniculatum		*P. urvillei*	
	Weed	Sugar cane	Weed	Sugar cane
No competition	423.9	809.9	622.3	862.0
Root competition	196.9	653.8	238.4	541.6
Shoot competition	187.5	974.8	408.9	749.6
Root + shoot competition	102.3	526.5	71.4	470.4

The aboveground biomass of the weeds tended to be adversely affected by root and shoot competition in this preliminary trial. Unlike the effect on sugar cane biomass, shoot competition between the weeds and sugar cane apparently caused a reduction in the development of the *Paspalum* species; *P. paniculatum* seemed to suffer more from shoot competition than *P. urvillei*. Root competition was more severe than shoot competition with *P. urvillei*. The effects of both root and shoot competition on the weed species were more marked on the biomass of both weeds when the treatments were combined.

5.3.1.3 Effect of root and shoot competition on root development of crop and weeds

Irrespective of the weed species, the root biomass of sugar cane tended to be reduced by both root and shoot competition; root competition caused greater reductions than shoot competition (Table 5.3). The higher reduction in root biomass of sugar cane observed when both competitions occurred simultaneously confirmed the adverse effects of both root and shoot competition.

Table 5.3 Tendencies in shoot and root competition effects from *P. paniculatum* and *P. urvillei* on root development of weeds and sugar cane 25 WAP (Trial I)

	Dry weight of roots (g m^{-2})			
	P. paniculatum		*P. urvillei*	
	Weed	Sugar cane	Weed	Sugar cane
No competition	94.9	342.2	180.9	314.2
Root competition	76.0	253.5	91.4	192.8
Shoot competition	64.0	290.9	84.4	245.3
Root + shoot competition	17.4	160.9	14.4	103.5

In absence of any competition, the amount of roots produced by *P. urvillei* tended to be higher than that of *P. paniculatum*. Irrespective of the weed species, both root and shoot competition caused a reduction in the biomass of weed roots produced. The amount of roots was further reduced when both types of competition occurred simultaneously. Weeds were apparently more affected by competition than the cane with regard to both shoots and roots.

5.3.2 Trial II

5.3.2.1 Effect of root and shoot competition on shoot elongation and cane growth

Paspalum paniculatum

Cane shoot elongation, measured from the end of December (seven weeks after planting), revealed no differences between the various combinations of root and shoot competition treatments and the control, i.e., no root or shoot competition until the first week of April 2007 (21 WAP) when a significant reduction in mean dewlap height from root competition between sugar cane and *P. paniculatum* was observed (Fig. 5.6). This difference was maintained until the end of the trial, i.e., for another two months. Shoot competition did not seem to affect cane elongation and the adverse effect of root competition on cane elongation was not apparent when sugar cane was exposed to both root and shoot competition from *P. paniculatum*.

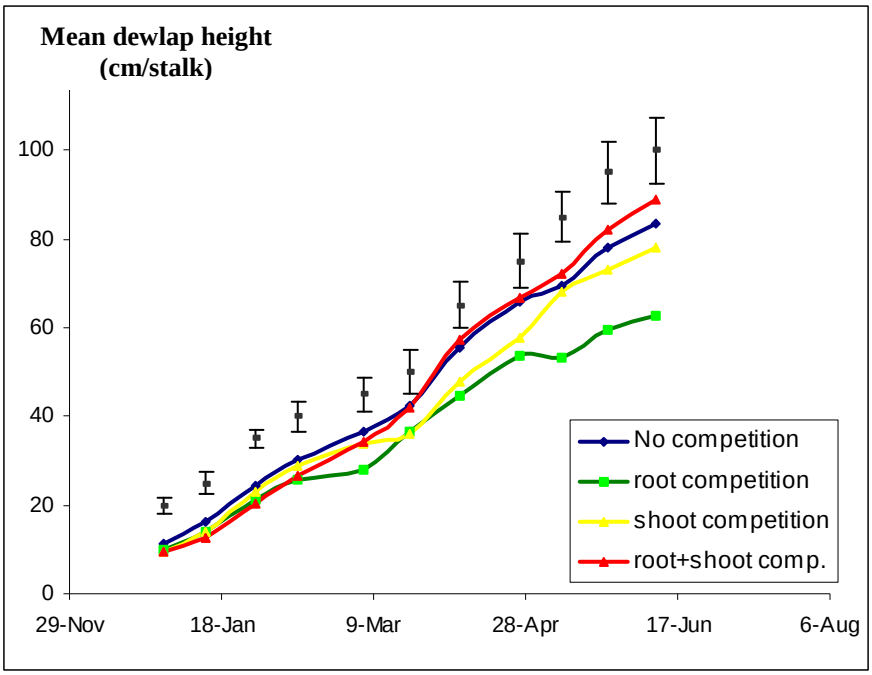


Fig. 5.6 Effects of various combinations of root and shoot competition from *P. paniculatum* on mean dewlap height of cane shoot. The vertical error bars indicate 2 x s.e.d. at each observation date.

Paspalum urvillei

The effects of root and shoot competition from *P. urvillei* were similar to that observed with *P. paniculatum*; the mean dewlap height was also found to be significantly reduced some 21 weeks after

the start of the trial by root competition (Fig. 5.7). Similarly, no difference in mean dewlap height was observed between the control and the treatments causing shoot competition. Combining root and shoot competition did not result in a significant decrease in mean dewlap height of the cane shoots.

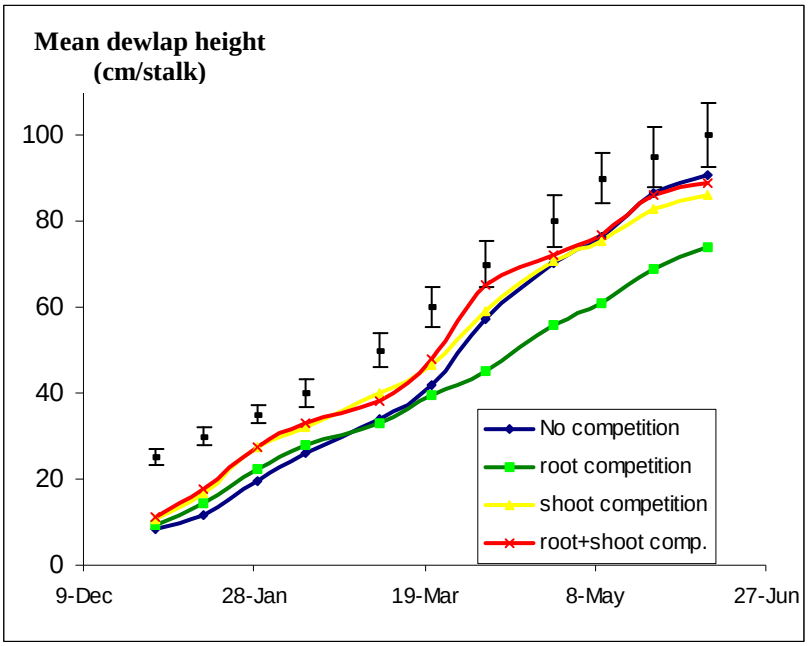


Fig. 5.7 Effects of various combinations of root and shoot competition from *P. urvillei* on mean dewlap height of cane shoots. The vertical error bars indicate 2 x s.e.d. at each observation date.

5.3.2.2 Effect of root and shoot competition on aboveground biomass

Cane shoot

The mean stalk weight (dry) of the three primary shoots which were tagged for elongation measurements confirmed that root competition had a significant adverse effect on stalk development of cane (Table 5.4). Unlike the effect on mean dewlap height, shoot competition caused a reduction in mean stalk weight of cane compared to its growth in the control trays (Table 5.4).

Irrespective of the weed species (main-plot means), root competition caused a higher reduction of mean stalk weight (of the primary shoots) than the shoot competition treatment. However, root competition effects from both weeds were not more pronounced than the effects of both types of competition combined. It appeared that shoot competition had an alleviating effect on root competition when they occurred together; most probably shoot competition adversely affecting root development and thereby reducing root competition.

Table 5.4 Effects of shoot and root competition from *P. paniculatum* and *P. urvillei* on mean dry weight of cane stalks (3 primary shoots) 30 weeks after planting in Trial II

Weeds	Mean weight (dry) of cane stalks (g)				
	No competition	Root competition	Shoot competition	Root + shoot competition	*Mean variety*
P. paniculatum	62.1 a	30.3 c	45.8 b	37.4 bc	*43.9*
P. urvillei	70.7 a	36.3 c	55.1 b	47.4 bc	*52.4*
Mean competition treatment	*66.4 a*	*33.3 c*	*50.5 b*	*42.4 bc*	

Values are means of four replications. Standard error of difference of means for main plot – weeds (d.f.=18) = 4.64 and standard error of difference of means with same level of weed (d.f. = 18) = 6.57. Mean values in the same row not sharing the same lower-case letter are significantly different at $P < 0.05$ (LSD test).

Total aboveground biomass

Total aboveground biomass (dry weight) data confirmed a greater adverse effect from root competition on cane development than from shoot competition (Table 5.5). The effect was not worsened by both effects occurring in combination.

Table 5.5 Effects of shoot and root competition from *P. paniculatum* and *P. urvillei* on mean total aboveground biomass of stalks (primary shoots) 30 weeks after planting in Trial II.

Weeds	Mean weight (dry) of total aboveground biomass per cane stalk				
	No competition	Root competition	Shoot competition	Root + shoot competition	*Mean variety*
P. paniculatum	76.6 a	40.4 c	57.7 b	51.1 bc	*56.5*
P. urvillei	85.1 a	48.2 c	69.0 b	61.7 bc	*66.0*
Mean competition treatment	*80.8 a*	*44.3 c*	*63.3 b*	*56.4 b*	

Values are means of four replications. Standard error for main plot – weeds (d.f.=18) = 5.02 and standard error of means with same level of weed (d.f. = 18) = 7.10. Mean values in the same row not sharing the same lower-case letter are significantly different at $P < 0.05$ (LSD test).

5.3.2.3 Effect of root and shoot competition on root development

Root biomass of weeds

The amount of roots produced per tray by the two weeds differed as *P. urvillei* produced significantly higher root biomass than *P. paniculatum*. Irrespective of weed species, shoot competition had no significant effect on root formation of the weeds (Table 5.6). Root competition between sugar cane and *P. urvillei* caused a significant reduction on root biomass of the weed; this reduction also occurred when root competition was coupled with shoot competition. A similar trend was observed for *P. paniculatum* but the differences were not significant, which may have been due to the relatively lower amount of roots produced by *P. paniculatum.*

Table 5.6 Effects of shoot and root competition between *Paspalum* species and sugar cane on weed root development (mean dry weight) 30 weeks after planting in Trial II

Weeds	Mean dry weight of weed roots (g m^{-2})				
	No competition	Root competition	Shoot competition	Root + shoot competition	*Mean variety*
P. paniculatum	127.7 a	85.4 a	91.0 a	64.8 a	*92.2*
P. urvillei	249.3 a	87.7 b	188.7 a	40.4 b	*141.5*
Mean competition treatment	*188.5 a*	*86.6 b*	*139.8 a*	*52.6 b*	

Values are means of four replications. Standard error of difference of means for main plot – weeds (d.f.=18) = 24.33 and standard error of difference of means with same level of weed (d.f. = 18) = 34.41. Mean values in the same row not sharing the same lower-case letter are significantly different at $P < 0.05$ (LSD test).

Root biomass of cane

Root development of sugar cane was adversely affected by root competition from both weed species. Shoot competition caused a reduction in cane root biomass when sugar cane was exposed to competition to *P. urvillei* (Table 5.7). The latter also caused a more severe loss in cane root biomass when both root and shoot competition were imposed.

Table 5.7 Effect of shoot and root competition between *Paspalum* species and sugar cane on cane root development (mean dry weight) 30 weeks after planting in Trial II

Weeds	Mean weight (dry) of cane roots (g m^{-2})				
	No competition	Root competition	Shoot competition	Root + shoot competition	*Mean variety*
P. paniculatum	534 a	343 b	374 ab	257 b	*377*
P. urvillei	789 a	571 b	582 b	352 c	*573*
Mean competition treatment	*661 a*	*457 b*	*478 b*	*304 c*	

Values are means of four replications. Standard error of difference of means for main plot – weeds (d.f.=18) = 63.3 and standard error of difference of means with same level of weed (d.f. = 18) = 89.5. Mean values in the same row not sharing the same lower-case letter are significantly different at $P < 0.05$ (LSD test).

5.4 Discussion and conclusions

Results showed that the mechanisms responsible for growth reduction in sugar cane in presence of *Paspalum* species seem to include root competition. In fact, for many of the parameters measured, root competition was found to be more severe than shoot competition. This finding supports those of other studies that compared shoot and root competition in rice (Assemat *et al*., 1981; Perera *et al*., 1992; Gibson *et al*., 1999) and in cereals (Aspinall, 1960; Satorre & Snaydon, 1992).

The effect of root competition on mean dewlap height of sugar cane was visible only after several weeks of exposure to the treatments or when the cane stems had reached more than 35 to 40 cm in dewlap height (Figs 5.4-5.7). Although the mean dewlap heights did not reveal major differences between combinations of shoot competition and the full (root + shoot) competition on the last day of the respective trials, bigger differences were noted between the control (no competition) and the root and shoot treatments for mean weight of the same 'tagged' stems measured. This may partly be explained by the etiolating effect of cane stems for light resources under shoot competition and may also explain the relatively lower damage observed in some cases by the full competition effect compared to root competition only.

Haugland (1993) reported an increase in specific leaf area by shading from shoot competition, which made target plants less susceptible to competition for light. An increase in plant height due to shoot competition by *E. phyllopogon* on rice was also observed by Gibson *et al*. (1999); the ability to increase plant height could have limited the effect of light competition on the target plant.

Root development of sugar cane was impaired by both root and shoot competition. A more severe reduction was not recorded when both occurred simultaneously which may suggest that they were not affecting root development in the same manner. Haugland (1993) reported that shoot competition reduced root dry weight and increased shoot/root ratio, which in turn probably can reduce plant survival. Root competition also reduced the amount of weed roots and this was significant for *P. urvillei,* which produces more roots than *P. paniculatum*. The reduction in root biomass of weeds by shoot competition was not significant in Trial II although there was a tendency that it was more important than shoot competition in Trial I.

The divided box technique has been criticised because of the restricted soil volumes often employed and the possibility of greater resources availability to those treatments involving no competition (Froud-Williams, 2002). However, due to the relatively large size of the tray used in this study and the planting density imposed, the percentage of crop and weed roots occupying the volume of soil placed in the tray should have been lower than that under field conditions. Therefore, cane root

development in the root competition treatment was not the result of limited space, and therefore resources, in the trays. This conclusion is supported by the fact that the sum of the amount of weed and cane roots was lower in the boxes with root competition than in the no competition control (Tables 5.6 and 5.7; Fig. 5.8).

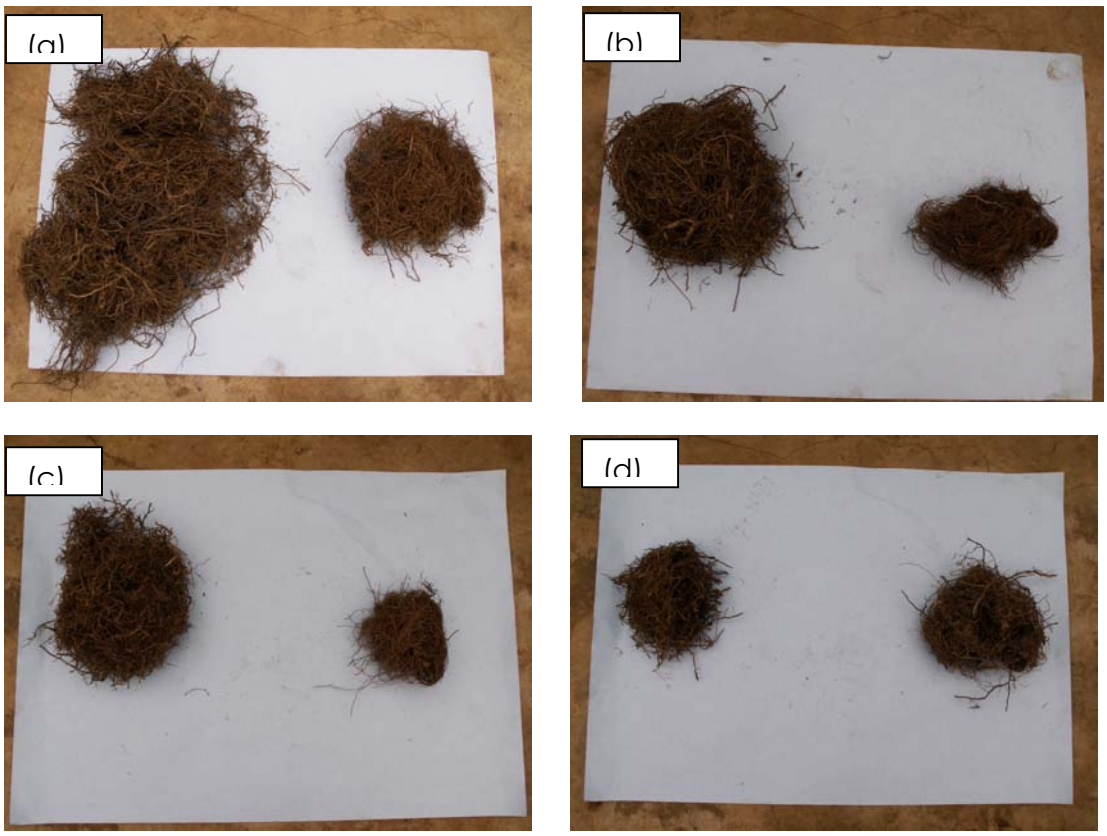


Fig. 5.8 The effect of various combinations of (a) no competition, (b) root competition, (c) shoot competition and (d) root and and shoot competition from *P. paniculatum* on amount of roots of cane (left) and weed (right) per tray placed on a A4 size paper.

Several researchers have associated the effect of below-ground competition to availability of nutrients, particularly N, although the contrary has also been demonstrated. Satorre and Snaydon (1992) found that root competition was still more important than shoot competition when higher levels of N were applied. For Suzuki (2002), who reported shoot competition being more important than root competition in rice, root competition might be an important factor in the competition with weed of rice cultivars under crucially nitrogen-limited conditions. In the present study, N should not have been a limiting factor as only 5% of the total N present in the soil would represent some 225 Kg ha^{-1} of mineral N available to the plants. Sugar cane that produces a total biomass of more than 100 t ha^{-1} over a one year period requires between 120 and 140 kg ha^{-1} of N (STASM, 1990). In the present study,

cane was grown for only seven months and biomass produced was much smaller than for a normal crop cycle. Similarly, the available amount of P_2O_5 should not have been a limiting factor influencing root development. In the absence of competition for N or other nutrients, there is a need for other explanations for root reduction. It is possible that allelopathy could have played a role in determining the growth of cane and weeds. However, several other factors not amenable to testing in the box experiments can also play a role in determining competition in the field. For example, the rooting depth and root distribution of some crops and weeds differ appreciably, causing considerable difference in competitive effects, due to differences in nutrient and water scavenging ability between the different root systems.

Findings presented in this chapter reveal (no previous work studying this aspect reported) that weed competition in sugar cane is caused by both root and shoot competition and the relative competitiveness of an individual weed is more complex and cannot solely be described by aboveground competition mechanisms, e.g., weed competition models based on relative leaf areas.

CHAPTER 6

ALLELOPATHIC EFFECT OF *PASPALUM PANICULATUM* AND *PASPALUM URVILLEI* ON GROWTH OF SUGAR CANE

6.1 Introduction

Sugar cane is a very important crop in Mauritius and occupies approximately 80% of the arable land. This perennial plant of the grass family is grown over a period of 12 to 18 months during the first year, followed by a 12-month ratoon crop for another six to eight years. As the growing period is relatively long, taking between 4 to 8 months for complete canopy closure, weeds need to be controlled efficiently (Rochecouste, 1967). The traditional practice has been to target 100% control of all weeds from sugar cane fields irrespective of the amount and species of the weeds and stage of growth of the cane, by use of large amounts of pre- and post-emergence herbicides. The average amount of herbicides used annually has varied between 8 to 10 kg a.i. ha^{-1} during the last three decades (MSIRI, 2004). The costs for weed control have increased significantly during the last ten years; the average cost for herbicides exceeds MUR 4 000 ha^{-1} (120 US $ ha^{-1}) annually (see Chapter 1).

Increasing pressure on farmers to optimise their use of pesticides to reduce environmental effects and to minimize costs has led to the development of strategies for integrated weed management (IWM) and use of alternative methods to herbicides for weed control. IWM has also become the basis of all FAO plant protection activities because it contributes directly towards the achievement of sustainable agriculture in developing countries (Labrada & Parker, 1994). Development of such strategies in the Mauritian sugar industry became even more urgent with the announcement and implementation of a price reduction of 37% by 2009 by the EU, the main importer of Mauritian sugar. Several projects have been initiated since 1998 to develop weed management strategies in sugar cane. Firstly, trials studying critical periods of weed competition under the worst agroclimatic conditions of the island have revealed that weed competition started 12 WAH and ended 26 WAH in ratoon cane, and control measures may need to be maintained up to 29 WAP to keep yield losses below 5% in plant cane (Chapter 2; Seeruttun & Lutman, 2004). These studies to compare relative competitiveness of various weed species commonly present in sugar cane fields have revealed sugar cane as a stronger competitor than most of the weeds tested; the time of emergence and rate of development of the weed species influencing the effect. The mechanism of the aboveground competition in sugar cane has been studied by comparing the competitive ability of two *Paspalum* species with different morphological

traits; *P. urvillei* being a tussocky mostly erect perennial reaching 150-200 cm in height and leaves 12-50 cm long while *P. paniculatum* reaches a maximum height of 100-150 cm with lanceolate leaves 20-40 cm long and 1.0-2.5 cm broad, with a more planophile arrangement (Mc Intyre, 1991). *Paspalum paniculatum* has been found to be relatively more competitive than *P. urvillei* despite the latter growing taller and having higher relative leaf areas. This difference led to investigations on mechanisms of competition occurring between sugar cane and the two *Paspalum* species (Chapter 5). Shoot versus root competition trials showed that root (underground) competition was important in sugar cane. However, the trials were not able to elucidate the cause of the difference in competitiveness between the two *Paspalum* species.

Weed interference is a term used to express competition by both indirect interaction (e.g. crop and weeds competing for limited resources such as light, mineral nutrients, water, or volume of space) and direct interactions/interference (e.g. suppression of growth of one individual by the other releasing phytotoxic chemicals). Allelopathy is a phenomenon observed in many plants that release chemicals into their near environment either from their aerial or underground parts in the form of root exudates (Rice, 1984). The chemical compounds released into the environment act on the other organisms, such as weeds, plants, animals and microorganisms, by inhibitory or excitatory ways. These chemicals accumulate and persist for a considerable time, thereby imparting significant interference on the growth and development of neighbouring weeds and plants (Putman & Duke, 1974). Literature reviews by Putnam (1988) and Williamson (1990) have described allelopathy caused by substances from a number of cultivated plants and weeds. Allelopathic potential of many gramineous weeds have been reported including that of extracts of *Paspalum notatum* Flueggé (bahiagrass) and other warm-season grasses on alfalfa and Italian ryegrass (Martin & Smith, 1994), interference between bermudagrass [*Cynodon dactylon* (L.) Pers] or johnsongrass [*Sorghum halepense* (L.) Pers] and cotton or corn (Vasilakoglou *et al*., 2005) and nutgrass (*Cyperus rotundus*) on rice seedlings (Quayyum *et al*., 2000). Ishmine *et al.* (1987) studied the potential of some dominant weeds of sugar cane on the Ryukyu Islands and reported that exudates of *P. urvillei* caused an adverse effect on growth of *Phaseolus vulgaris* in greenhouse trials. Root exudates of *P. notatum* have also been reported to reduce soybean and okra (*Hibiscus esculentus*) height increments (Pope *et al*., 1984). Mc Intyre (1998) reported an allelopathic effect of *C. rotundus* on sugar cane.

Considerable current research on allelopathy is focused on its use in weed management strategies, either by identifying allelochemicals for production of bioherbicides or to serve as leads for synthetic herbicides. Much research effort is also spent on identification of crop cultivars having allelopathic properties which can suppress weeds. One means of exploiting allelopathy for weed

control is through the use of decaying crop residues, for example, the release of allelochemicals from rice straw (Fujii, 1992; Chou, 1999; Ahn & Chung, 2000). In sugar cane, evidence of allelochemical substances continually being leached from trash that suppressed weeds has been reported by Lorenzi *et al.* (1988). The leachates from sugar cane trash have also been reported to cause autotoxicity; Viator *et al.* (2006) contended that benzoic acid in leachates from trash blanket impairs cane ratooning and growth.

One concern often voiced by researchers of allelopathic interactions is that many laboratory bioassays do not adequately predict the responses observed in field situations. Inderjit and Weston (2000) concluded that a laboratory bioassay could not demonstrate that allelopathy is operational in natural settings. Current research is addressing this issue and many new methodologies and techniques for identification, assessment, etc. are being developed. Recent examples include a 'sandwich method' for elucidating allelopathic effect of leaf litter leachates under laboratory conditions (Fujii *et al*., 2004) and use of dose-response curves with known standard allelochemicals in bioassay based on hydroponic culture to screen cultivars for allelopathic traits (Belz & Hurle, 2004).

Benzoxazolin-2(3*H*)-one (BOA) or hydroxamic acids are commonly occurring secondary metabolites in cultivated and wild Gramineae (Zuniga *et al*., 1983; Niemeyer, 1988 and Friebe *et al*., 1998) and have been shown to have an effect on radicle growth and elongation (Aiupova *et al*., 1979) or causing abnormal growth (Wolf *et al*., 1985). BOA has been reported by Barnes and Putnam (1987), and Belz (2004) as the responsible agent for the inhibitory activity of rye residues.

In the present study root exudates (leachates) from *P. urvillei* and *P. paniculatum* have been tested for allelopathic properties in four glasshouse experiments between December 2005 and July 2007. The main objectives of the trials were (i) to determine if root exudates from the two *Paspalum* species exert allelopathic effects on sugar cane and, if yes, (ii) would there be different varietal responses to such chemicals, and (iii) to compare the two *Paspalum* species with respect to their allelopathic properties.

6.2 Materials and methods

Methodology for collection and application of leachates

The methodology used in classical allelopathy trials, i.e. laboratory bioassays with extracts applied on seeds in Petri dishes or other techniques such as the "sandwich method" for leaf litter, could not be used with sugar cane as the plant is vegetatively propagated using cuttings from the stem and the growth period is relatively long. Furthermore, the collection of leachates from the donor plant was more difficult and the approach for continuous trapping of chemicals from an undisturbed root system as developed by Tang and Young (1982) was not possible for practical reasons. The methodology used by Mc Intyre (1998) for transferring leachates from *Cyperus rotundus* to young sugar cane shoots was also physically limiting, as the *Paspalum* species would grow much taller than *C. rotundus*.

For this study, the methodology consisted of applying leachates collected from the donor plant grown in a relatively 'inert' medium to young pre-germinated cane setts of four sugar cane varieties grown in a similar medium.

Trial site and plant material

The experiments were carried out in an unheated glasshouse with no supplementary lighting at Réduit (MSIRI) experiment station. Seedlings or young plants of the donor plants, i.e. *P. paniculatum* and *P. urvillei*, were uprooted/collected from sugar cane fields or abandoned lands in the Belle Rive area where it is more humid and these two *Paspalum* species are common weeds. The recipient plant in the four experiments consisted of young sugar cane plants of four widely grown varieties namely M 3035/66, R 570, R 579 and M 695/69. They were selected on the basis of the total area cultivated with them and their tolerance to post-emergence herbicide treatments (MSIRI, 2003). M 3035/66, cultivated on approximately 5% of the area cultivated by Miller-Planters (growers possessing a mill and owning approximately 45% of total land under sugar cane) in 2005, is classified as a tolerant variety (MSIRI, 2006). R 570, occupying more than 23% of the area grown by that group of growers, is very susceptible to herbicide treatments. R 579 and M 695/69, respectively covering 10% and 8% of the acreage by Miller-Planters, are classified as moderately susceptible varieties.

Sugar cane was planted using two-eyed cuttings (cane setts with two buds each) obtained by cutting cane stalks 9 to 12 months old (plant cane) from fields on the station or nearby nursery. They were allowed to germinate in filter mud before transplanting in the buckets.

Containers and growing medium

Plastic containers with a diameter of 20 cm and 15 cm deep (10 litres capacity) were used for the weeds. These were perforated at the bottom to allow excess irrigation water (leachates) to collect in plastic bowls/trays placed 10 cm below each container. The clearance between the growing container and the collecting device was assured by placing the container on wooden frames (Fig. 6.1). When the pre-germinated sugar cane setts were at the 2-leaf stage they were uprooted from the filter mud medium, cleaned to remove most of the filling medium before being transplanted in larger plastic containers (buckets) of 20 L capacity. These buckets also had perforations at the bottom but were placed directly on the collecting bowls to enable excess water to be absorbed back into the medium though capillarity movement.

Fig. 6.1 *Paspalum paniculatum* (left) and *P. urvillei* (right) transplanted in trays filled with mixture of rocksand and filter mud (left), and containers and collecting bowls arrangement for leachates collection from weeds (right)

The growing medium used for both cane and the weeds was a mixture of 'rocksand' and filter mud at a ratio of 2:1. The 'rocksand' consists of small size (max. 4 mm) particles obtained by crushing basaltic rocks (volcanic origin); this material is usually used in construction. The inert property of the rocksand was assured by washing it with clean water prior to mixing with filter mud. The latter is a cake which is produced after filtration of the precipitated cane juice and also contains much of the colloidal organic matter anions that precipitate during clarification. The filter mud consists mainly of moisture (>60%) and has approximately 1% by weight of phosphate (P_2O_5) (Paturau, 1989).

The medium used was analysed by the Agricultural Chemistry department of MSIRI for pH, CEC, total N, P & K, and dry matter content. Pre-experimentation analysis of the filling medium in

Trial IV had revealed the presence of total N at 1.17%, total P at 0.83% and total K at 0.11%; the soil pH was 6.7 with a CEC of 19.3 cmol kg^{-1}. At the end of the experiment, analysis showed the presence of total N at 0.75%, total P at 0.46% and total K at 0.07%, with a pH of 7.0 and a CEC of 14.0 cmol kg^{-1}.

Planting weeds and transplanting of sugar cane

The collected weeds were transplanted at a density of four stools per container after their leaves were pruned to reduce transpiration. In all trials, 15 containers were planted with each weed species for leachate collection while 10 others were kept unplanted to act as a control.

The two-eyed cane setts for each variety were treated (cold dip) against 'pineapple' disease (caused by *Ceratocystis paradoxa*) with a solution of benomyl at 0.3 g per litre before being planted in large trays filled with rocksand and filter mud (50:50) for germination. Once the setts had germinated, they were uprooted and transplanted in the buckets – one pre-germinated sett per bucket (Fig. 6.2). This step was done to guarantee homogeneity of having two well-developing primary shoots per bucket. For Trial III, due to a poor and erratic germination, the two-eyed cuttings were cut into planting material with only one primary shoot before transplanting into the buckets.

Fig 6.2 Pre-germinated two-eyed cuttings planted in buckets to receive leachates from *P. paniculatum* and *P. urvillei.*

Leachate collection and application to recipient plant

Distilled water was used to irrigate all weeded containers on a daily basis as from establishment; the containers without weeds also received the same amount of water. All excess water percolating through the containers were collected from the bowls every morning and were bulked together into three treatments: leachate from *P. paniculatum*, leachate from *P. urvillei* and leachate from unplanted containers. The containers with the collected leachates were covered and stored under the bench to avoid direct sunlight.

Cane setts were irrigated with distilled water for one or two weeks after transplanting before treatments commenced. Once treatment started the cane received only leachates collected from the donor containers or control. The onset of treatments varied across trials as the establishment of the weeds differed (Table 6.1). The volume of water used to irrigate the weeds varied between 300 and 750 ml depending on the stage of growth and rate of evapotranspiration. This was monitored closely and adjustments were made according to volume of water left in collecting bowls and physiological state of the weeds – water-stress conditions or the presence of too much (diluted) leachates were avoided. All cane buckets received the same volume of leachates from the treatments; the volume applied again varied with water requirements of cane plant with respect to evapotranspiration and its stage of growth. In Trial I, distilled water was applied directly in the control buckets whereas in the other experiments the control received water collected through the similar containers without weeds.

Table 6.1 Treatment dates in trials assessing allelopathic potential of two *Paspalum* species on sugar cane

Trial	Dates			
	Weeds transplanted	Cane transplanted	Start irrigating with leachates	End of trial
Trial I	14 December 2005	28 December 2005	12 January 2006	23 March 2006
Trial II	14 April 2006	2 May 2006	15 May 2006	7 October 2006
Trial III	20 October 2006	4 November 2006	11 November 2006	12 February 2007
Trial IV	3 February 2007	23 February 2007	5 March 2007	7 July 2007

Experimental layout and data collection

The buckets with cane plants were placed on a bench (1 m above floor) on one side of the glasshouse while the weeds were placed in a similar manner on the opposite side. The temperature in the glasshouse was slightly higher than the outside temperatures during the day; all window/opening were left open with a fine mesh wire gauze screen to prevent any insects, etc. Natural day-light was used and the main advantage of placing the trays indoors were to control water regimes by preventing the effect of rainfall.

Data collection consisted of measuring dewlap heights of the primary shoots in each bucket at regular intervals. For Trial I, the first measurement of cane shoot height (dewlap height) was made on 11 January 2006 and was followed by a second one on 6 February 2006. On 23 February 2006 (12 weeks after transplanting), all cane shoots were cut and measurements were taken for stalk height. The harvested material was sorted into primary tillers and new tillers from each bucket and weighed. Sub-samples from the harvested material were weighed before and after being oven-dried at 105^{o}C for 48 hours. The buckets were emptied on 25 February 2006 for dry weight analysis of root biomass.

For Trial II, cane measurements started on 15 May 2006 and subsequently were taken on 2 June 2006, 19 June 2006, 3 July 2006, 17 July 2006, 1 August 2006, 14 August 2006, 29 August 2006, 13 September 2006 and 28 September 2006. On 6 October 2006, all shoots were measured for the last time before being cut at ground level and the roots excavated. All harvested samples were weighed before and after oven-drying at 105^{o}C for 48 hours.

For Trial III, dewlap height was measured for each primary shoot on 24 November 2006, 4 December 2006, 14 December 2006, 26 December 2006, 10 January 2007, 19 January 2007 and 29 January 2007. Aboveground and root biomass (dry weights) of cane were measured for each treatment at the end of the trial, as described above.

Cane measurements in Trial IV started on 6 March 2007 and were also carried out on 21 March 2007, 6 April 2007, 26 April 2007, 10 May 2007, 25 May 2007, 20 June 2007 and 5 July 2007. All cane shoots were chopped and roots excavated on 5 July 2007. They were weighed before and after being oven-dried at 105 ^{o}C for 48 hours; dry weight of cane stalks, cane leaves and biomass of cane root per bucket were recorded.

For determining root biomass, the buckets were emptied and all roots separated from the filling material before being washed to remove all filter mud. The roots were separated from cane setts and oven-dried for 48 hours before being weighed.

Statistical design and analysis

Genstat (Discovery Edition 2) was the statistical package used for all the statistical analyses. All data recorded from cane measurements (dewlap heights), aboveground and root biomasses were subjected to analysis of variance (ANOVA) by using a split-plot design, and main effects and interactions were tested for significance. The four cane varieties were the main-plots and the three sub-plot treatments consisted of leachates from *P. paniculatum*, *P. urvillei* and control; each treatment was replicated three times. Treatment means obtained by ANOVA were compared using LSD procedures at $P = 0.05$ level of significance.

Chemical analysis of leachates from P. paniculatum and P. urvillei

Leachates from the two grass weeds were collected from Trial IV and brought to the Agricultural Chemistry department of MSIRI for analysis for the presence (and quantification if present) of 2(3H)-benzoxazalinone, commonly called BOA, and for identification of other allelopathic substances present using gas chromatography-mass spectrometry (GC-MS).

Test for BOA

Analysis of BOA in the leachates was conducted using an HPLC equipped with a DAD detector (HP 1050). A polar C-18 reversed phase column was used, and eluted with a gradient of 5% acetonitrile and 95% Na_2HPO_4–buffer (1 mM, pH 2.4, 10% acetonitrile) at 0.35 ml min^{-1} flow rate. Quantitative analysis was done by the external calibration method using certified BOA (2-Benzoxazolinone) standards (Sigma-Aldrich, Germany; CAS 59-49-4). Identification of BOA peaks was based on retention time window of pure standards; the retention time was 6.5 ± 0.05 minutes.

Identification of allelopathic substances by GC-MSD

Leachate aliquots of 100 ml from both *Paspalum* species plus samples collected from bowls without weeds and irrigated with distilled water were extracted twice with dichloromethane and once with hexane. The combined organic extract was rotary evaporated to 1-2 ml, followed by reconstitution into 7-8 ml hexane. The hexane extracts were evaporated under a gentle N_2 stream, followed by reconstitution in 1 ml hexane (US EPA, 1996). An aliquot of 1 ml was injected (splitless) into the GCMSD (GC HP 6890, MSD 5973). The chromatographic data were obtained on an HP 5mS column (30 m x 0.25 mm I.D., 0.25 µm film thickness) and were screened for allelochemicals using the NIST 2002 Mass Spectral library, inbuilt in the software.

6.3 Results

6.3.1 Trial I

6.3.1.1 Effect of leachates on shoot elongation and cane growth

Pre-treatment cane measurement

Cane measurement made on 11 January 2006 showed a difference in mean stalk height among the main factors (varieties) and no difference between leachate treatments and control (distilled water), thus confirming that all shoot heights were similar before irrigation with leachates started (Table 6.2).

Table 6.2 Mean dewlap height at start of experimentation (before irrigating with leachates) in Trial I

Cane variety	Mean dewlap height (cm shoot^{-1})			
	Distilled water	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	8.8	12.0	12.2	*11.0*
R 570	8.5	8.2	8.7	*8.4*
R 579	10.3	8.0	9.3	*9.2*
M 695/69	11.3	13.5	12.8	*12.6*
Mean (leachates)	*9.8*	*10.4*	*10.8*	

Values are means of three replications. Standard error of difference (s.e.d.) of means for variety (d.f.=6) = 1.10 and s.e.d. of means for leachate treatments (d.f. = 16) = 0.92. S.e.d. for comparing between individual varieties x leachate treatments = 1.85 (d.f. = 16).

Second cane measurement

Dewlap height of cane stalks in the all buckets was again measured on 6 February 2006 (3.5 weeks after start of irrigation with leachates). A few new shoots (tillering) were observed in some of the buckets. Statistical analysis carried out separately on the mean height of primary shoots alone or the latter together with the new tillers revealed no significant difference between the leachate treatments (Table 6.3). Irrespective of the effect of the leachate treatments, variety M 695/69 produced taller cane shoots than the other three varieties.

Table 6.3 Effect of leachates from *P. paniculatum* and *P. urvillei* on mean dewlap height of four cane varieties 3 weeks after start of treatments

Variety	Mean dewlap height (cm shoot^{-1})			
	Distilled water	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	23.7	26.3	24.8	*24.4*
R 570	26.5	22.5	23.5	*24.2*
R 579	22.7	23.0	23.2	*22.9*
M 695/69	32.7	32.5	31.3	*32.2*
Mean (leachates)	*26.4*	*26.1*	*25.7*	

Values are means of three replications. Standard error of difference (s.e.d.) of means for main plot – variety (d.f. = 6) = 1.82 and s.e.d. of means for subplot treatments (d.f. = 16) = 1.47. S.e.d. for comparing between individual varieties x leachate treatments = 2.95 (d.f. = 16).

Final cane measurement

The experiment was stopped 10 weeks after the start of irrigation with leachates (on 23 March 2006). There were significant differences ($P < 0.01$) in total dewlap heights between the cane varieties (main plots). For the leachate treatments, a significant difference in the dewlap height of all shoots (primary + tillers) for variety M 695/69 was noted with leachates of *P. paniculatum*. This difference was also observed in the means of all four varieties (Table 6.4). *Paspalum urvillei* did not cause a significant decrease in shoot height.

Table 6.4 Effect of leachates on total dewlap height (primary shoots + tillers) 10 weeks after start of leachate application in Trial I

Variety	Mean dewlap height (cm bucket^{-1})			
	Distilled water	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	139.7 a	115.0 a	113.3 a	*122.7*
R 570	129.0 a	94.7 a	113.0 a	*112.2*
R 579	177.3 a	118.7 a	155.3 a	*150.4*
M 695/69	340.3 a	227.0 b	270.7 ab	*279.3*
Mean (leachates)	*196.6 a*	*138.8 b*	*163.1 ab*	

Values are means of three replications. Standard error of difference (s.e.d.) of means for variety (d.f.=6) = 19.44 and s.e.d. of means for leachate (d.f. = 16) = 21.33. S.e.d. for comparing between individual varieties x leachate treatments= 42.67 (d.f.=16). Mean values in the same row not sharing the same lower-case letter are significantly different at $P < 0.05$ (LSD test).

However, measurements of the individual primary shoot (two per bucket) showed a highly significant ($P< 0.01$) difference between both the leachate treatments and the control (Table 6.5). The decrease in mean dewlap height with leachates from *P. paniculatum* was highly significant ($P< 0.01$) while that from *P. urvillei* was significant at $P< 0.05$. Irrespective of the data set analysed, the difference in dewlap heights between the four varieties was highly significant, and no interaction between the main-plot factors (variety) and the sub-plot treatments (leachates) was recorded. However, the response of the leachates was mainly due to that observed on cane variety M 695/69.

Table 6.5 Effect of leachates on mean shoot dewlap height of primary shoots 10 weeks after start of leachate application in Trial I

Variety	Mean dewlap height (cm shoot^{-1})			
	Distilled water	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	55.2 a	39.8 a	44.2 a	*46.4*
R 570	64.5 a	41.0 a	47.7 a	*51.1*
R 579	65.2 a	52.2 a	49.7 a	*55.7*
M 695/69	125.0 a	73.2 b	89.2 b	*95.8*
Mean (leachates)	*77.5 a*	*51.5 b***	*57.7 b**	

Values are means of three replications. Standard error of difference (s.e.d.) of means for main plot – variety (d.f.=6) = 5.23 and s.e.d of means for subplot treatments – leachate (d.f. = 16) = 6.0. S.e.d. for comparing between individual varieties x leachate treatments= 12.0 (d.f.=16). Mean values in the same row not sharing the same lower-case letter are significantly different at $P < 0.05$ (LSD test). Treatment significant at * $P < 0.05$ and ** $P < 0.01$.

6.3.1.2 Effect of leachates on cane biomass

Total aboveground biomass

The dry weights of the 'aboveground' biomass of each treatment are shown in Table 6.6. Irrespective of cane variety, leachates from both weed species caused a reduction in aboveground biomass compared to cane shoots receiving distilled water; the decrease was more pronounced with leachates from *P. paniculatum*. Cane variety M 695/69 did not show any sensitivity to leachates from the *P. urvillei*.

Table 6.6 Effect of leachates on total aboveground biomass (dry wt) in Trial I

Variety	Total biomass (g)			
	Distilled water	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	99.2 a	67.9 b	73.3 b	*80.1*
R 570	102.5 a	64.1 c	80.3 b	*82.3*
R 579	105.5 a	65.3 b	76.1 b	*82.3*
M 695/69	104.3 a	77.7 b	96.2 a	*92.7*
Mean (leachates)	*102.9 a*	*68.8 c*	*81.4 b*	

Values are means of three replications. Standard error of difference (s.e.d.) of means for main plot – variety (d.f.=6) = 6.48 and s.e.d. of means for subplot treatments - leachate (d.f. = 16) = 3.81. S.e.d. for comparing between individual varieties x leachate treatments= 7.63 (d.f.=16). Mean values in the same row not sharing the same lower-case letter are significantly different at $P < 0.05$ (LSD test).

6.3.1.3 Effect of leachates on root development

Root biomass

The root biomass was easily removed and washed from the filling mixture used. The effect of the leachates on development of cane roots was visible, particularly for those being receiving leachates from *P. paniculatum* (Fig. 6.3).

Dry weight of roots

The dry weight analysis of root biomass showed that leachates from *P. paniculatum* had an adverse effect on root formation of sugar cane (main-plot - mean of four varieties) (Table 6.7). Among the four varieties, leachates applied to M 3036/66 and M 695/69 caused a significant reduction. Irrespective of leachates/distilled water treatment, R 579 had a higher biomass of roots compared to the other three varieties.

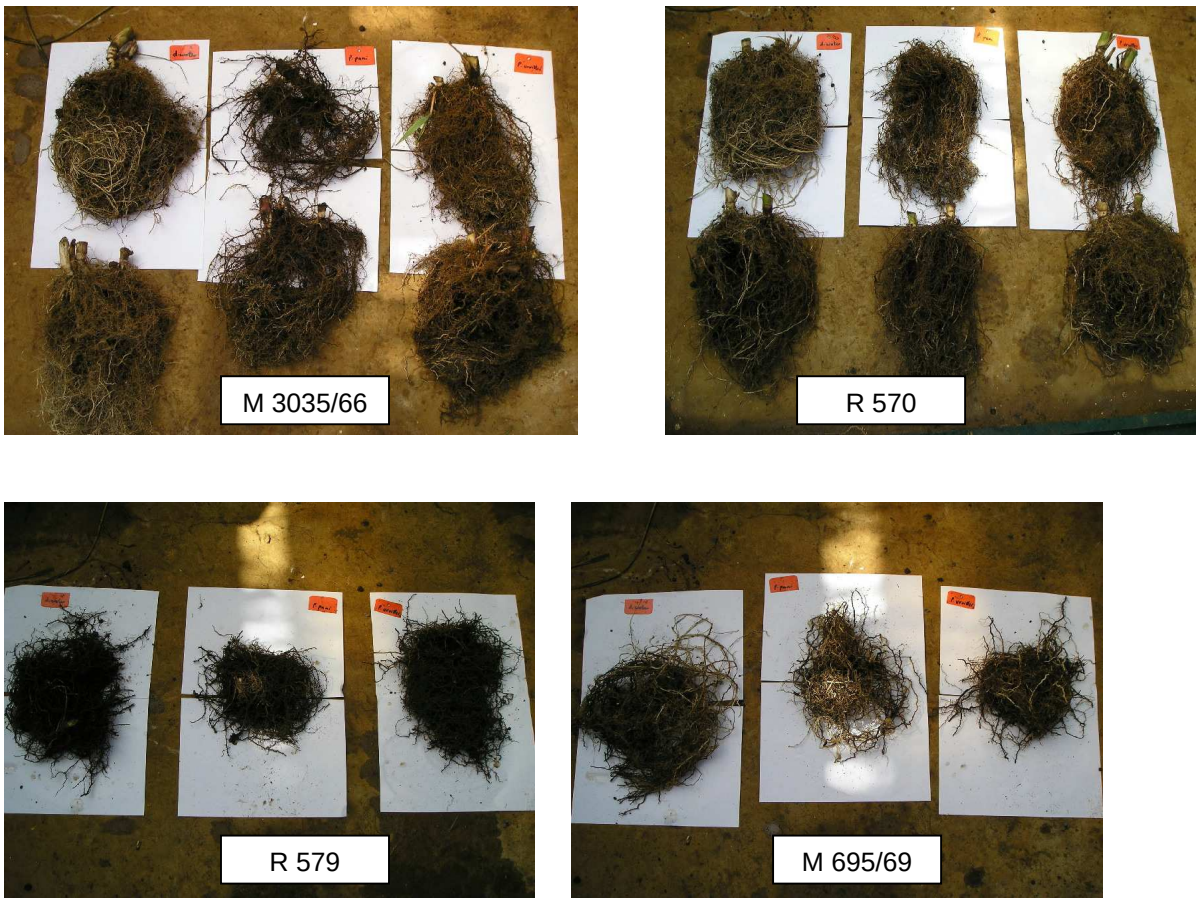


Fig. 6.3 Effect of leachates from *Paspalum species* on root biomass of sugar cane. For each variety, roots on left are from distilled water, in centre for *P. paniculatum* and right for *P. urvillei.* (For M 3035/66 and R 570, roots from two repetitions (top & bottom) are shown)

Table 6.7 Effect of leachates from *P. paniculatum* and *P. urvillei* on root biomass (dry wt) of sugar cane in Trial I

Variety	Total root biomass (g bucket^{-1})			
	Distilled water	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	12.8 a	6.8 b	11.2 ab	*10.3*
R 570	12.1 a	8.6 a	10.4 a	*10.3*
R 579	14.8 a	12.9 a	15.3 a	*14.3*
M 695/69	12.3 a	7.2 b	11.7 a	*10.4*
Mean (leachates)	*13.0 a*	*8.9 b*	*12.2 a*	

Values are means of three replications. Standard error of difference (s.e.d.) of means for main plot – variety (d.f.=6) = 1.57 and s.e.d. of means for subplot treatments - leachate (d.f. = 16) = 1.05. S.e.d. for comparing between individual varieties x leachate treatments= 2.09 (d.f.=16). Mean values in the same row not sharing the same lower-case letter are significantly different at $P < 0.05$ (LSD test).

6.3.2 Trial II

6.3.2.1 Effect of leachates on shoot elongation and cane growth

Pre-treatment cane measurement

The first cane measurement made on 5 May 2006 showed a slightly lower germination and initial development of variety R 579 compared to the others but showed no difference between treatments (leachates v/s control) for the same level of variety (Table 6.8). The latter confirmed that all shoot heights were similar before start of irrigation with leachates.

Table 6.8 Mean dewlap height at start of experimentation (before irrigating with leachates) in Trial II

Cane variety	Mean dewlap height (cm shoot^{-1})			
	Control	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	13.2	11.2	15.0	*13.1*
R 570	11.7	13.2	11.7	*12.2*
R 579	8.3	7.7	8.7	*8.2*
M 695/69	11.5	11.3	10.3	*11.1*
Mean (leachates)	*11.2*	*10.8*	*11.4*	

Values are means of three replications. Standard error of difference (s.e.d.) of means for main plot - variety (d.f.= 6) = 0.78 and s.e.d. of means for subplot treatments - leachate (d.f.= 16) = 0.72. S.e.d. for comparing between individual varieties x leachate treatments= 1.44 (d.f.= 16).

Cane elongation

Dewlap height measurements over a 20 weeks period showed that stalk elongation varied for each variety, but were in general relatively slow, particularly as from end of June. Variety M 3035/66 grew 5 cm during the first month but slowed down almost completely later on (Fig 6.4) and no difference between the respective treatments was observed.

The elongation rate for variety R 570 was relatively higher during the first six weeks after start where a 15 cm increase was recorded (Fig. 6.4). The rate of growth slowed down later and no difference between the various treatments was recorded.

The early growth of variety R 579 was similar to R 570 but had a slightly higher rate of growth as from the end of August for the 'control' and *P. urvillei* treatments (Fig. 6.4). Cane shoots irrigated with water collected from the *P. paniculatum* containers seemed to reduce stalk elongation.

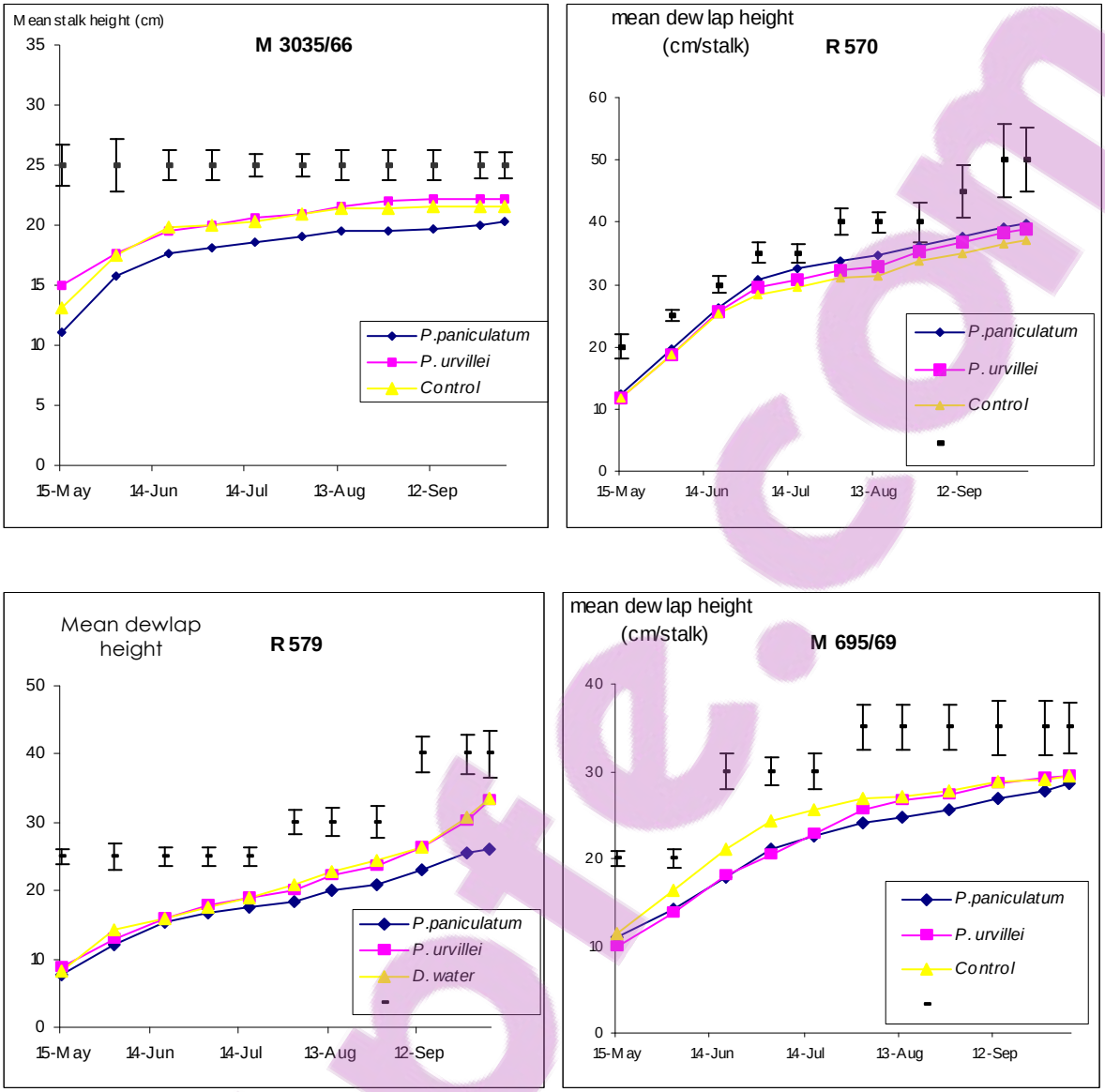


Fig 6.4 Effect of leachates from *P. paniculatum* and *P. urvillei* on stalk elongation of variety M 3035/66 (top left), R 570 (top right), R 579 (bottom left) and M 695/69 (bottom right) in Trial II. The vertical error bars indicate 2 x s.e.d. at each observation date.

The stalk elongation for variety M 695/69 was also slowed down as from the month of August and no difference between the three treatments was observed for each date of measurement (Fig 6. 4).

Final cane measurement

The experiment was stopped 20 weeks after start of irrigation with leachates (on 6 October 2006). Cane measurements showed a mean increase in dewlap height of shoots of 10 cm, 26 cm, 18 cm and 18 cm for varieties M 3035/66, R 570, R 579 and M 695/69 respectively. The final dewlap height for variety R 570 was significantly higher than R 579 and M 695/69, which were themselves higher than

M 3035/66. The final dewlap measurement also revealed that there was no significant difference among the treatments (means of four varieties). However, a decrease in the dewlap height was confirmed for variety R 579, the mean dewlap height of shoots receiving leachates from *P. paniculatum* was significantly reduced (Table 6.9).

Table 6.9 Effect of leachates on final mean dewlap height (primary shoots) 20 weeks after start of leachates application in Trial II

Variety	Mean dewlap height (cm shoot^{-1})			
	Control	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	21.5 a	20.3 a	22.2 a	*21.3*
R 570	37.2 a	39.8 a	38.8 a	*38.6*
R 579	33.3 a	26.2 b	33.3 a	*30.9*
M 695/69	29.5 a	28.5 a	29.5 a	*29.2*
Mean (leachates)	*30.4 a*	*28.7 a*	*31.0 a*	

Values are means of three replications. Standard error of difference (s.e.d.) of means for main plot – variety (d.f.=6) = 2.06 and s.e.d. of means for subplot treatments (d.f. = 16) = 1.65. S.e.d. for comparing between individual varieties x leachate treatments= 3.31 (d.f.=16). Mean values in the same row not sharing the same lower-case letter are significantly different at $P < 0.05$ (LSD test).

6.3.2.2 Effect of leachates on shoot biomass

Dry weight of stalks and leaves

The dry weight of cane stalks for variety R 570 were found to be higher than for R 579 and M 3035/66. No difference in weight of stalks was found between treatments for the same variety (Table 6.10). The higher dewlap heights for R 579 with the control and leachates from *P. urvillei* did not result in higher biomass of stalk compared to those receiving leachates from *P. paniculatum* though the difference approached significance.

For each variety, the total aboveground biomass (stalk + leaves) was also found to be similar for all treatments (Table 6.10).

Table 6.10 Effect of leachates on aboveground biomass (dry weight) 20 weeks after start of application in Trial II

Variety	Mean dry weight (g bucket^{-1})							
	Control		*P. paniculatum*		*P. urvillei*		*Mean*	
	Stalk	stk+lvs	Stalk	stk+lvs	Stalk	stk+lvs	*Stalk*	*stk+lvs*
M 3035/66	5.5	17.1	9.5	19.1	3.7	11.5	*6.2*	*15.9*
R 570	29.6	70.7	27.2	71.2	29.9	68.6	*28.9*	*70.2*
R 579	12.3	30.6	8.8	28.3	13.7	35.6	*11.6*	*70.2*
M 695/69	12.8	28.6	14.1	28.6	12.2	26.7	*13.1*	*28.0*
Mean (leachates)	*15.1*	*36.7*	*14.9*	*36.8*	*14.9*	*35.6*		

Stk+lvs = stalk + leaves. Values are means of three replications. For stalk dry weight, standard error of difference (s.e.d.) of means for main plot – variety (d.f.= 6) = 6.54; s.e.d. of means for subplot treatments (d.f.=16) = 1.60 and s.e.d. for comparing between individual varieties x leachate treatments= 3.21 (d.f.=16). For total aboveground biomass, s.e.d. of means for main plot – variety (d.f.= 6) = 12.88, s.e.d. of means for subplot treatments (d.f.= 16) = 2.54 and s.e.d. for comparing between individual varieties x leachate treatments= 5.08 (d.f.=16).

6.3.2.3 Effect of leachates on root development

The dry weight analysis showed no difference in root biomass between the various treatments; i.e. leachates from the two weed species had no effect of root biomass (Table 6.11). The difference between the main-plot factor (variety) was significant; variety R 570 which produced higher aboveground biomass also had more roots.

Table 6.11 Effect of leachates from *P. paniculatum* and *P. urvillei* on root biomass (dry wt) of sugar cane in Trial II

Variety	Mean dry weight (g bucket^{-1})			
	Control	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	4.3	3.7	2.3	*3.4*
R 570	38.8	38.0	47.4	*41.4*
R 579	15.9	12.4	15.1	*14.5*
M 695/69	5.1	3.5	6.0	*4.9*
Mean (leachates)	*16.1*	*14.4*	*17.7*	

Values are means of three replications. Standard error of difference (s.e.d.) of means for main plot – variety (d.f.=6) = 1.94 and s.e.d. of means for subplot treatments (d.f. = 16) = 2.49. S.e.d. for comparing between individual varieties x leachate treatments= 4.97 (d.f.=16).

6.3.3 Trial III

6.3.3.1 Effect of leachates on shoot elongation and cane growth

Pre-treatment cane measurement

The first cane measurement made on 24 November 2006 showed a slightly lower germination and initial development with varieties R 579 and M 695/69 compared to the others but no difference between treatments (leachates v/s control) was obtained for the same level of variety (Table 6.12). The data confirmed that all shoot heights were similar before start of irrigation with leachates.

Table 6.12 Mean dewlap height at start of experimentation (before applying leachates) in Trial III

Cane variety	Mean dewlap height (cm shoot^{-1})			
	Control	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	14.7	9.7	16.7	*13.7*
R 570	10.3	9.7	10.3	*10.1*
R 579	5.7	7.7	7.3	*6.9*
M 695/69	8.3	7.7	7.2	*7.7*
Mean (leachates)	*9.8*	*8.7*	*10.4*	

Values are means of three replications. Standard error of difference (s.e.d.) of means for main plot – variety (d.f.=6) = 0.96 and s.e.d. of means for subplot treatments (d.f. = 16) = 1.19. S.e.d. for comparing between individual varieties x leachate treatments= 2.38 (d.f.=16).

Cane elongation

Dewlap height measurements made over a 12 weeks period showed that stalk elongation was quite satisfactory; each stalk gained an average of 70 cm over that period. The elongation was quite similar for all varieties, irrespective of the treatments, for the first four to six weeks before some differences started to occur. For variety M 3035/66, stalk elongation for the three treatments were similar till the first weeks of January 2007 when a slowing down in the *P. urvillei* treatment was observed (Fig. 6.5). Similarly, a more rapid growth was recorded in the control treatment compared to *P. paniculatum*; the difference was, however, not significant.

Stalk elongation of variety R 570 was similar for the three treatments for the first seven weeks (Fig. 6.5). After that, the cane shoots receiving leachate from containers with no *Paspalum* plants (control) elongated at a higher rate than the two treatments receiving leachates from the weeds.

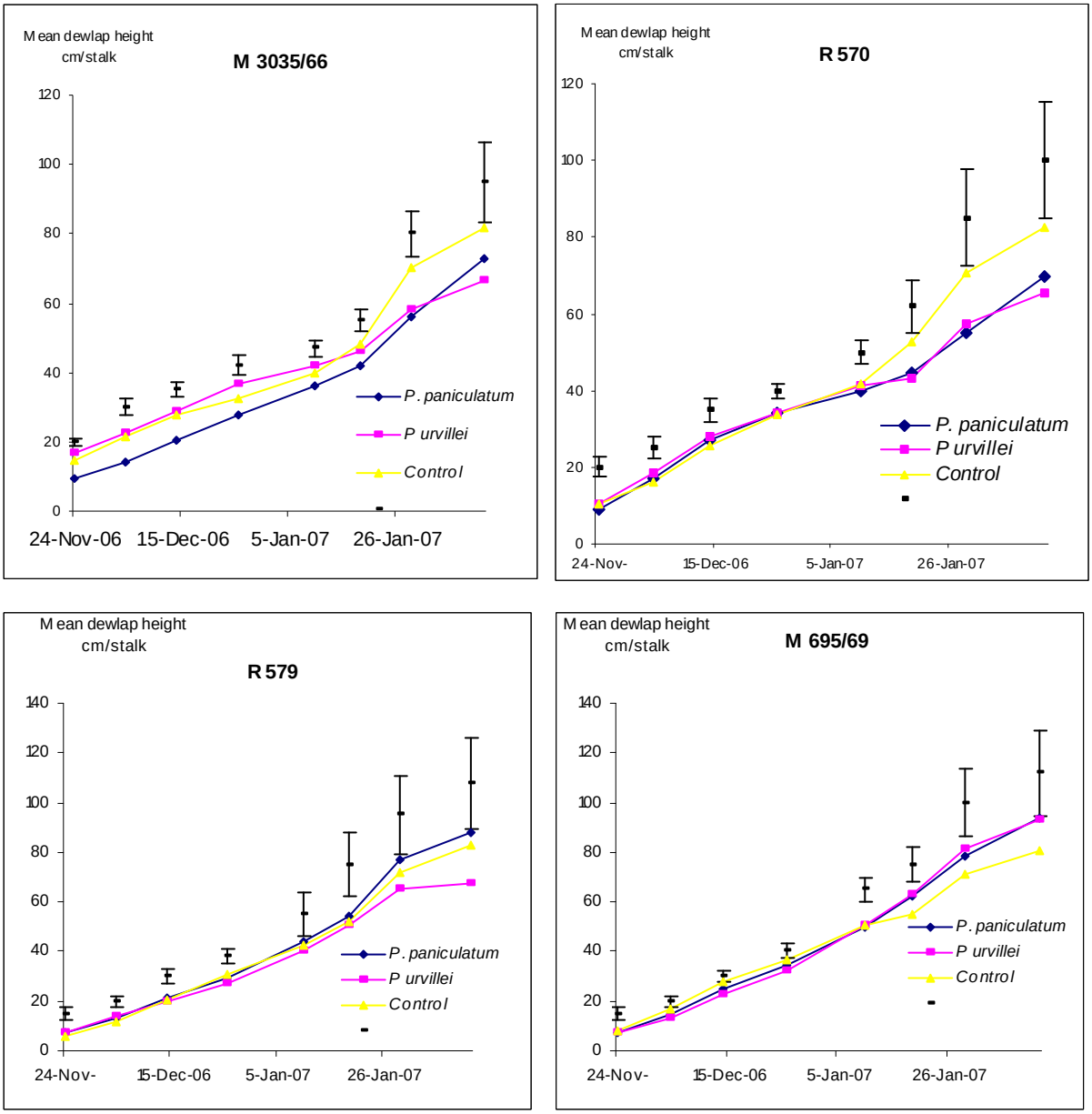


Fig 6.5 Effect of leachates from *P. paniculatum* and *P. urvillei* on stalk elongation of variety M 3035/66 (top left), R 570 (top right), R 579 (bottom left) and M 695/69 (bottom right) in Trial III. The vertical error bars indicate 2 x s.e.d. at each observation date.

Cane shoots in the three subplot treatments with variety R 579 elongated at the same rate for the initial five weeks (Fig. 6.5). It seemed that leachates from *P. urvillei* caused a reduction in the elongation rate of R 579 as from the third week of January 2007. No significant difference was, however, noted.

Variety M 695/69 did not seem to be affected by the leachates treatments (Fig. 6.5).

Final cane measurement

As some of the cane shoots had reached more than 80 cm in dewlap height, the experiment was stopped 12 weeks after start of leachates application. Cane measurements showed the mean dewlap height of M 695/69 to be slightly higher than the other varieties, the difference, however, was not significant. Compared to the control, a tendency for *P. urvillei* causing a reduction in dewlap heights of all the varieties was observed; the differences were, however, not significant.

6.3.3.2 Effect of leachates on shoot biomass

Dry weight of stalks and leaves

The aboveground biomass (dry weight) of cane shoots was found to vary with variety; R 570 producing higher biomass and M 695/69 the least (Table 6.13). Irrespective of cane variety, the effect of leachates on mean (main-plot means) aboveground biomass was significant, *P. urvillei* caused a reduction in shoot development. *Paspalum urvillei* adversely affected shoot development of varieties M 3035/66 and R 570. Leachates from *P. paniculatum* caused no adverse effect on weight of aboveground biomass, thus confirming effect on dewlap height.

Table 6.13 Effect of leachates on aboveground biomass (dry weight) 12 weeks after start of application in Trial III

Variety	Mean dry weight (g bucket^{-1})			
	Control	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	83.0 a	71.4 ab	52.8 b	*69.1*
R 570	100.4 a	101.6 a	81.1 b	*94.4*
R 579	83.1 a	83.2 a	67.2 a	*77.8*
M 695/69	51.3 a	66.7 a	49.4 a	*55.8*
Mean (leachates)	*79.5 a*	*80.7 a*	*62.6 b*	

Values are means of three replications. For stalk dry weight, standard error of difference (s.e.d.) of means for main plot – variety (d.f.= 6)= 3.35 and s.e.d. of means for subplot treatments (d.f.= 16)= 4.54. S.e.d. for comparing between individual varieties x leachate treatments= 9.08 (d.f.= 16). Mean values in the same row not sharing the same lower-case letter are significantly different at $P < 0.05$ (LSD test).

6.3.3.3 Effect of leachates on root development

A significant reduction in root biomass between the control and the two leachates treatments was obtained for the main-plot treatments (four varieties). Significant effects on individual cultivars were

less evident, though the data showed similar trends for all cultivars. Leachates from *P. urvillei* were found to cause a significant reduction only in variety M 695/69 (Table 6.14).

Table 6.14 Effect of leachates on root biomass (dry weight) 12 weeks after start in Trial III

Variety	Mean dry weight (g bucket^{-1})			
	Control	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	17.1 a	14.8 a	14.5 a	*15.4*
R 570	18.8 a	18.3 a	20.9 a	*19.4*
R 579	15.7 a	13.1 a	13.5 a	*14.1*
M 695/69	12.9 a	10.6 a	8.2 b	*10.5*
Mean (leachates)	*16.1 a*	*14.2 b*	*14.3 b*	

Values are means of three replications. For stalk dry weight, standard error of difference (s.e.d.) of means for main plot – variety (d.f.= 6)= 0.48 and s.e.d. of means for subplot treatments (d.f.= 16)= 0.83. S.e.d. for comparing between individual varieties x leachate treatments= 1.67 (d.f.=16). Mean values in the same row not sharing the same lower-case letter are significantly different at $P < 0.05$ (LSD test).

6.3.4 Trial IV

6.3.4.1 Effect of leachates on shoot elongation and cane growth

Pre-treatment cane measurement

The first cane measurement made on 6 March 2007 showed a lower germination and initial development with variety R 579 (Table 6.15). No difference between treatments (leachates v/s control) was obtained for the same level of variety, thus confirming that all shoot heights were similar before start of irrigation with leachates.

Table 6.15 Mean dewlap height at start of experimentation (before applying leachates) in Trial IV

Cane variety	Mean dewlap height (cm shoot^{-1})			
	Control	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	11.8	11.3	10.8	*11.3*
R 570	11.3	10.7	12.0	*11.3*
R 579	8.7	8.0	8.2	*8.3*
M 695/69	11.8	11.0	10.7	*11.2*
Mean (leachates)	*10.9*	*10.3*	*10.4*	

Values are means of three replications. Standard error of difference (s.e.d.) of means for main plot – variety (d.f.=6) = 0.73 and s.e.d. of means for subplot treatments (d.f. = 16) = 0.80. S.e.d. for comparing between individual varieties x leachate treatments= 1.60 (d.f.=16).

Cane elongation

Dewlap height measurements made over a 17 weeks period showed that stalk elongation was quite steady; stalk elongation gained between 55 and 70 cm over that period. Variety R 579 had the highest gain in dewlap and M 3035/66 the least. The elongation was quite similar for all varieties, irrespective of the treatments, during the first six weeks before some differences started to occur as from the end of April 2007.

For variety M 3035/66, stalk elongation for the three treatments were similar till the end of April 2007. As from early May, the rate of elongation recorded in the *P. urvillei* treatment was slower than the other two treatments, the gap increasing with time (Fig. 6.6). No difference in rate of elongation was noted between the *P. paniculatum* treatment and the control.

For R 570, a similar tendency as for M 3035/66 was observed but this time, the rate of elongation of both leachates treatments was lower than the control (Fig 6.6). The effect of the leachates seemed to increase with time.

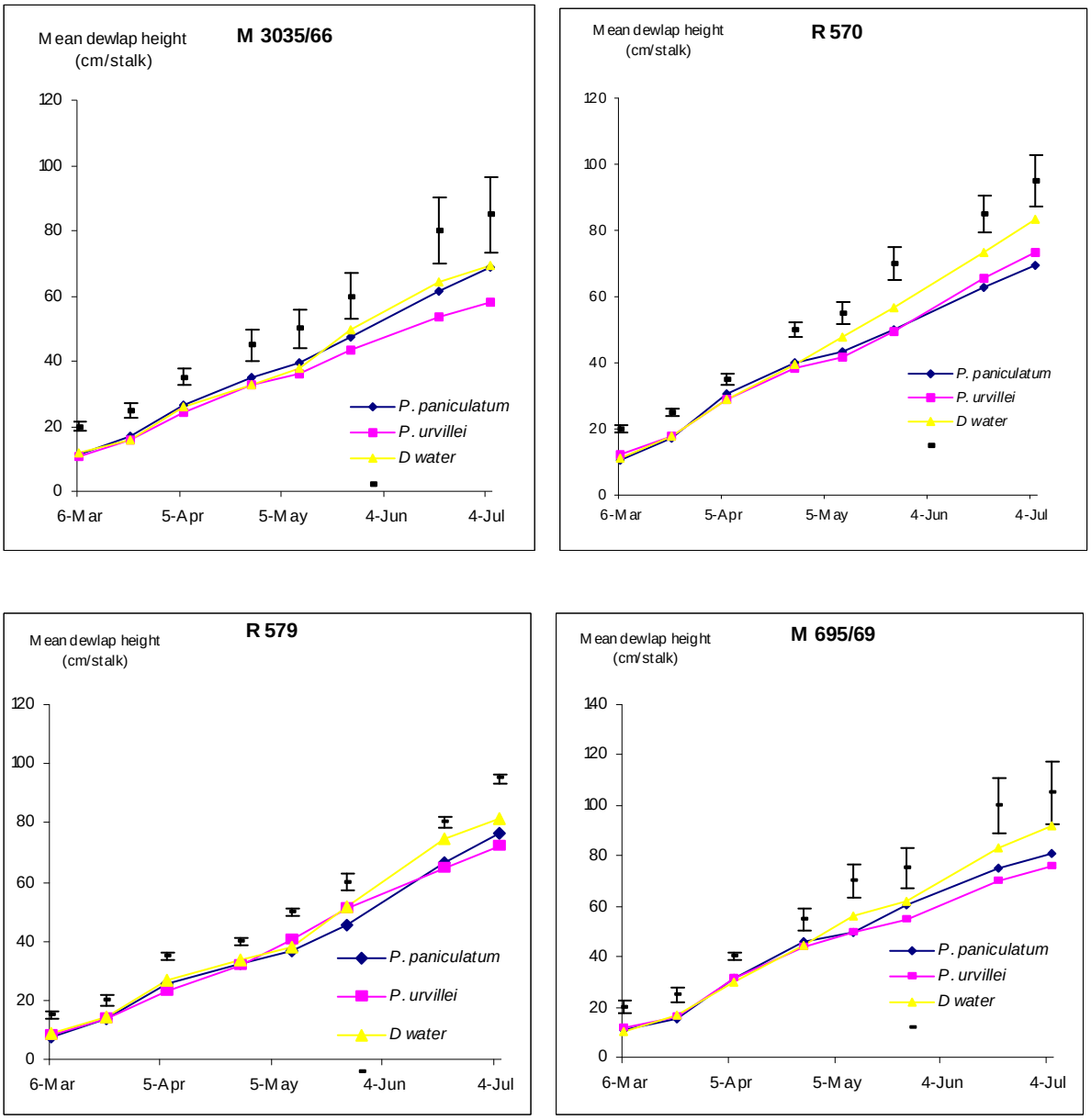


Fig 6.6 Effect of leachates from *P. paniculatum* and *P. urvillei* on stalk elongation of cane variety M 3035/66 (top left), R 570 (top right), R 579 (bottom left) and M 695/69 (bottom right) in Trial IV. The vertical error bars indicate 2 x s.e.d. at each observation date.

The difference between the control and the *P. urvillei* treatment was observed later in variety R 579 (Fig. 6.6); the gap was more visible during the last two measurements. *Paspalum paniculatum* did not seem to reduce elongation rate of this variety.

Variety M 695/69 behaved similarly to R 570 and the mean dewlap height with the control seemed to increase faster than those treated with leachates from the two grasses at the later observation dates (Fig. 6.6).

Final cane measurement

The experiment was stopped 17 weeks after start of leachates application as cane was relatively tall in the buckets. Cane measurements showed the mean dewlap height of M 695/69 to be significantly higher than M 3035/66 but they were not different to R 570 and R 579. Leachates from *P. urvillei* caused a reduction in the mean dewlap height of cane shoots of main-plot treatments (varieties) though no significant effects were recorded for the individual varieties (Table 6.16). *Paspalum paniculatum* also appeared to cause a reduction compared to the control but the difference was not significant.

Table 6.16 Effect of leachates on final mean dewlap height (primary shoots) 17 weeks after start of application of treatments in Trial IV

Variety	Mean dewlap height (cm shoot^{-1})			
	Control	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	69.5	68.5	56.5	*64.8*
R 570	83.3	68.0	73.2	*74.8*
R 579	80.5	75.8	72.2	*76.2*
M 695/69	91.2	83.2	79.7	*84.7*
Mean (leachates)	*81.1 a*	*73.9 a*	*70.4 b*	

Values are means of three replications. Standard error of difference (s.e.d.) of means for main plot – variety (d.f.=6) = 5.21 and s.e.d. of means for subplot treatments (d.f. = 16) = 4.61. S.e.d. for comparing between individual varieties x leachate treatments = 9.22 (d.f.=16). Mean values in the same row not sharing the same lower-case letter are significantly different at $P < 0.05$ (LSD test).

6.3.4.2 Effect of leachates on shoot biomass

Aboveground biomass

The total biomass of leaves and stalks were reduced by the *P. urvillei* treatment (mean of main-plot treatments) (Table 6.17). For individual varieties, the response was again not significant as for the total dewlap and weight of leaves.

Table 6.17 Effect of leachates on aboveground biomass (dry weight) 17 weeks after start of application in Trial IV

Variety	Mean dry weight (g bucket^{-1})			
	Control	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	137.6	124.5	109.7	*123.9*
R 570	139.7	129.0	128.9	*132.6*
R 579	124.2	131.0	117.0	*124.0*
M 695/69	114.9	90.9	91.4	*99.0*
Mean (leachates)	*129.1 a*	*118.8 a*	*111.7 b*	

Values are means of three replications. Standard error of difference (s.e.d.) of means for main plot – variety (d.f.=6) = 6.20 and s.e.d. of means for subplot treatments (d.f. = 16) = 7.49. S.e.d. for comparing between individual varieties x leachate treatments = 14.99 (d.f.=16). Mean values of four varieties not sharing the same lower-case letter are significantly different at $P < 0.05$ (LSD test).

6.3.4.3 Effect of leachates on root development

As seen in earlier trials, M 695/69 produced less roots irrespective of treatments. For the main-plot treatments, a reduction in root biomass was observed between the control and treatments consisting of leachates from *P. paniculatum*; the latter was not different from *P. urvillei* (Table 6.18).

Table 6.18 Effect of leachates on root biomass (dry weight) 17 weeks after start in Trial IV

Variety	Mean dry weight (g bucket^{-1})			
	Control	*P. paniculatum*	*P. urvillei*	*Mean (varieties)*
M 3035/66	33.4	29.4	33.2	*32.0*
R 570	50.6	41.4	40.5	*44.1*
R 579	28.7	17.6	20.9	*22.4*
M 695/69	19.3	12.3	17.8	*16.5*
Mean (leachates)	*33.0 a*	*25.2 b*	*28.1 ab*	

Values are means of three replications. Standard error of difference (s.e.d.) of means for main plot (variety) = 3.53 (d.f.= 6) and s.e.d. of means for subplot treatments= 2.89 (d.f.= 16). S.e.d. for comparing between individual varieties x leachate treatments= 5.78 (d.f.=16). For mean of four varieties, values not sharing the same lower-case letter are significantly different at $P < 0.05$ (LSD test).

6.3.5 Chemical analysis of leachates from *P. paniculatum* and *P. urvillei*

6.3.5.1 Presence of BOA (2-benzoxazolinone)

The samples analysed did not show any presence of BOA in the leachate samples collected. Although BOA often exists or is converted to other derivatives such as DIBOA, MBOA, etc, any trace of BOA should have been detected by the analysis. These preliminary analyses therefore excluded detectable levels of BOA in leachates from the two *Paspalum* species.

6.3.5.2 Chemical composition of leachates from *P. paniculatum* and *P. urvillei*

The GC-MSD revealed the presence of 2-Propenoic acid, 3-(4-methoxyphenyl)- (CAS number: 5466-77-3) in leachates from both weeds but not from the control treatment. The retention time was 26.94/26.95 minutes. 2-Propenoic acids form part of the family commonly known as cinnamic acids which include cinnamic acid (2-propenoic acid, 3-phenyl), ferulic acid (2-propenoic acid, 3-(4-hydrxy-3-methoxyphenyl)-), p-coumaric acid (2-propenoic acid, 3-(4-hydroxyphenyl)-), isoferulic acid (2-propenoic acid, 3-(3-hydroxy-4-methoxyphenyl)-) and caffeic acid (2-propenoic acid, 3-(3,4-dihydroxyphenyl)-). All these compounds are known to have allelopathic properties (Fernandez *et al*., 2006). P-Coumaric acid, in particular, has been proven to cause a significant effect on the growth of roots and aboveground organs of *Linum usitatissimum* (Ray & Hastings, 1992).

The chromatograph area (%) covered by the 2-propenoic acid, 3-(4-methoxyphenyl) was three to four times higher in the *P. paniculatum* samples than in leachates from *P. urvillei* (Appendix 1). This may suggest that *P. paniculatum* produced more of that allelopathic chemical, but this needs to be studied further as the amount of chemicals released from the roots would vary with time and several other factors. However, the presence of this chemical in the two *Paspalums* confirms the potential interference from allelopathic substances released by weeds over and above the other mechanisms of competition between sugar cane and weeds.

6.4 Discussion and conclusions

Stalk elongation and cane growth

This study has shown that leachates from both *Paspalum* species can cause an adverse effect on cane growth. Irrespective of varieties (mean of main-plot treatments), leachates from *P. urvillei* caused a significant reduction in mean dewlap of primary shoots in three trials (Trial I, III and IV). A significant reduction was obtained by leachates of *P. paniculatum* in Trial I where the effect was more pronounced to that of *P. urvillei*. No difference between the three treatments was observed in Trial II where cane growth was much slower than the other trials; this may be attributed to the lower mean temperatures which prevailed during the respective trials (Table 6.19).

Table 6.19 Effect of temperature on rate of cane stalk elongation

Trial	Mean daily temperatures (°C)		Rate of stalk elongation
	Max.	Min.	cm/week
Trial I	28.4	21.0	6.7
Trial II	23.9	15.3	1.0
Trial III	28.7	20.6	6.0
Trial IV	26.0	18.2	4.2

The lower cane growth in Trial II resulted in maximum dewlap heights not exceeding 35 cm per shoot except for variety R 570. A reduction in stalk elongation with *P. paniculatum* leachates on R 579 was also recorded in this trial.

Cane growth and initiation of allelopathic effect

Cane measurements showed that the difference between the control and the 'leachate' treatments was not apparent during the early weeks after start of experimentation. The difference was in general visible after the cane shoots had reached a mean dewlap height of 40 cm or more. This may also explain why no difference was noted in Trial II. In general, the differences between the control and the leachate treatments increased with time; it is possible that more significant differences would have been observed if the trials were prolonged for a few weeks more. Increasing growth-inhibiting or

phytotoxic effects from the weeds on sugar cane with time could have been due to increased allelochemical release from weed roots as the plants matured.

Variety response to leachate treatments

There was no interaction between variety and treatments; all varieties showed susceptibility to the leachates. The order of susceptibility of the cane varieties to leachates differed from their known relative tolerances towards herbicides or herbicide mixtures. M 3035/66 is known to be a more resistant variety towards herbicides than M 695/69 and R 579, with R 570 classified as a susceptible variety. As the leachates were applied as irrigation water underneath the leaves (not applied on cane leaves), it means that water and allelochemical uptake were solely by the roots. Variability in the tolerance of sugar cane varieties to herbicides is mostly associated with foliar-applied herbicides.

Effect of leachates on root biomass

The leachates from both weed species were found to have a growth-inhibiting effect on root development in all the trials except in Trial II where a slight (non-significant) reduction was caused by *P. paniculatum* leachate on roots of varieties M 3035/66 and M 695/69. The difference in root biomass observed in Trials I and III seems to explain the difference caused by the leachates; a correlation between reduction in root biomass and effect on dewlap height indicated that the primary effect of the allelochemicals was on root development. An adverse effect on root development also impacted negatively on aboveground biomass development, although M 695/69 with the least root biomass produced the tallest stalks (dewlap height).

P. paniculatum vs *P. urvillei*

On basis of results from the four trials, *P. urvillei* was found to cause more allelopathic (phytotoxic) effects than *P. paniculatum*, although the reverse occurred in Trial I. Although both weeds were transplanted at the same initial density, growth of *P. urvillei* was more vigorous and it produced more leaves and biomass; suggesting that more root exudates may have been released. Both weeds had a quick and similar development in Trial I and this may have influenced the allelochemical production of *P. paniculatum* to the extent that the latter species seemed to cause more reduction in root biomass than *P. urvillei* in that trial. The implication of this finding is that, on a unit mass basis, *P. paniculatum* may be more allelopathic than *P. urvillei*.

The effect on root growth may have been due to the presence of 2-propenoic acid, 3-(4-methoxyphenyl) found in root exudates from both weeds. Cinnamic acids are known for their allelopathic properties, in particular for impairing root development (Rice, 1984; Fernandez *et al*., 2006). The presence of a higher concentration of 2-propenoic acid in *P. paniculatum* leachates may partly explain the greater reduction in root biomass of sugar cane that was observed at this treatment. These results confirm the allelopathic potential of weeds on sugar cane; the effect of leachates from *Cyperus rotundus* has been reported by Mc Intyre (1998). However, the results presented in this study are only preliminary ones as there may be other allelochemicals involved and the exact effects of cinnamic acids need to be confirmed by simulating effects using pure chemicals. With the same approach, dose-response curves may be used to estimate the minimum concentrations required for any effect on cane. Allelopathic effects also need to be verified under natural conditions.

Although this study proved some interference due to allelopathic effects from the two *Paspalums* on sugar cane, the results cannot completely explain the higher interference (competitiveness) reported earlier for *P. paniculatum,* as both weeds seemed to cause similar allelopathic effects. Their relative rates of development and competitiveness under field conditions need to be studied more closely together with the identification and quantification of the major allelochemicals involved as well as their effects on sugar cane. Further studies are also required to ascertain whether allelochemical production in the live weeds and their release from live plants or from decomposing plant material is governed by growth stage, plant part (leaves or roots), or by stage of decomposition of residual plant material.

CHAPTER 7

A NEW HERBICIDE TANK-MIX OF TRIFLOXYSULFURON + AMETRYN AND AMICARBAZONE TO PROVIDE A COST-EFFECTIVE BROAD-SPECTRUM PRE- AND POST-EMERGENCE TREATMENT FOR MANAGING WEEDS IN SUGAR CANE

7.1 Introduction

Traditionally, weed control in sugar cane in Mauritius was geared towards eradication of all weeds from planting or harvest up to complete canopy closure. In the humid and superhumid areas, canopy closure may take between 20 to 30 weeks; consequently, two or three herbicide applications had to be made, often complemented by manual weeding (MSIRI, 2004). The work presented in earlier Chapters have shown that it is possible to reduce costs of weed control by developing, new weed management strategies based on critical periods of weed competition. The research presented in Chapter 2 showed that critical periods varied between 6 and 27 weeks after planting or 12 and 26 weeks after harvest in the humid areas where cane growth is slower and weed infestations are higher (Chapter 2; Seeruttun & Lutman, 2004). The new strategies proposed included delaying of the first herbicide application to coincide with onset of the critical periods of weed competition. The success of such an approach would rely on the efficacy of the herbicide treatment in knocking down all emerged weeds present on the day of spraying and providing a relatively long residual activity against a broad spectrum of weeds.

A mixture of trifloxysulfuron 1.85% + ametryn 73.15% (Krismat® - WDG 75), developed by Syngenta Crop Protection AG has been tested in Brazil where all the key sugar cane weed species including the most economically important grass species such as *Brachiaria* spp., had been controlled (Howard *et al*., 2001). The efficacy of this mixture on many grass species including *Rottboellia cochinchinensis* (Lour.) Claiton and some broad-leaved weeds such as *Euphorbia heterophylla* L. has also been reported in Cuba (Diaz *et al*., 2004). At rates of 1.5 kg a.i. ha^{-1}, the new herbicide was well tolerated by sugar cane. Amicarbazone (triazolinone) (Dinamic® WDG 70), from Arysta LifeScience has also been reported to provide excellent control of many major annual dicotyledonous weeds and grasses in sugarcane (Philbrook *et al*., 1999).

The current standard herbicide treatments available in Mauritius have limited effectiveness on some grasses and sedges and are not fully effective if control is delayed until after early weed

emergence. A tank-mixture of trifloxysulfuron + ametryn and amicarbazone appeared from research elsewhere to have the potential to provide broad-spectrum pre- and post-emergence control. The new management strategies proposed would imply the application of early post-emergence treatments at timings which differ from the traditional approach where the selectivity of the herbicides was achieved by applying either pre-emergence of the cane, or when the latter had reached at least a growth stage of 12 to 14 weeks after planting. At 12 or 14 weeks, the crop better tolerates some of the herbicide treatments. According to the new strategies, herbicide treatments would be applied post-emergence of the crop (and weeds) and most probably at a stage of growth between four to eight weeks after planting when risks of herbicide phytotoxicity would be higher. Consequently, this set of experiments was done to assess the performance of these two new products and to investigate the feasibility of developing new weed control approaches based on the critical period research. The objectives of the trials were to:

1. Evaluate the pre-emergence potential of the two products and their tank-mixes against the weeds present in sugar cane in Mauritius, and to compare the length of residual activities obtained to that of other currently available herbicides.
2. Assess the potential and spectrum of control of the new herbicides and their tank-mixes applied post-emergence to weeds in both plant and ratoon cane.
3. Determine any phytotoxicity of the new products or tank-mixes on the crop when applied both pre- and post-emergence of cane.

7.2 Materials and methods

Trial characteristics and treatments

Eleven trials were conducted in plant and ratoon cane between March and December 2005. Details and characteristics of the trial sites are given in Table 7.1. In the first four trials, treatments were applied pre-emergence of plant cane and weeds. Amicarbazone at 0.7, 0.875, 1.05 and 1.4 kg a.i. ha^{-1}, trifloxysulfuron+ametryn at 0.0263 + 1.097 and 0.0315 + 1.317 kg a.i. ha^{-1}, and amicarbazone at 0.875 and 1.05 kg a.i. ha^{-1} tank-mixed with trifloxysulfuron + ametryn at 0.0263 + 1.097 kg a.i. ha^{-1} were compared to two standards, namely, oxyfluorfen + diuron (0.5 + 2.0 kg a.i. ha^{-1}) and tebuthiuron + atrazine (1.6 + 2.0 kg a.i. ha^{-1}). An untreated control was also included.

In the second series of four trials (Trials V - VIII), treatments were applied post-emergence at the same corresponding sites between 10 and 12 weeks after planting. Treatments comprised of amicarbazone at 0.875, 1.05, 1.25 and 1.4 kg a.i. ha^{-1}, trifloxysulfuron + ametryn at 0.0263 + 1.097 and 0.0315 + 1.317 and amicarbazone at 0.875 and 1.05 kg a.i. ha^{-1} tank-mixed with trifloxysulfuron + ametryn at 0.0263 + 1.097 kg a.i. ha^{-1}. A standard treatment consisting of the tank-mix tebuthiuron + atrazine + 2,4-D amine salt (1.3 + 2.0 + 2.0 kg a.i. ha^{-1}) and an untreated control were also included.

The last three trials (Trials IX, X and XI) were conducted in ratoon cane and post-emergence of the weeds. The rates of amicarbazone, trifloxysulfuron + ametryn and amicarbazone + trifloxysulfuron+ametryn were similar to those used post-emergence of plant cane, except that amicarbazone alone at 1.25 kg a.i. ha^{-1} was excluded. A tank-mix of hexazinone + atrazine + 2,4-D amine salt (0.6 + 2.0 + 2.0 kg a.i. ha^{-1}) was included as an additional standard.

Experimental layout and treatment application

In all post-emergence trials, a non-ionic surfactant at 0.025% v/v was added to all treatments. At all sites, the experimental design was a randomized complete block with three replicates and a plot size of 64 m^2 (4 rows of 10 m length at a spacing of 1.6 m). Treatments were applied with hand-operated knapsack sprayers with double hollow cone jet nozzles delivering 350 L ha^{-1} of spray mixture at a working pressure of 300 kPa.

Table 7.1. Characteristics and details of trial sites

Trial no.	Site	Soil group *	Mean annual rainfall (mm)	Altitude (m)	Date of planting	Cane variety	Date of spraying
I	Sans Souci	Humic Ferruginous Latosol	3800	290	28.02.05	M 1400/86	02.03.05
II	Deux Bras	Latosolic Brown Forest	2350	140	10.03.05	M 1394/86	16.03.05
III	Belle Mare	Lithosol	1500	40	12.04.05	M 2024/88	15.04.05
IV	Valetta	Latosolic Brown Forest	3200	430	07.04.05	M 52/78	13.04.05
V	Sans Souci	Humic Ferruginous Latosol	3800	290	28.02.05	M 1400/86	05.05.05
VI	Deux Bras	Latosolic Brown Forest	2350	140	10.03.05	M 1394/86	20.05.05
VII	Belle Mare	Lithosol	1500	40	12.04.05	M 2024/88	11.07.05
VIII	Valetta	Latosolic Brown Forest	3200	430	07.04.05	M 52/78	27.07.05
IX	Gros-Bois	Latosolic Brown Forest	2950	245	04.07.05	R 575	18.08.05
X	Combo	Humic Ferruginous Latosol	3300	410	13.07.05	M 52/78	02.09.05
XI	Côte D'Or	Humic Ferruginous Latosol	2800	450	19.07.05	M 52/78	22.09.05

* According to Parish & Feillafé (1965). Soil groups are described in Chapter 1.

Data collection and statistical analysis

For pre-emergence trials in plant cane, data collection comprised regular observations on weed infestation and cane growth. Visual observations were made at 4 and 8 weeks after spraying (WAS), whereas weed surveys were carried out twice between 12 and 19 WAS using the 'Frequency Abundance Method' (Rochecouste, 1967). The latter method consists of, firstly, a listing of all weeds present in the treatment plots, and then assigning their relative presence/cover on a scale varying between 0 and 8. Stalk height was measured from ground level to the first visible dewlap at 12 WAS.

For the post-emergence trials in plant cane, a weed survey was carried out prior to spraying in each individual plot to identify and quantify all weeds present. The first post-treatment weed survey was conducted between 4 and 6 weeks after spraying to assess the post-emergence potential of each treatment. Results were expressed in % weed kill for each plot by dividing the difference in weed infestation (Frequency Abundance Method) between the two surveys by the initial infestation. The second survey carried out between 10 and 13 WAS was mainly geared towards assessing the residual activity following early post-emergence application.

For the post-emergence trials in ratoon cane, a weed survey was conducted to record weed species and infestation levels in all plots a few days prior to spraying of treatments. Two formal weed surveys were carried out between 6 and 12 WAS using the 'Frequency Abundance Method' to calculate the % weed kill. Regular visual observations were made to assess any phytotoxicity on the different cane varieties.

Data for weed control (expressed as % of the untreated control) and % weed kill were transformed using the arcsine square root before statistical analysis was performed. Likewise, the % increase in stalk height (x) for effect of the treatments on cane elongation was transformed using $(x + 0.5)^{0.5}$ (Steel *et al*., 1997).

7.3 Results and discussion

7.3.1 Potential of amicarbazone and trifloxysulfuron + ametryn for pre-emergence weed control

Efficacy on weeds

Both trifloxysulfuron + ametryn and amicarbazone provided good pre-emergence control compared to the two standards. The efficacy of amicarbazone improved with increasing rates as opposed to trifloxysulfuron + ametryn where the two rates tested provided a similar level of control (Table 7.2). In general, trifloxysulfuron + ametryn was superior to amicarbazone as the former proved more effective on sedges (*C. rotundus* and *Kyllinga* spp.) and some grasses (Table 7.3). Amicarbazone showed a higher efficacy on broad-leaved weeds which explains its better efficacy in Trial III. Amicarbazone also provided good control of *Digitaria horizontalis* which was poorly controlled by trifloxysulfuron + ametryn (Table 7.3). Tank-mixing amicarbazone with trifloxysulfuron + ametryn improved the level and spectrum of control (Table 7.2). The residual activity of the tank-mix trifloxysulfuron + ametryn + amicarbazone was comparable to the two standards. Weed surveys at 16 or 19 WAS showed a satisfactory level of control in Trials I, III and IV. Cane growth was faster at Deux Bras (Trial II) and the cane canopy had almost closed before 16 WAS.

Observations made during the first eight weeks showed that all the treatments were safe towards the four cane varieties tested. These observations were confirmed when cane measurements taken between 12 and 16 WAS revealed no significant differences in stalk height and number of shoots. The tank-mix trifloxysulfuron + ametryn and amicarbazone showed no adverse effect on the mean dewlap height (Fig. 7.1) compared to the standard treatment. There were very few weeds left uncontrolled in the plots treated with either the standard herbicides or the new tank-mixes, so these could not have caused any additional adverse effect on the cane due to weed competition.

Table 7.2. Pre-emergence control of weeds presented as % of weed infestation on the untreated treatment (detransformed arcsine data) by trifloxysulfuron+ametryn and amicarbazone in plant cane. Values in parentheses represent transformed (arcsine) data

Treatments	kg a.i. ha^{-1}	Weed control (expressed as % of untreated control *)						
		Trial I		Trial II	Trial III		Trial IV	
		12 WAS	16 WAS	12 WAS	12 WAS	19 WAS	12 WAS	16 WAS
Amicarbazone	0.7	78 (1.08)	81 (1.11)	64 (0.92)	24 (0.51)	44 (0.72)	57 (0.86)	91 (1.26)
Amicarbazone	0.875	63 (0.912)	73 (1.02)	63 (0.92)	24 (0.51)	35 (0.64)	51 (0.80)	83 (1.15)
Amicarbazone	1.05	71 (1.00)	71 (1.00)	58 (0.87)	11 (0.34)	27 (0.54)	33 (0.61)	73 (1.02)
Amicarbazone	1.4	66 (0.95)	70 (0.99)	51 (0.79)	9 (0.30)	20 (0.46)	25 (0.52)	67 (0.96)
Trifloxysulfuron+ametryn	0.0263+1.097	46 (0.75)	59 (0.88)	44 (0.73)	16 (0.42)	34 (0.62)	44 (0.72)	68 (0.97)
Trifloxysulfuron+ametryn	0.0315+1.317	55 (0.84)	60 (0.89)	33 (0.61)	19 (0.45)	37 (0.67)	49 (0.78)	68 (0.97)
Amicarbazone + trifloxysulfuron+ametryn	0.875 + 0.0263+1.097	33 (0.61)	47 (0.76)	54 (0.83)	12 (0.36)	42 (0.70)	32 (0.60)	69 (0.98)
Amicarbazone + trifloxysulfuron+ametryn	1.05 + 0.0263+1.097	45 (0.74)	57 (0.85)	49 (0.77)	13 (0.37)	32 (0.60)	30 (0.58)	73 (1.03)
Oxyfluorfen + diuron	0.5 + 2.0	48 (0.76)	67 (0.96)	45 (0.74)	23 (0.37)	37 (0.66)	28 (0.56)	66 (0.94)
Tebuthiuron + atrazine	1.6 + 2.0	52 (0.80)	56 (0.84)	42 (0.71)	9 (0.31)	18 (0.44)	26 (0.53)	59 (0.87)
Standard error of transformed data		*0.20*	*0.19*	*0.12*	*0.18*	*0.25*	*0.13*	*0.12*

WAS = weeks after spraying
* values represent detransformed (arcsine) data

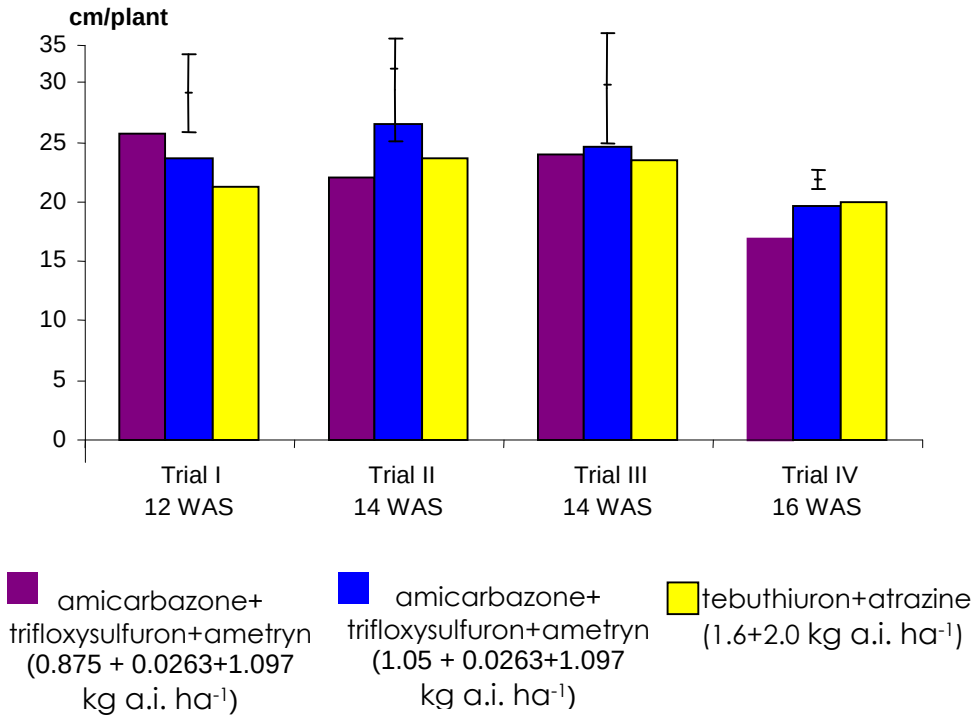


Fig. 7.1 Effect of trifloxysulfuron+ametryn and amicarbazone on cane growth. Error bars represent 2 x s.e.d.

Table 7.3 Relative efficacy of amicarbazone, trifloxysulfuron + ametryn and the tank-mix amicarbazone + trifloxysulfuron+ametryn for the pre-emergence control of some common weeds in sugar cane

	Herbicide treatments (kg a.i. ha^{-1})				
	Amic (1.4)	trif+amet (0.0315+1.317)	trif+amet+amic (1.05+0.0263+1.097)	oxyf+diur (0.5+2.0)	teb+atraz (1.6+2.0)
Ageratum conyzoides	+++	++	++++	+++	+++
Amaranthus dubuis	++++	+++	++++	++++	++++
Cyperus rotundus	+	++	++	+	+
Digitaria horizontalis	+++	+	++++	++++	++++
Digitaria timorensis	+++	+	++++	++++	++++
Drymaria cordata	+++	+++	++++	++++	++++
Kyllinga bulbosa	+	+++	+++	+++	+++
Oxalis corniculata	+++	++	+++	+++	+++
Paspalum paniculatum	+	+++	+++	+++	+++
Phyllanthus sp.	+++	+++	+++	+	+++

+ Poor ++ Fair +++ Good ++++ very good
amic = amicarbazone, trif+amet = trifloxysulfuron+ametryn, oxyf+diuron= oxyfluorfen + diuron, teb+atraz= tebuthiuron + atrazine

7.3.2 Potential of amicarbazone and trifloxysulfuron + ametryn for post-emergence control

Efficacy on weeds

With the exception of Trial V, the efficacy of the two new herbicides applied alone was comparable or superior to the standard (tebuthiuron + atrazine + 2,4-D amine salt). In general, both herbicides effectively controlled most broad-leaved weeds. Trifloxysulfuron + ametryn provided good knockdown of *C. rotundus*, *Kyllinga* spp. and *Paspalum* spp. that were poorly controlled by amicarbazone (Table 7.4). Likewise, amicarbazone was effective on *D. horizontalis*, which was not controlled by trifloxysulfuron + ametryn (Table 7.4). Tank-mixing the two products improved significantly their level of control (Table 7.5); the combination controlled *Digitaria timorensis* (Kunth.) Balans, which was found to be weakly controlled by both products applied alone (Table 7.4). For post-emergence control, increasing the rate of amicarbazone within the new tank-mix did not improve the level of efficacy (Table 7.5).

Table 7.4 Level of post-emergence control on weed species by amicarbazone, trifloxusulfuron + ametryn and the tank-mix amicarbazone + trifloxusulfuron + ametryn

Weeds	Herbicide treatments		
	amicarbazone	trifloxysulfuron+ametryn	amicarbazone + trifloxysulfuron+ametryn
Ageratum conyzoides	+	+	+
Cyperus rotundus	-	+	+
Digitaria horizontalis	+	-	+
D. timorensis	-	-	+
Eleusine indica	-	+	+
Kyllinga sp.	-	+	+
Oxalis debilis	-	+	+
Paspalum paniculatum	-	+	+
P. urvillei	-	+	+
Setaria barbata	-	+	+
Youngia japonica	+	-	+

+ Good control - Poor control

Table 7.5 Post-emergence control by trifloxysulfuron+ametryn and amicarbazone in plant cane expressed as % kill (detransformed arcsine data) by trifloxysulfuron+ametryn and amicarbazone in plant cane. Values in parentheses represent transformed (arcsine) data

Treatments	kg a.i. ha^{-1}	Weed control (% kill*)			
		Trial V	Trial VI	Trial VII	Trial VIII
		5 WAS	5 WAS	6 WAS	6 WAS
Amicarbazone	0.875	55 (0.83)	52 (0.80)	83 (1.14)	74 (1.04)
Amicarbazone	1.05	69 (0.98)	76 (1.05)	79 (1.09)	76 (1.05)
Amicarbazone	1.25	73 (1.02)	72 (1.01)	83 (1.14)	78 (1.08)
Amicarbazone	1.4	68 (0.97)	69 (0.98)	75 (1.05)	87 (1.21)
Trifloxysulfuron+ametryn	0.0263+1.097	73 (1.03)	63 (0.91)	66 (0.95)	77 (1.07)
Trifloxysulfuron+ametryn	0.0315+1.317	74 (1.03)	62 (0.91)	81 (1.12)	78 (1.08)
Amicarbazone + trifloxysulfuron+ametryn	0.875+ 0.0263+1.097	89 (1.23)	82(1.14)	84 (1.16)	96 (1.38)
Amicarbazone + trifloxysulfuron+ametryn	1.05+ 0.0236+1.097	96 (1.36)	77 (1.07)	86 (1.19)	98 (1.42)
Tebuthiuron + atrazine + 2,4-D	1.3 + 2.0 + 2.0	73 (1.02)	57 (0.85)	87 (1.21)	73 (1.03)
Standard error of transformed data		*0.092*	*0.133*	*0.105*	*0.086*

* values represent detransformed (arcsine) data

Effect on cane growth

Cane measurements made prior to spraying and 6 weeks later revealed that neither of the two new herbicides nor their tank-mixes caused a reduction in tillers or lower cane dewlap heights when compared to the standard (tebuthiuron + atrazine + 2,4 D amine salts). As the latter is known to be safe for post-emergence application in sugar cane, the new tank-mix should therefore be relatively safe for such application. As the level of post-emergence weed control by the new tank-mixes was superior to that obtained in the standard plots, the few weeds left uncontrolled in the latter plots may suggest some weed competition which would mask the effect of crop damage by the new herbicides. The possibility of the latter occurring was minimised by also comparing the cane growth parameters with the measurements recorded in the plots from the pre-emergence trials, which were initiated in the same field at each locality (same variety and planting dates).

7.3.3 Potential of amicarbazone and trifloxysulfuron+ametryn for early post-emergence weed control in ratoon cane

Post-emergence control of weeds

The three trials conducted in ratoon cane were sprayed 6 to 8 weeks after harvest to assess trifloxysulfuron+ametryn and amicarbazone for use within the newly developed weed management strategy. The two new herbicides, applied alone, were again found to be as effective as the two standards for their knockdown effect. Higher rates of amicarbazone resulted in increased efficacy (Table 7.6). The tank-mix of trifloxysulfuron+ametryn + amicarbazone once more tended to show higher level of control than the two standards. Thus, superiority was achieved as a result of a more effective control of species such as *D. horizontalis, P. paniculatum, P. urvillei, S. barbata, Kyllinga* spp. and *C. rotundus* (see Table 7.4).

Table 7.6 Post-emergence control and residual activity following application of trifloxysulfuron+ametryn and amicarbazone in ratoon cane expressed as % kill (detransformed arcsine data) and % of untreated control (detransformed data) respectively. Values in parentheses represent transformed (arcsine) data.

Treatments	kg a.i. ha^{-1}	Trial IX		Trial X		Trial XI
		% kill[a]	% of untreated control[b]	% kill	% of untreated control	% kill
		7 WAS	12 WAS	7 WAS	11 WAS	6 WAS
Amicarbazone	0.875	64 (0.92)	27	54 (0.82)	53 (0.81)	57 (0.86)
Amicarbazone	1.05	57 (0.86)	30	59 (0.87)	42 (0.71)	68 (0.97)
Amicarbazone	1.4	79 (1.10)	27	66 (0.66)	38 (0.66)	83 (1.155)
Trifloxysulfuron+ametryn	0.0263+1.097	68 (0.97)	20	67 (0.96)	16 (0.42)	84 (1.15)
Trifloxysulfuron+ametryn	0.0315+1.317	61 (0.90)	24	58 (0.86)	22 (0.49)	85 (1.17)
Amicarbazone+ trifloxysulfuron+ametryn	0.875+ 0.0263+1.097	87 (1.21)	20	82 (1.13)	16 (0.41)	90 (1.25)
Amicarbazone+ trifloxysulfuron+ametryn	1.05+ 0.0263+1.097	65 (0.94)	10	80 (1.11)	19 (0.45)	87 (1.20)
Tebuthiuron+atrazine+2,4-D	1.6+2.0+2.0	57 (0.86)	23	56 (0.84)	39 (0.68)	73 (1.03)
Hexazinone+atrazine+2,4-D	0.6+2.0+2.0	49 (0.77)	49	63 (0.91)	43 (0.71)	71 (1.00)
Standard error of transformed data		*(0.192)*	*n/a+*	*(0.071)*	*(0.092)*	*(0.037)*

[a] – post-emergence control; [b] – residual activity= recovery of weeds + new emergence
+ data from only one rep – no statistics

Residual herbicide activity on weeds

The residual activity of the new tank-mix following the knockdown of weeds was significantly superior to the two standards (Table 7.6), particularly to the one containing tebuthiuron which is known to provide fairly long pre-emergence control (approx. 14 WAS). It seemed that the higher rate of amicarbazone within the tank-mix extended the residual activity.

Visual observations made throughout the duration of the trials did not show any phytotoxic effects of the tank-mix on the different cane varieties.

7.4 Discussion and conclusions

The good potential of herbicides trifloxysulfuron + ametryn and amicarbazone as both pre- and post-emergence treatments was demonstrated in plant and ratoon cane. Applied pre-emergence of weeds, both herbicides were effective on most broad-leaved weeds and some annual grasses. Trifloxysulfuron + ametryn was less effective on *Digitaria horizontalis* and *D. timorensis*, and amicarbazone did not control *Cyperus rotundus*, *Paspalum* spp. and *Kyllinga* spp (Table 7.3). Tank-mix at lower rates of both herbicides overcame their individual weaknesses while maintaining a residual activity of over 14 to 16 weeks. When applied early post-emergence of weeds, both trifloxysulfuron + ametryn and amicarbazone were effective on most broad-leaved weeds and some grasses. The efficacy of trifloxysulfuron + ametryn on *Paspalum* spp., *C. rotundus* and other sedges, and that of amicarbazone on *Digitaria horizontalis* compensated for their individual inefficacies when they were tank-mixed (Table 7.4). As far as could be ascertained from the trials, which were not set up to specifically assess crop tolerance, the tank-mixes trifloxysulfuron + ametryn + amicarbazone were well tolerated by both young plant and ratoon cane.

The efficacy (pre- and post-emergence) of the new tank-mix offers a new perspective for managing weeds in sugarcane by delaying of the first herbicide application which will result in savings of at least one herbicide treatment per season. The tank-mix trifloxysulfuron + ametryn + amicarbazone (0.0263 + 1.097 + 0.875-1.05 kg a.i. ha^{-1}) has been registered and recommended for use in Mauritius; the higher rate of amicarbazone would be useful where a relatively longer residual activity is required. At these rates, the cost of the new tank-mix is comparable to the conventional treatments, but the possibility of saving one treatment per season renders the new tank-mix more cost-effective.

CHAPTER 8

GENERAL DISCUSSIONS & CONCLUSIONS

8.1 Weed competition in sugar cane

Competition between sugar cane and the major weeds

This study has shown that sugar cane is affected by competition from weeds just like other crops but the effect is often relatively small. Under the worst scenarios assessing the critical period of weed competition in sugar cane, the maximum reduction in cane yield was recorded in plant cane and was 53% of the weed-free treatments after weeds were left in competition with sugar cane for nearly 30 weeks. This reduction is lower than that reported by Suwanarak (1990) who found cane yields to be lowered by more than 70% after no weeding during the first four months after planting in the wet season in Thailand. In ratoon cane, the maximum losses in cane yields varied between 20% and 30%. Similarly, in the trials evaluating competition from individual species (Chapters 3 & 4), competition on the total dewlap height or biomass from very high weed densities rarely exceeded 50%. In other crops, some yield losses due to weed competition have been reported by Naylor (2002); a summary of 51 experiments carried out in UK and involving wild oats densities ranging 8 to 662 plants m^{-2} caused yields of spring barley to decrease by 0 to 72% while canary grass (*Phalaris minor*) and black grass (*Alopecurus myosuroides*) reduced yields of winter wheat by 26% and 45% at densities of 300 and 500 plants m^{-2} respectively.

Relative competitiveness ‘q’ values of eight weed species commonly found in sugar fields, determined by model developed by Kropff and Spitters (1991), showed that sugar cane was a stronger competitor than most of the weeds tested. Although use of this model, based on the relative leaf areas of the weed and crop, showed similar trends when the same weeds were compared, their q values were found to vary across trials. However, the variations in q values found for weeds in sugar cane are smaller than those reported for competition between *Sinapis alba* L. (white mustard) and sugar beet (*Beta vulgaris* L.) or spring wheat (*Triticum aestivum* L.) (Lotz *et al.*, 1996). The varying q values may limit the use of this model for predicting yield losses in sugar cane and comparisons between various species would only be possible if all the weeds were tested under a range of similar conditions. Despite these limitations, it was, however, possible to identify some of the weeds as being more competitive, i.e. *A. conyzoides, P. paniculatum, D. horizontalis* and *S. barbata*, compared to a lesser competitive group including *B. pilosa, P. urvillei, P. conjugatum* and *P. commersonii*. The latter

information conflicts with the perception of many growers that grasses are more competitive than broad-leaved weeds. The difficulty of achieving control of all grasses with selective herbicides in sugar cane may have created this belief.

Timing of competition

The critical periods of weed competition determined in Chapter 2 revealed that the adverse effect of weed competition in sugar cane was not experienced before several weeks following cane and weed emergence. This was also confirmed in the different trials, both under glasshouse and field conditions, assessing competition from one weed species at a time; the adverse effects on cane growth were measurable only 10-12 weeks after imposing weed infestations. In some of the trials with the broad-leaved weeds, some treatments at higher densities showed the adverse effects earlier due to the quicker rate of growth of the weeds. This lag period between weed emergence and competition explains why the onset of the critical periods of weed competition is several weeks later in ratoon cane. Competition started earlier (6 WAP) in the critical period trial carried out in plant cane and this may be explained by the presence of more broad-leaved weeds at that site, the period of the year and the relatively slower cane growth.

The relative competitiveness based on 'q' values of both *P. paniculatum* and *P. urvillei* was found to remain unchanged with time within the first nine weeks after establishment of weed infestations. A reduction in their competitiveness was recorded after 13 WAT (in Trial III, chapter 4), mainly explained by the distribution of the leaves within the canopy though they had similar relative leaf areas (L_w).

The timing of weed emergence on the final cane yield was illustrated in Chapter 4 (Trials 1 & III). Both trials revealed that the second transplanting of weeds tested caused no significant difference on cane yield. The physiological difference between the two dates of transplanting included both mean height of shoots and the stage of tillering. The results indicate that weed infestations, occurring when the cane approaches peak tiller density for that variety and when shoot heights are more than 40 cm, would be less prone to weed competition.

Measurements of the total cane dewlap height at the different observation dates had shown some significant reduction although the same treatments did not show any difference at harvest. It is believed that due to its long growing period after the cane leaves are less exposed to the competition for light till harvest, sugar cane has an ability to recover and compensate for earlier losses. Apparent

effects of weed competition observed before canopy closure do not necessarily translate into yield losses.

Effect of weed density on weed competition

Although it was difficult to maintain the 'original' densities as at transplanting, increasing weed density was found to influence weed competition and result in earlier weed competition. However, there was often little difference between the higher weed densities, as a result of high level of intra-specific competition between the weeds. Broad-leaved weeds such as *A. conyzoides* and *B. pilosa* have a more prostrate growth and hence were subjected to more intra-specific competition as compared to the grasses with a more upright growth of the leaves. This may explain the lack of a major difference between the two infestation levels studied in some of the critical period trials; the 50% infestation level was most probably not so different to the natural infestations.

Mechanisms of weed competition

Weed competition impaired both tillering (shoot density) and stalk elongation (dewlap height of stalks). In most of the trials, early weed competition resulted more in a reduction of the number of shoots or stalks. Stalk elongation was reduced when competition occurred after the peak of the tillering phase or stalks had reached a mean dewlap height of 25 cm or more. The effect of competition on stalk elongation was also demonstrated in the split-box and allelopathy trials where the effect of competition was observed only after the stalks had reached a dewlap height of 35 to 40 cm.

One of outcomes of this study has been the identification of the involvement of other mechanisms of weed competition as well as that for light. In the critical period trials, competition was still observed with weeds that emerged towards the end of the CPWC or when the cane stalks were higher than the weeds. This was confirmed with the comparison of *P. paniculatum* and *P. urvillei* where the former proved to be more competitive in some treatments although the latter produced more leaf area (for similar densities) and grew taller to intercept more light within the canopy. The vertical distribution of leaf area of cane and weeds (Chapter 4) showed that *P. paniculatum* was as or more competitive even though most of the cane leaf area was found higher in the canopy than the weeds. This indicated that other mechanisms might be involved and that competition for light was more important during the earlier growth stages where tillering was mostly affected.

Root competition was shown to be as important as shoot competition or more in Chapter 5. Root development of sugar cane was impaired by both root and shoot competition and the fact that they

were not resulting in a more severe competition when both occurred simultaneously suggested that they were not affecting root development in the same manner. The effects of root competition were observed several weeks after imposing competition when the cane stalks reached more then 35 cm in dewlap height suggesting that root competition was more important than competition for light after the post-tillering phase.

Although root competition seemed to cause more reduction in root biomass of *P. urvillei* compared to *P. paniculatum*, the higher competitiveness of the latter was still not completely explained. Collection of leachates (root exudates) from the two grasses applied daily to sugar cane confirmed an effect from allelopathic compounds resulting in a reduction of root biomass of sugar cane. In one trial (Trial I), *P. paniculatum* developed vigorously and the effect of its leachates on cane growth was more pronounced than those from *P. urvillei*. In the other trials, where an adverse effect from the allelochemicals was observed, *P. urvillei* was more competitive; *P. paniculatum* had not developed so vigorously as in the first trial. One chemical identified from the leachates that may be responsible for the allelopathic effects was 2-Propenoic acid, 3-(4-methoxyphenyl), from the known (for their allelopathic properties) family of cinnamic acids. The presence of higher concentration of this chemical in the leachates (samples taken in Trial IV) from *P. paniculatum* suggests a link with the greater reduction in root biomass observed between this treatment and the control (distilled water).

In conclusion, although weeds appear to impact on the growth of sugar cane by competing for light, there are also effects arising from below ground competition. This may be linked to competition for water and nutrients but may also involve allelochemicals. The allelopathic potential of the other weeds, particularly grasses such as *D. horizontalis* and *Panicum species*, occurring in sugar cane fields need to be assessed. The allelopathic properties of *C. rotundus* on sugar cane had been demonstrated by Mc Intyre (1998). Further research is needed in the mechanism of below ground competition and its importance for other weed species apart from the two *Paspalum* spp.

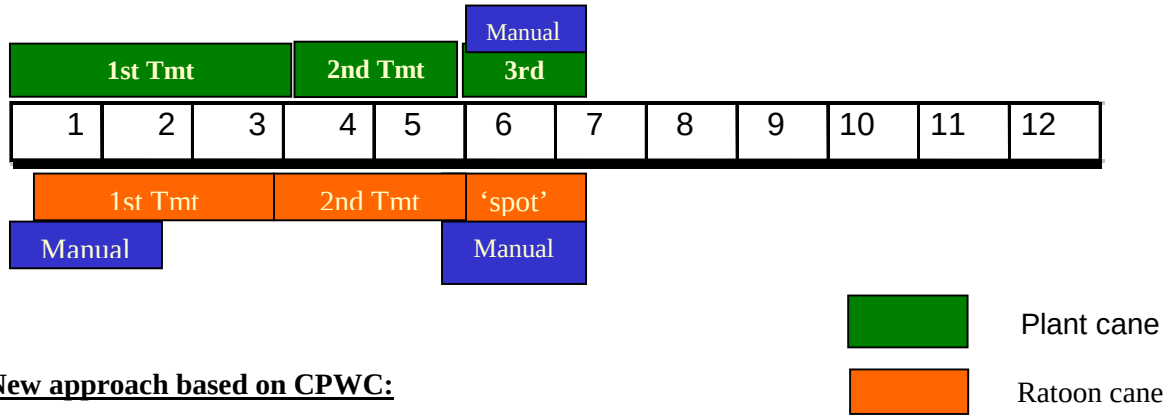
The mechanisms of weed competition may be summarized by competition for light at the earlier stages of growth (germination/tillering) and root competition, with or without allelopathic exudates from the weeds, later within the tillering/elongation phase.

8.2 Applications and recommendations for the Mauritian sugar industry arising from this research study

The main application of the above findings for the Mauritian sugar industry would be a change in the timing of application of herbicide treatments. The critical periods study shows that the ‘traditional’

approach of applying a pre-emergence treatment immediately after planting or within a few days after harvest to prevent any weed emergence is not totally justified. Although the trials to determine the CPWC were established under the most severe agro-climatic conditions, the results can be extrapolated on the basis of the GDDs to other areas and cane varieties (early v/s late maturing). Similarly, the CPWC would imply an earlier end of weed control compared to the current approach where fields are maintained almost weedfree until the complete closure of the crop canopy. Application of the CPWC will, in general, result in the reduction of at least one herbicide application per season. This is possible by delaying the first herbicide treatment until onset of the first flush of weeds and applying an effective herbicide treatment to kill all weeds present and provide a fairly long residual activity to keep field weed-free until the end of the CPWC (Fig. 8.1).

Traditional approach:



New approach based on CPWC:

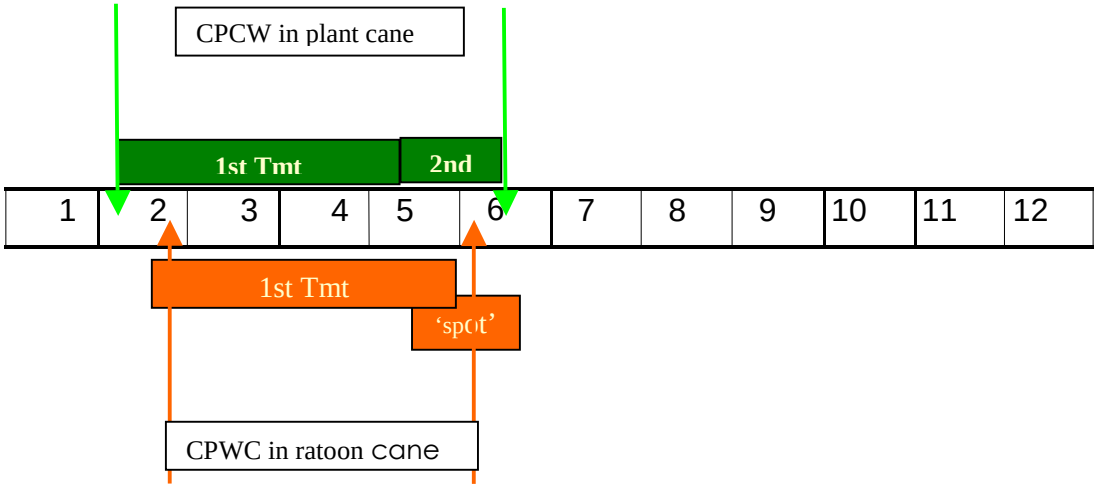


Fig. 8.1 Timing of herbicide applications in sugar cane based on CPWC (arrows showing start and end of control period) (bottom) compared to the conventional method (top). Figures in boxes represent months after planting or harvest. Treatments for plant cane are represented in green boxes and ratoon cane in orange boxes.

Row spacing influences the critical timing for weed removal (Knezevic *et al*., 2003). Planting cane at higher density by changing the row spacing would reduce further the period of control based on the CPWC. Dual row planting, consisting of pairs of cane rows 0.5 m apart with 1.8 m between their centres, has been tested successfully and recommended to the producers in 2006 (MSIRI, 2006; Ismael *et al*., 2007). The new row spacing also has the potential of increasing cane yield with the same amount of planting material and with no increase in fertilizer used compared to conventional planting (1.62 m spacing). It also reduces costs of production by improving weed management and the efficiency of chopper-harvesters. This improvement in weed management results from earlier canopy closure and consequently the end of the CPWC is reached four to eight weeks earlier (Ismael *et al*., 2007).

The success of such a weed management strategy as above would only be possible if the herbicide treatments are able to kill all the weeds present at the time of application and provide effective residual control of most of the weeds present for the duration of the CPWC. Traditional herbicide treatments did not have that potential and the evaluation and the recommendation of the new tank-mix amicarbazone + trifloxysulfuron+ametryn (Chapter 7) has satisfied this requirement. The new tank-mix consisting of trifloxysulfuron+ametryn (0.0263+1.097 kg a.i. ha^{-1}) and amicarbazone (0.875 to 1.05 kg a.i./ha) has a residual activity varying between 14 to 16 weeks and, has post-emergence activity. It is able to control almost all weeds found in sugar cane in Mauritius including *D. horizontalis, D. timorensis, C. rotundus, Paspalum* spp. and *Kyllinga* spp. Moreover, trifloxysulfuron+ametryn has the potential of controlling partly *C. rotundus* pre-emergence. The tank-mix, amicarbazone + trifloxysulfuron+ametryn (0.875-1.05 + 0.0263+1.097 kg a.i. ha^{-1}) did not cause crop injury in young plant or ratoon cane. The efficacy (pre- and post-emergence) of this new tank-mix has offered a new opportunity for managing weeds in sugar cane, as delaying of the first herbicide application will result in savings of at least one herbicide treatment per season.

New weed management strategies based on the CPWC include the exploitation of control methods other than use of herbicides. The use of mechanical weeding during the first two or three months after planting has also been tested successfully (MSIRI, 2006). Two or three passes of duck's foot cultivators have proved to be sufficient to control weeds up to the end of the critical periods. This method of weed control has been recommended in plant cane and where fields are either in rock-free soils or have been derocked for mechanized harvest; this approach would be possible on some 50% of the replanted area every year.

The concept of limiting weed control during the CPWC period, particularly that of leaving weeds uncontrolled after the end of the CPWC, has been discussed by many growers in the past. They

were concerned about the production of seeds from the 'residual' weeds and its consequences on the seedbank in the mid- or long-term. Trials (not reported in this study) initiated in parallel to the above development have shown that there was no significant increase in the seedbank between the same plots where weed control had been stopped 16 weeks after harvest for three consecutive years and plots which were kept weed-free. This study is being pursued but as the new weed management strategies are geared towards weed control until 20 to 26 WAH, the risks of increasing the seedbank is minimised. Riemens *et al.* (2007) has shown that appropriate weed management practices in organic farming resulted in no increase in the weed seedbank after seven years. Weed control strategies based on density thresholds were found more cost-effective than spraying every year after modelling seed production of *Alopecurus myosuroides* and *Poa annua* (Munier-Jolain *et al.,* 2002). Similarly, Smith *et al.* (1999) reported a reduction in the population of *Anisantha sterilis* in winter wheat through changes in patterns of management. In sugar cane, Witharama *et al.* (1997) reported that the similarity between species in the seed bank and emerged seedling population in the field was low. This may imply that all the seeds produced do not necessarily pose a threat of more competition later on.

Green cane trash blanketing (GCTB) is practised on approximately 25% of the area harvested and is expected to increase as more fields are harvested mechanically in the near future. The trash blanket controls the weeds effectively until it decays; in humid areas this may happen before end of the CPWC and a herbicide treatment may be required. Similarly under some agro-climatic conditions, especially in plant cane, a second treatment, over and above the new tank-mix applied before the onset of the CPWC, may be justified. Under these conditions, the use of models to predict the weed competition expected from the different infestation levels and weed species present would be beneficial and would suggest further savings of herbicides. However, the findings of this study have revealed varying relative competitiveness (q) values across trials and standardization of the results needs more work. Furthermore, the use of such parameters in sugar cane would be more difficult due to the length of the growing season; the q values changes with time of weed emergence and assessment date.

The allelopathic potential of the other weeds needs to be determined before making any decision on leaving such weeds in the fields after the end of the CPWC. As root competition seems to be important and sugar cane roots do not exploit the cane interrows entirely, weed management could be envisaged that was focused in the vicinity of the stubble or cane roots. This is supported by work carried out by Witharama *et al.* (2007) who found that more weeds emerged in the cane furrows than on the ridges and the difference was influenced by the soil moisture. The latter may imply a herbicide treatment on a localised band nearer to the cane stools in situations where a second post-emergence

treatment would be required to reach the end of the CPWC. As the soil moisture varies within the three agroclimatic zones of Mauritius, such approaches would require more research and development.

8.3 Suggestions for future research

Relative competitiveness (q value) for more weeds

This study has indicated two groups of weeds according to their relative competitiveness. More trials should be conducted to evaluate the relative competitiveness (q values) of more weed species occurring in sugar cane fields; the data would be useful for prediction of yield losses for management purposes or Decision Support Systems. The q values could be used to regroup weeds into two or three categories. The results of this study would assist in redefining the various densities for estimating q values. New technologies using Multi Spectral Reflectance (MSR) or radiospectrometry are being successfully tested and calibrated in sugar cane. The use of such technology would give quicker leaf areas estimations.

Threshold for sugar cane and testing of herbicides

The variability within the weed infestations and cane measurements or leaf area estimates observed in this study may restrict the use of threshold infestation levels in sugar cane under the Mauritian conditions. However, with a reliable estimation of leaf areas with the new or forthcoming technologies, prediction of yield losses near the end of the critical periods may assist in the necessity of a second or ‘spot’ application.

The q values of the different weed species will certainly be useful in the choice of the herbicide treatments. DSS using the relative competitiveness (or any other index) together with information on the level of infestation of each species (e.g. frequency abundance method) will certainly enable more precise selection of herbicide treatments and their rates for cost-effective management of weeds.

The current methods for evaluating herbicides for sugar cane do not provide information on the interaction between weed infestation level or size of weeds and rates of treatments. The efficacy of lower rates on weaker weed infestation levels or smaller weeds or less competitive ones would permit further savings of herbicides.

Allelopathic potentials of more weeds

The screening of more allelopathic compounds from the weeds occurring in sugar cane fields will not only enable a better understanding of the mechanisms of weed competition, but could be used to identify some potential bio-herbicides, for use in other crops.

Future work would be necessary to identify, using dose-response curves with known amounts of the chemicals, the minimum dose of the allelochemicals (e.g. cinnamic acids) required to cause adverse effects on sugar cane. The release of the various chemicals with time and the amounts released will also enable a more complete understanding of the mechanism of weed competition in sugar cane.

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Weed management in sugar cane: critical periods of weed competition and mechanisms of interference from *Paspalum paniculatum* and *P. urvillei*

by

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SUMMARY

The aim of this project was to provide sound scientific underpinning for the development of new weed management strategies in sugar cane by exploring competition from the major weeds, and explaining the different mechanisms of weed interference from *Paspalum paniculatum* and *P. urvillei*.

Critical periods of weed control (CPWC) were studied in six field trials. In ratoon cane, CPWC with natural weed infestations started between 228 and 916 GDD, and ended between 648 and 1311 GDD, depending on the site and cane variety. These results represented a maximum CPWC of 12 to 28 weeks after harvest (WAH). In plant cane, the CPWC started earlier (6 WAP) and was longer than those in ratoon cane.

Relative competitiveness ‘q’ values of eight common weed species showed that sugar cane was a stronger competitor than most of the weeds tested. The adverse effect of weed competition in sugar cane is not experienced before several weeks following weed emergence. The competitiveness of both *P. paniculatum* and *P. urvillei* was found to remain unchanged with time within the first nine weeks after transplanting (WAT). A reduction in their competitiveness was recorded from 13 WAT, mainly explained by the distribution of the leaves within the canopy.

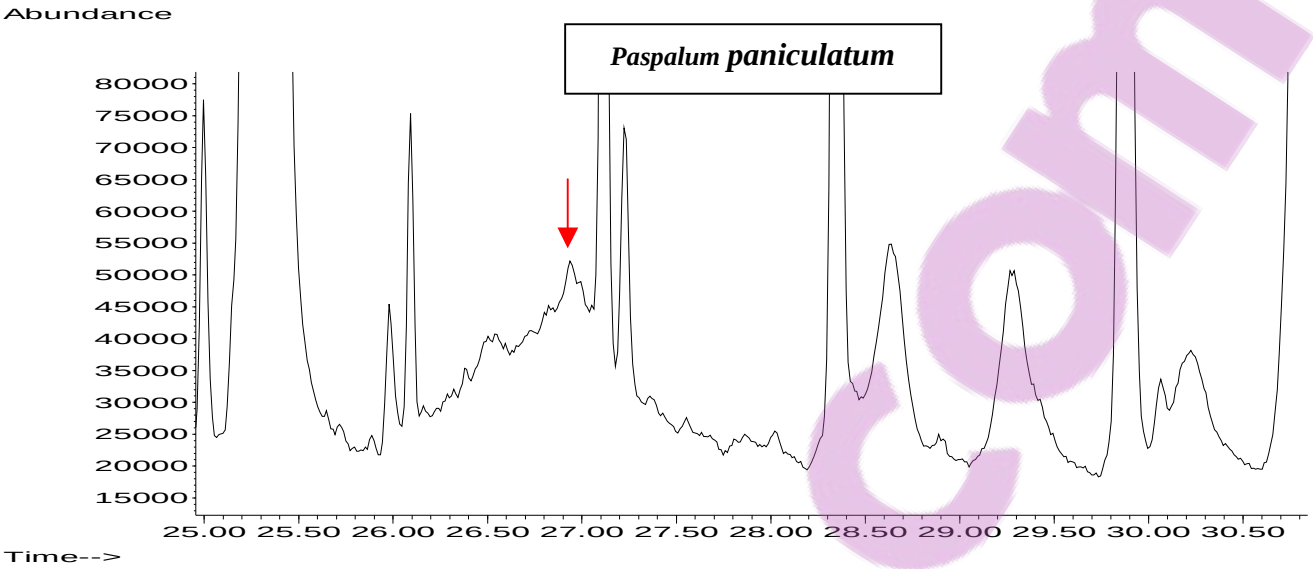
Trials, studying two timings of weed emergence, revealed that transplanting weeds later caused no significant change in cane yield response. However, measurements made after the second transplanting showed some significant reduction in the total cane dewlap height. Due to its long

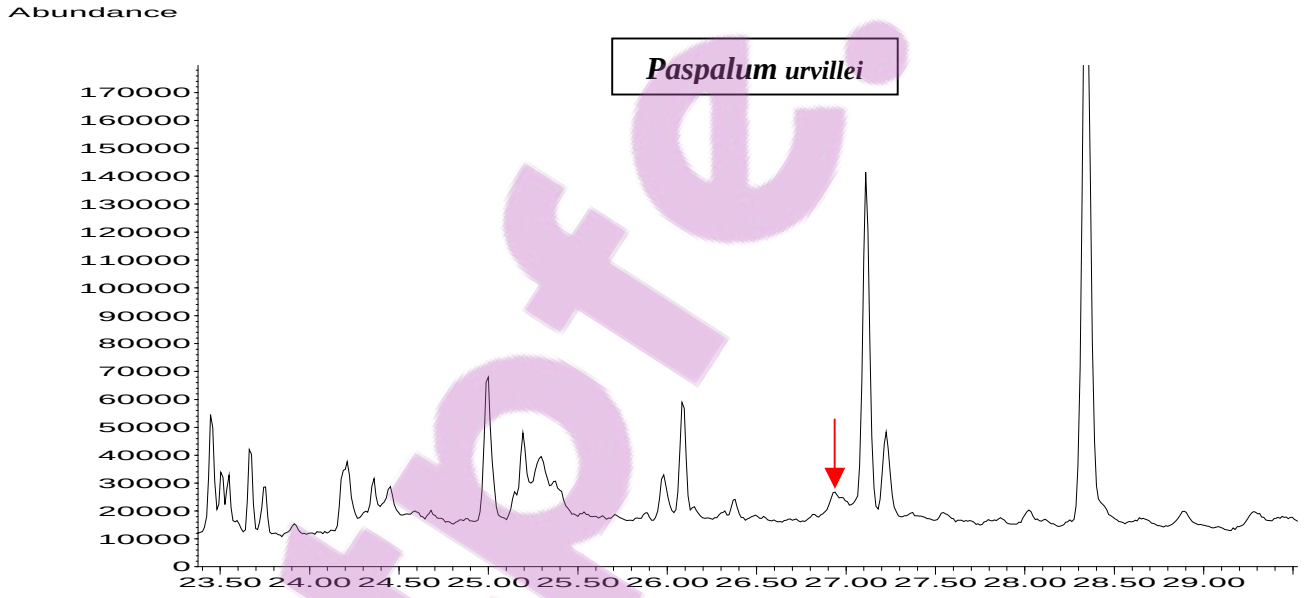
growing period sugar cane has the ability to recover and compensate for some impediments caused by weeds.

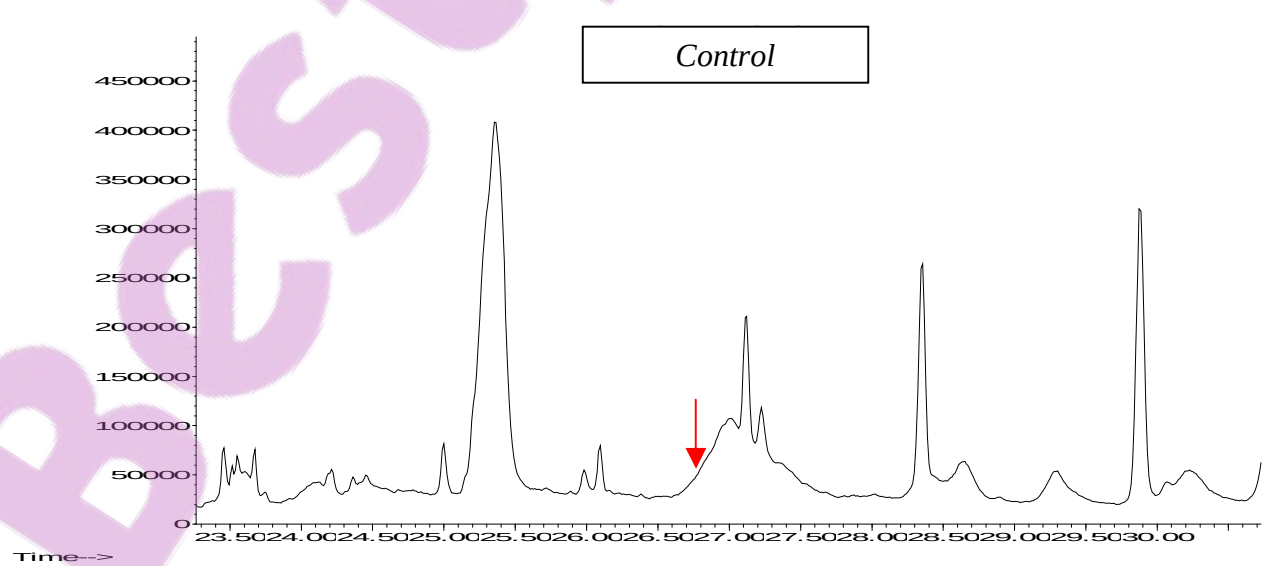
Paspalum paniculatum was often found to be more competitive than *P. urvillei*, although the latter produced more leaf area and grew taller to intercept more light within the canopy. This indicated that other mechanisms of weed interference might be involved and that competition for light was more important during the earlier (tillering) growth stages. Root competition was shown to be as important as shoot competition. Root competition effects were observed several weeks after imposing competition, when cane stalks reached more than 35 cm in dewlap height, suggesting that root competition was more important than competition for light after the post-tillering phase. The shoot versus root competition trials were not able to completely explain the higher relative competitiveness of *P. paniculatum* compared to *P. urvillei*. Application of root exudates from the two grasses to sugar cane confirmed an allelopathic effect on the root biomass of sugar cane. One chemical identified for the allelopathic effects was 2-propenoic acid, 3-(4-methoxyphenyl).

The main implications of the above findings for the Mauritian sugar industry would be to delay the first treatment until onset of the first flush of weeds. A new tank-mix consisting of trifloxysulfuron+ametryn and amicarbazone has been studied and was found to meet this objective. This strategy will enable a savings of at least one herbicide treatment per season.

APPENDIX 1







Chromatograms from leachates (root exudates) collected from *P. paniculatum* and *P. urvillei* showing peak for 2-propenoic acid (RT: 26.95 mins)