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.

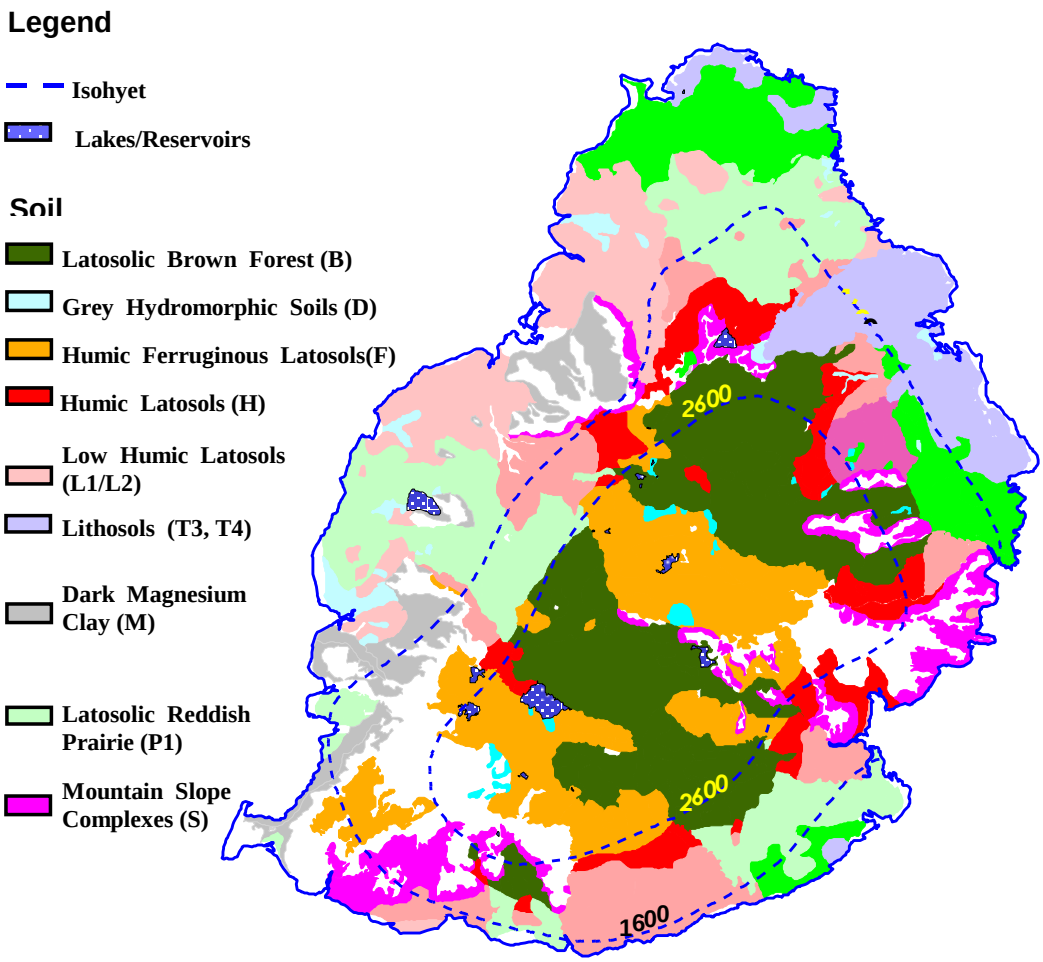


Fig. 1.1 Agro-climate of Mauritius and soil groups of Mauritius (after Parish & Feillafé, 1965)

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).

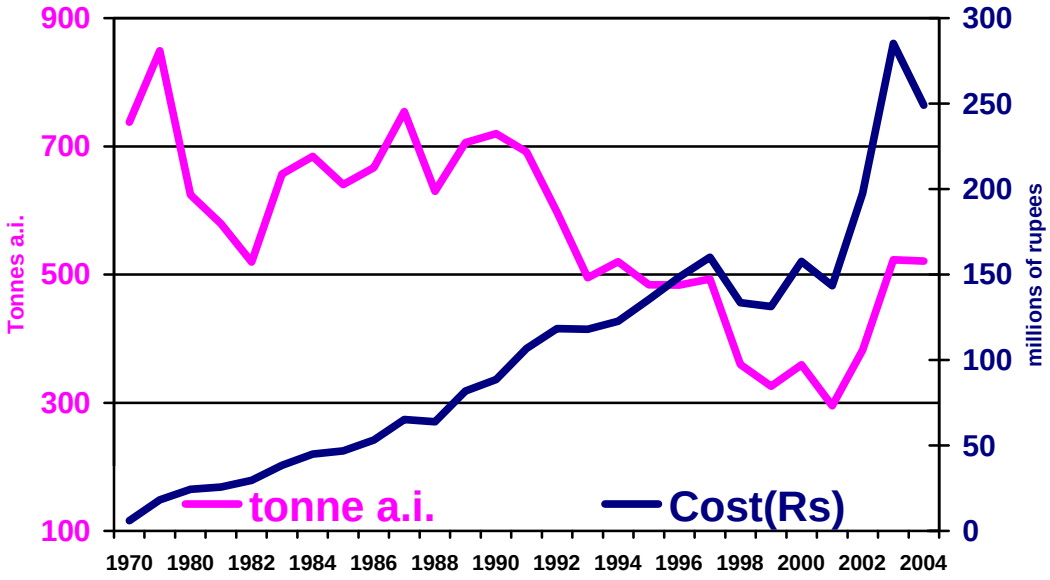


Fig. 1.4 Amount (tonnes of active ingredients) and costs of herbicides used in sugar cane. (1 US$ = ~30 MUR)

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).

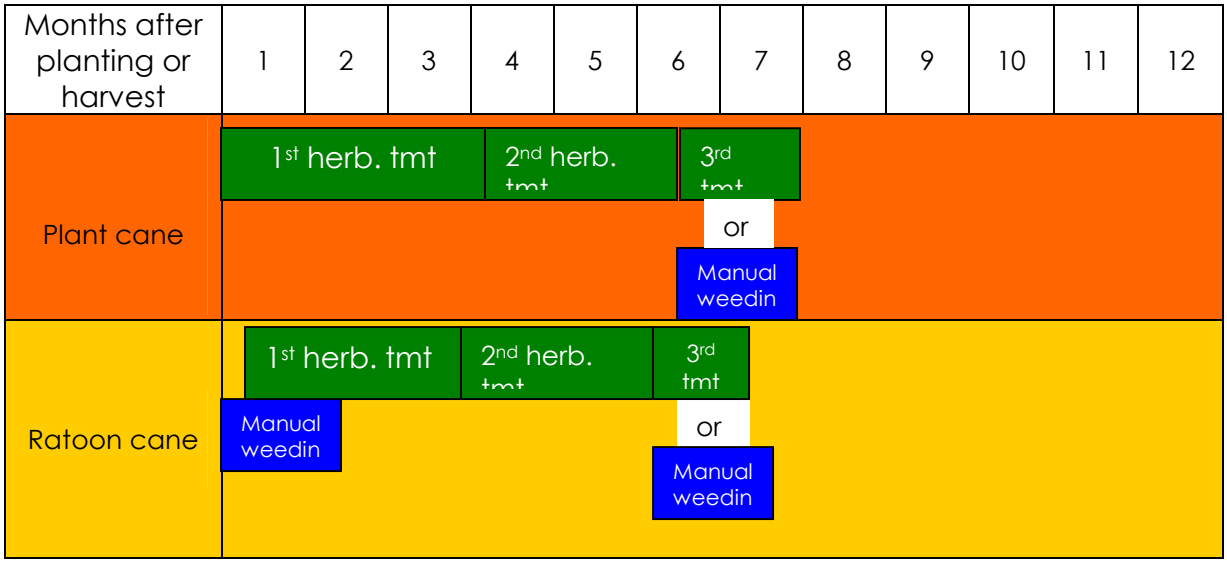


Fig. 1.5 Timing of weed control and herbicide applications in sugar cane

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.

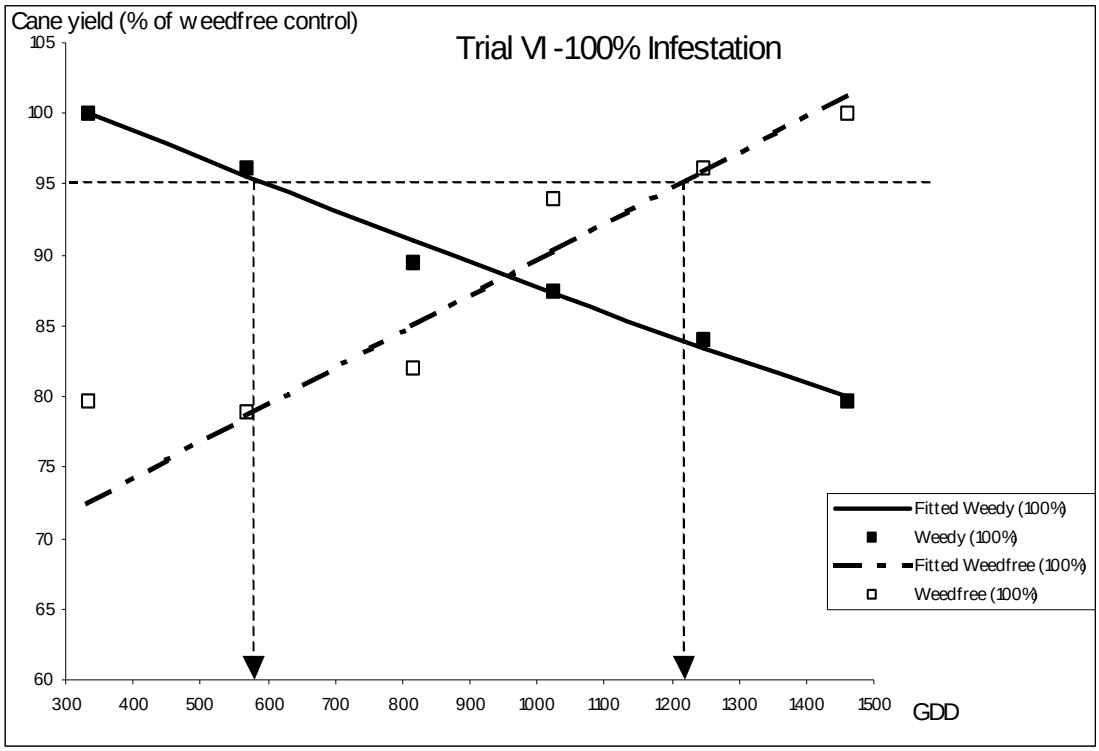
Table 2.4 Evolution of weed infestations in Trial III as a result of increased delay in the weed control treatment

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.



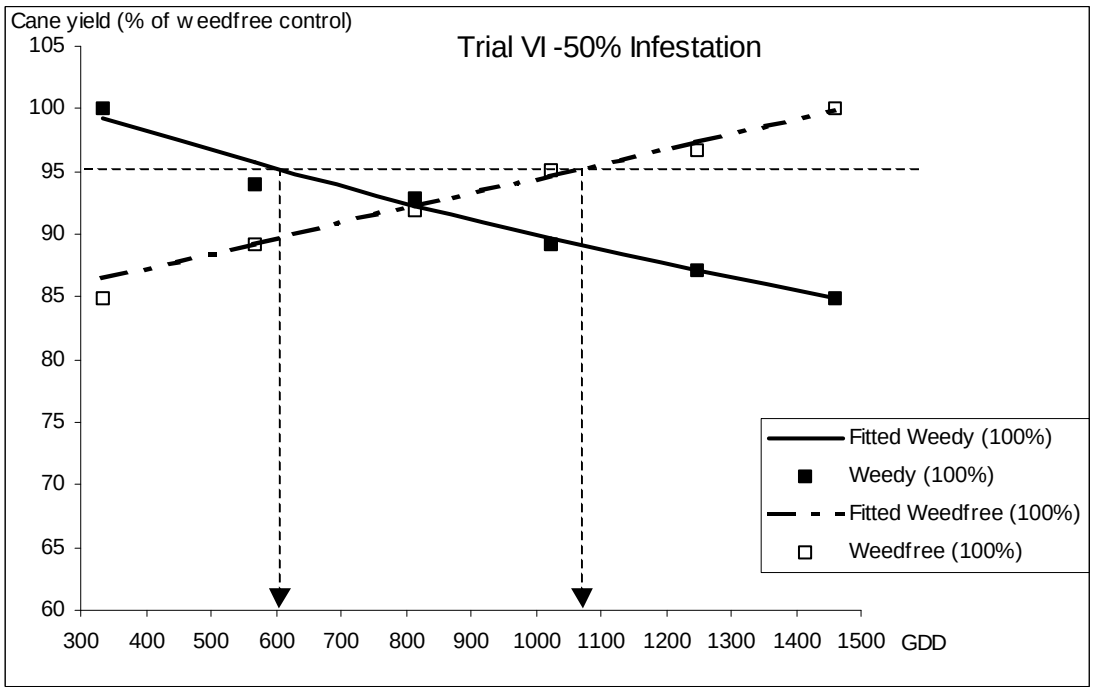


Fig. 2.1 Effect of increasing duration of weed interference (solid line) fitted by the logistic equation and increasing weed-free periods (dashed line) fitted by the Gompertz equation on yield of sugar cane (ratoon crop) at Belle Rive (Trial VI). Dots represent observed data. Horizontal dashed line indicates 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).

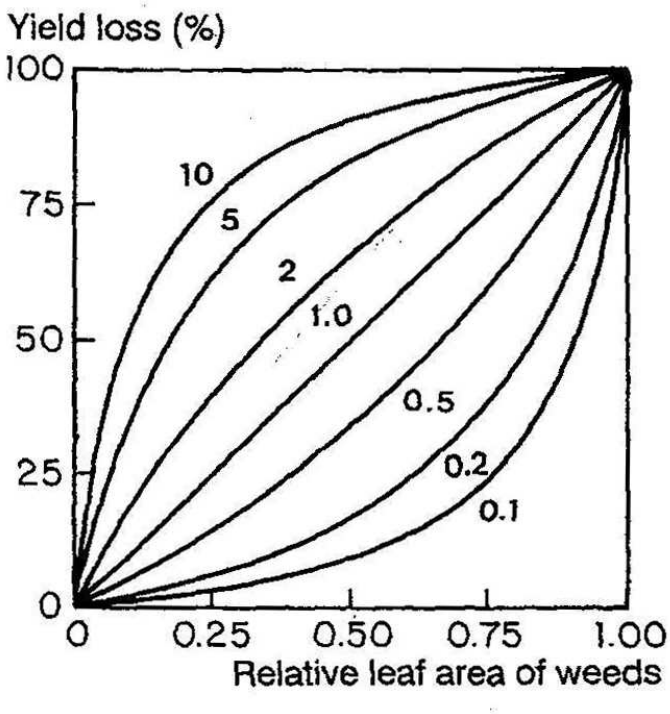


Fig. 3.1 Theoretical relationships between yield loss and relative leaf area of weeds at different values of the parameter q. (Copied from Kropff & van Laar, 1993; source: Kropff and Spitters, 1991)

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).

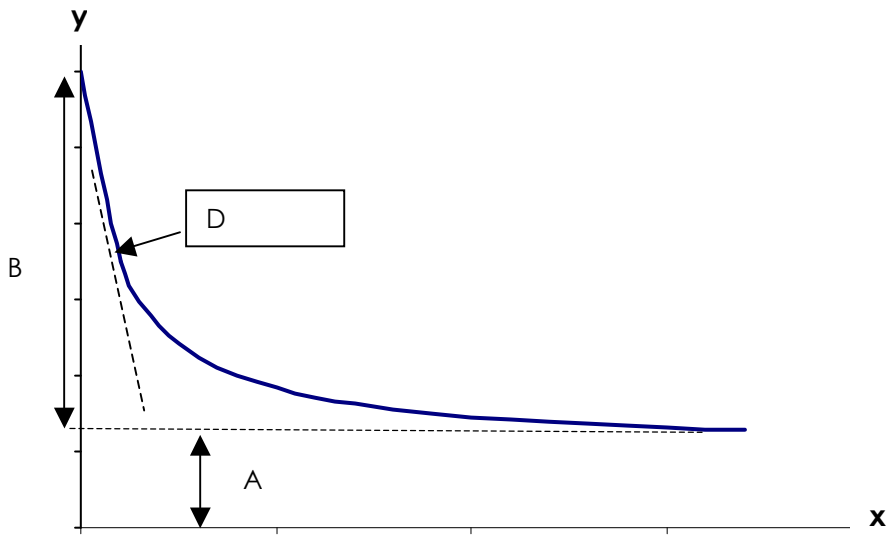


Fig. 3.2 Example of a rectangular hyperbolic (linear-by-linear) model showing parameters.

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.

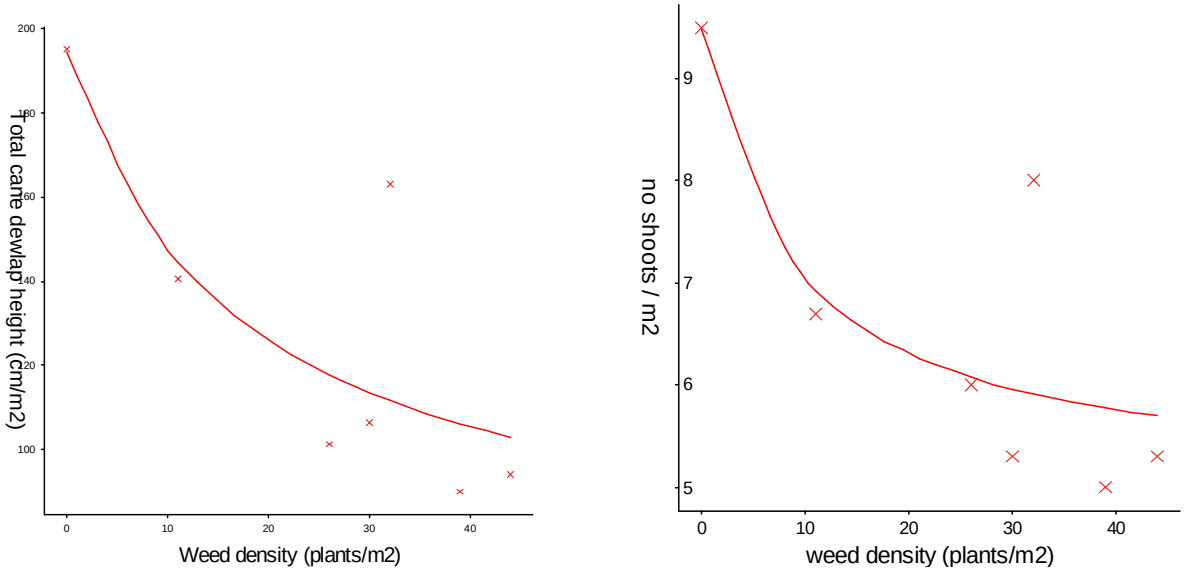


Fig. 3.3 Relationship between the density (plants m^{-2}) of *A. conyzoides* and *left* - total dewlap height (cm m^{-2}) and *right* - tillering (no. of shoots m^{-2}) of sugar cane. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density; 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).

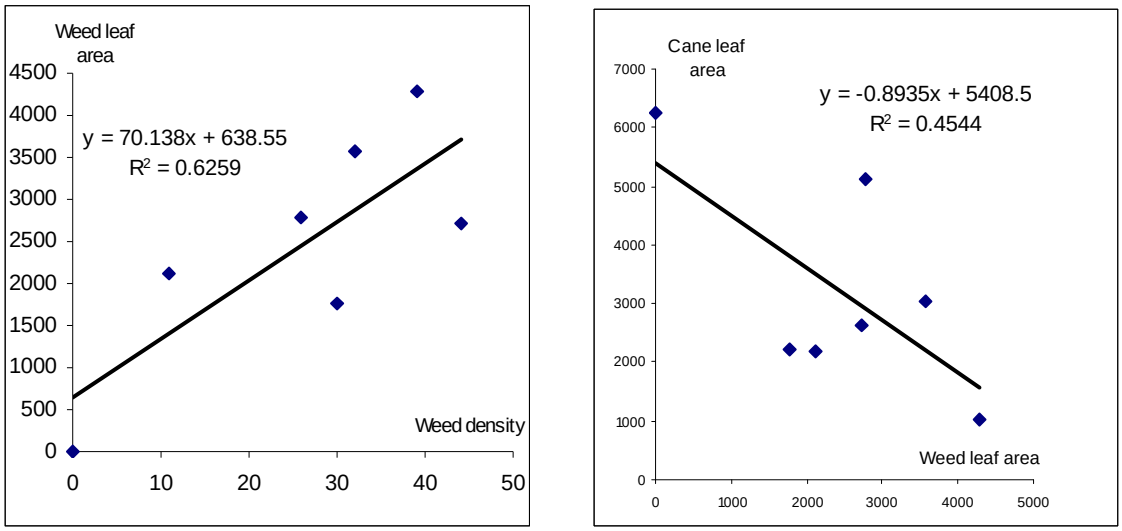


Fig. 3.4 Relationships between the density (plants m^{-2}) and leaf area (cm^2 m^{-2}) of *A. conyzoides* (left) and between the leaf area of *A. conyzoides* (cm^2 m^{-2}) and leaf area of sugar cane (cm^2 m^{-2}) (right)

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.

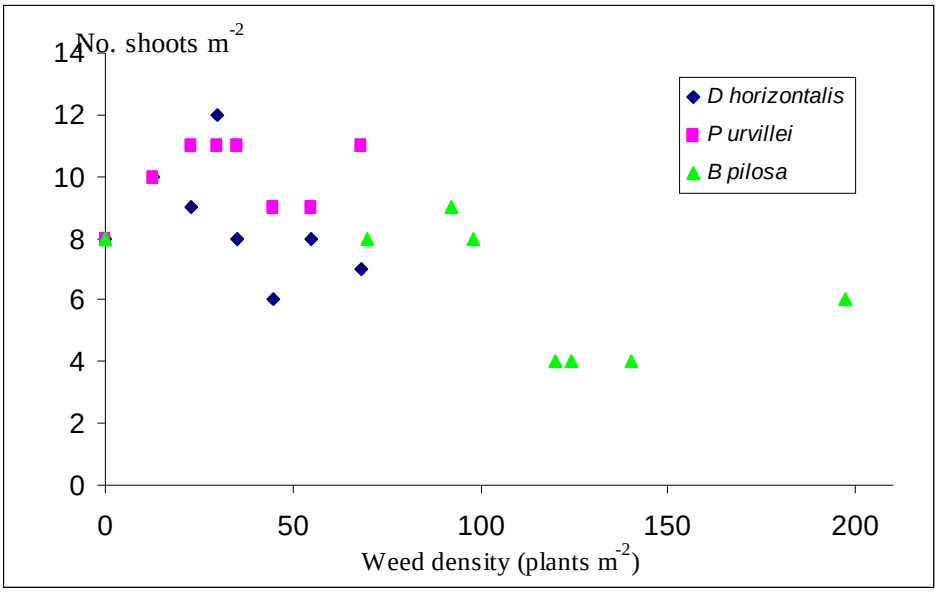


Fig. 3.5 Effect of different weed densities of *B. pilosa*, *D. horizontalis* and *P. urvillei* on cane tillering 14 WAT.

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.

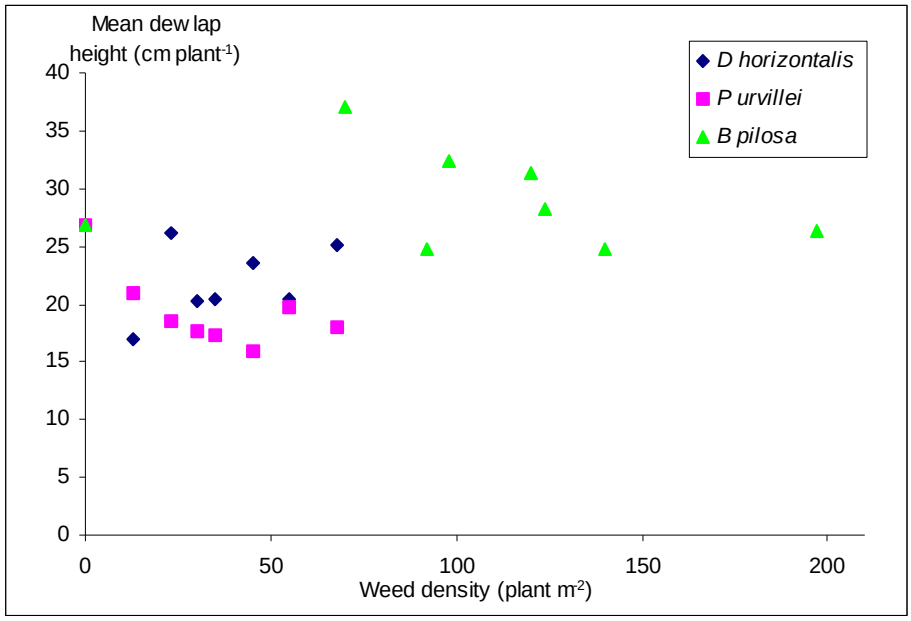


Fig. 3.6 Effect of different weed densities of *B. pilosa*, *D. horizontalis* and *P. urvillei* on the mean dewlap height (cm $shoot^{-1}$) of cane 14 WAT.

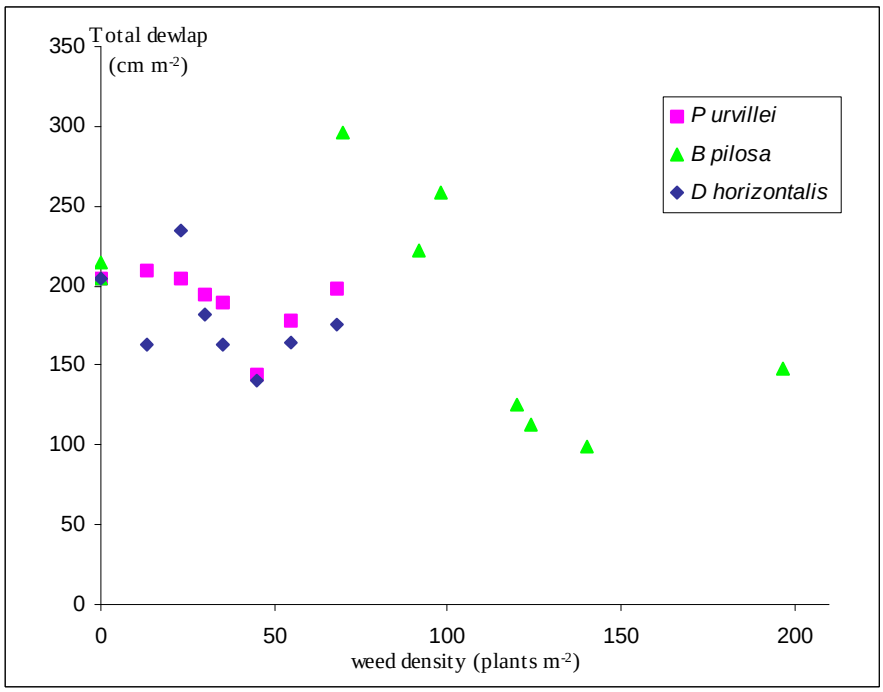


Fig. 3.7 Effect of different weed densities (plants m^{-2}) of *B. pilosa*, *D. horizontalis* and *P. urvillei* on total dewlap height (cm m^{-2}) of cane 14 WAT.

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

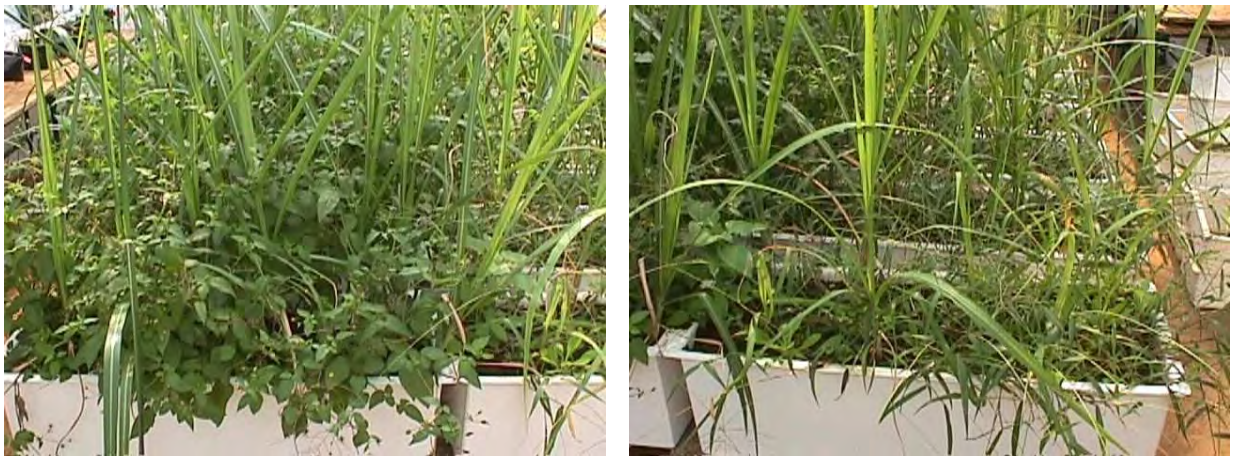


Fig. 3.8 Weed competition from *D. horizontalis* (right) causing cane leaf chlorosis compared to competition from *B. pilosa* (left).

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.

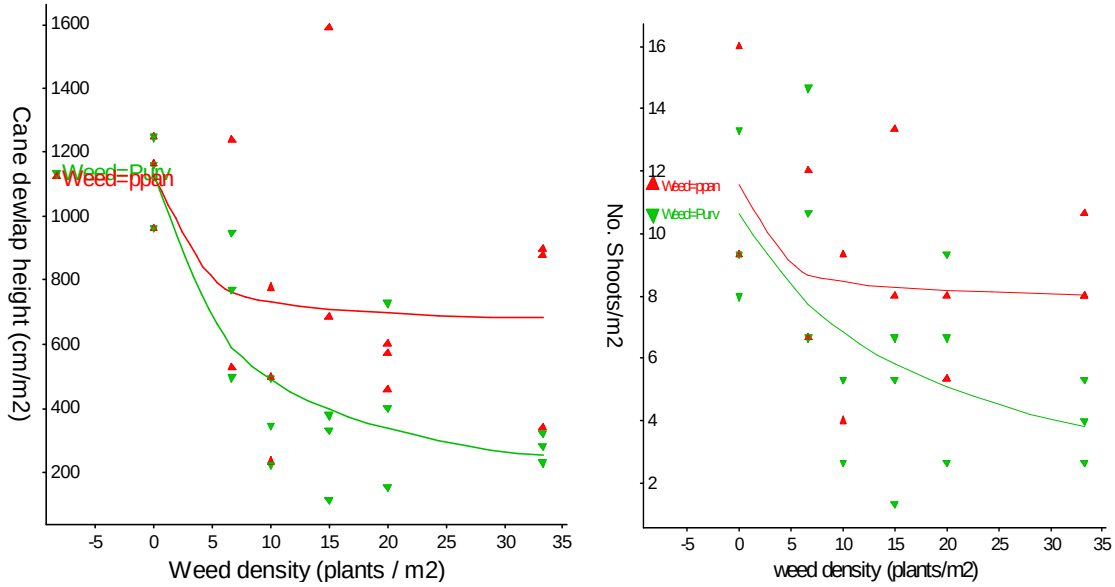


Fig. 3.9 Relationships between the density (plants m^{-2}) of *P. paniculatum* (red) and *P. urvillei* (green) and ***left***- total dewlap height (cm m^{-2}) and ***right***- tillering (no. of shoots m^{-2}) of sugar cane 16 WAT. Response curves are those from parameters given in Table 3.4.

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.

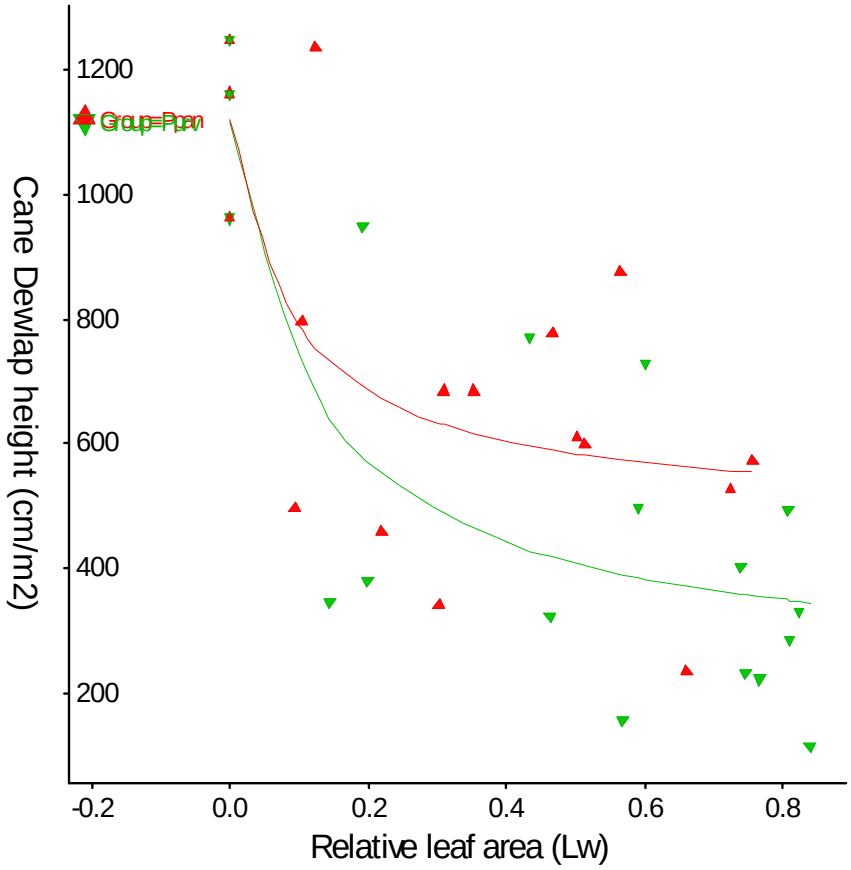


Fig. 3.10 Relationship between the total cane dewlap height (cm m^{-2}) and the relative leaf area of *P. paniculatum* (red) and *P. urvillei* (green) at 16 WAT. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density; for *P. paniculatum* 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).

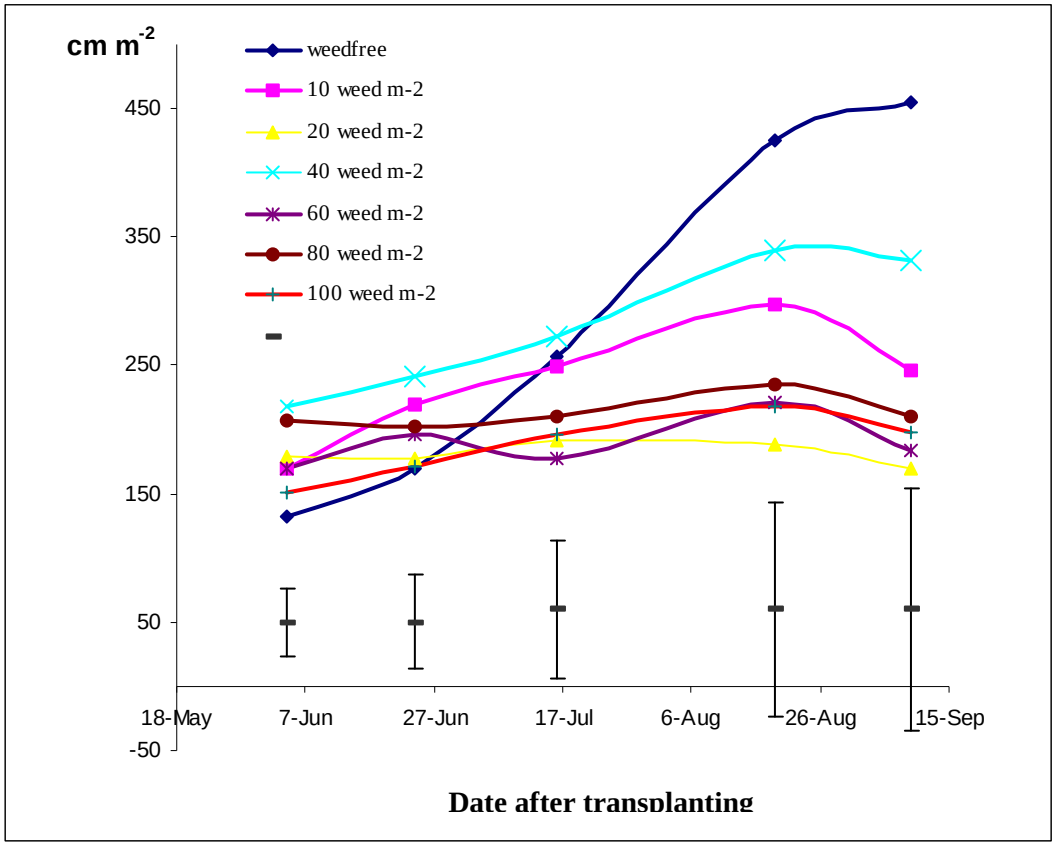


Fig. 3.11 The effect of different densities of *B. pilosa* on total dewlap height of cane stalks. The vertical error bars indicate 2 x s.e.d. of mean at each observation date.

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.

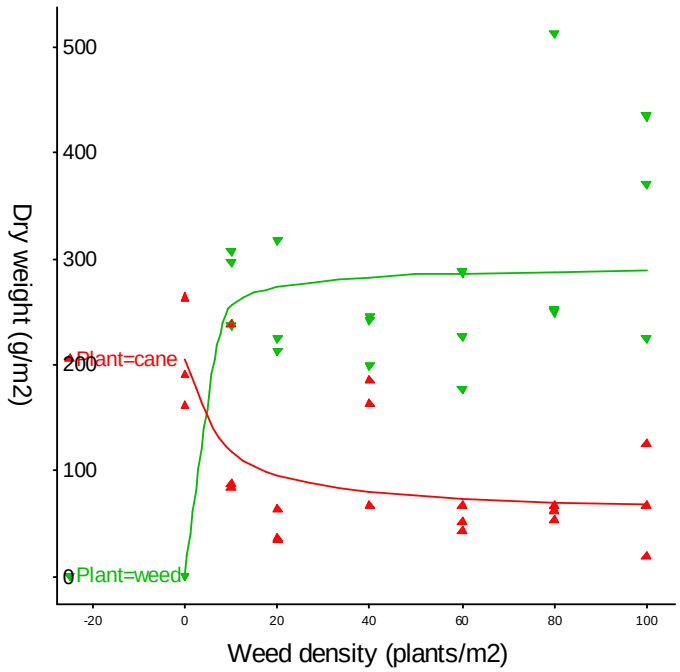


Fig. 3.12 Relationships between the dry weight (g m^{-2}) of cane (red) and *B. pilosa* (green) with weed density. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density; for cane R^2= 0.39 and parameter values D= 0.156 (0.175), B= 150.2 (40.7) 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.

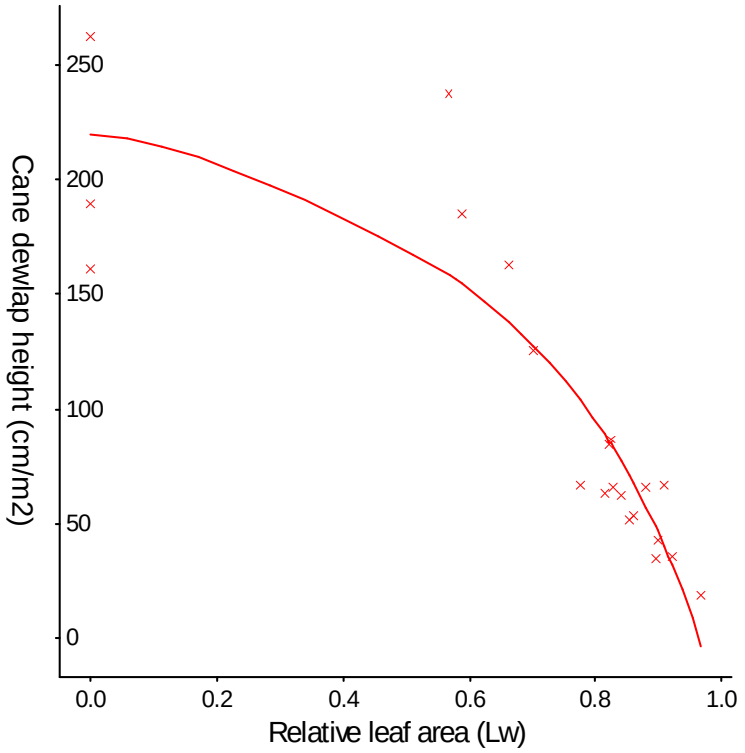


Fig. 3.13 Relationship between cane dewlap height (cm m^{-2}) and relative leaf area of *B. pilosa*. Response curve represents fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density; R^2= 0.79 and parameter values D= -0.756 (0.106), B= -81.6 (40.2) and A= 301.6 (54.0).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

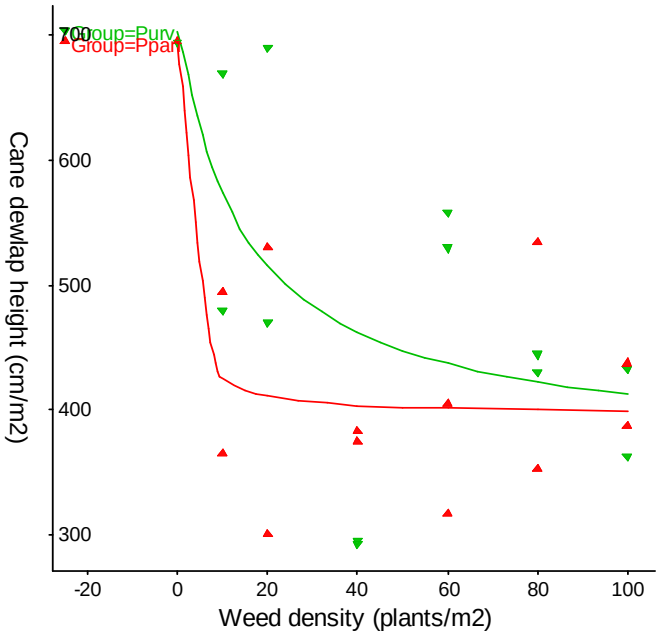


Fig. 3.14 Relationships between total cane dewlap height (cm m^{-2}) and the relative leaf area of *P. paniculatum* (red) and *P. urvillei* (green) at 14 WAT. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density; for *P. paniculatum* R^2= 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).

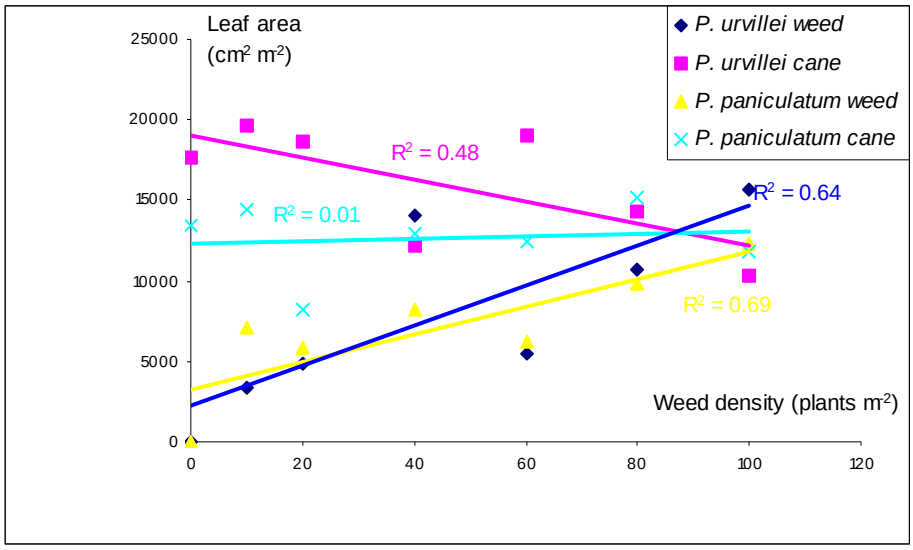


Fig. 3.15 Effect of increasing weed density of *P. paniculatum* and *P. urvillei* on weed and cane leaf areas (14 WAT)

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.

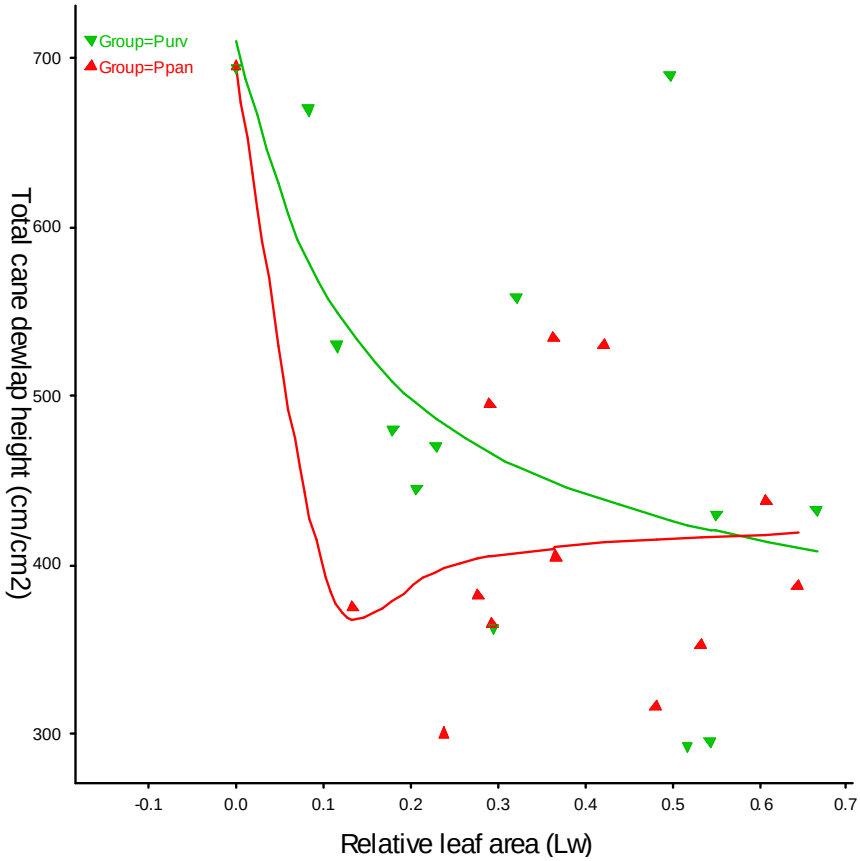


Fig. 3.16 Relationship between the loss in cane dewlap height and the relative leaf area of *P. paniculatum* (red) and *P. urvillei* (green) 14 WAT. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density; for *P. paniculatum* R^2= 0.46 and 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.

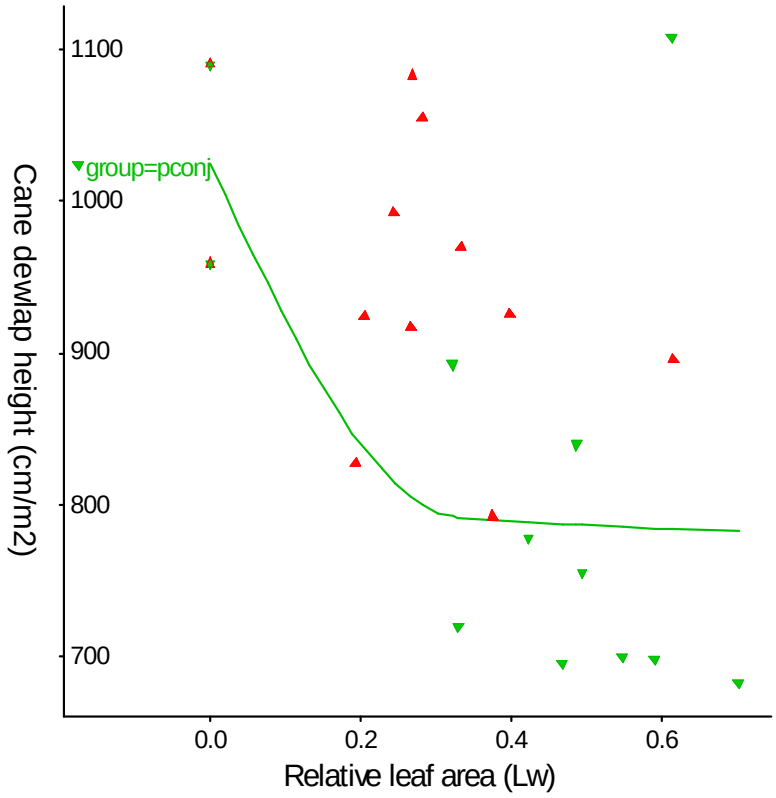


Fig. 3.17 Relationship between cane dewlap height (cm m^{-2}) and the relative leaf area of *P. commersonii* (red) and *P. conjugatum* (green). Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density; for *P. conjugatum* R^2= 0.22, D= 41 (543), 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.

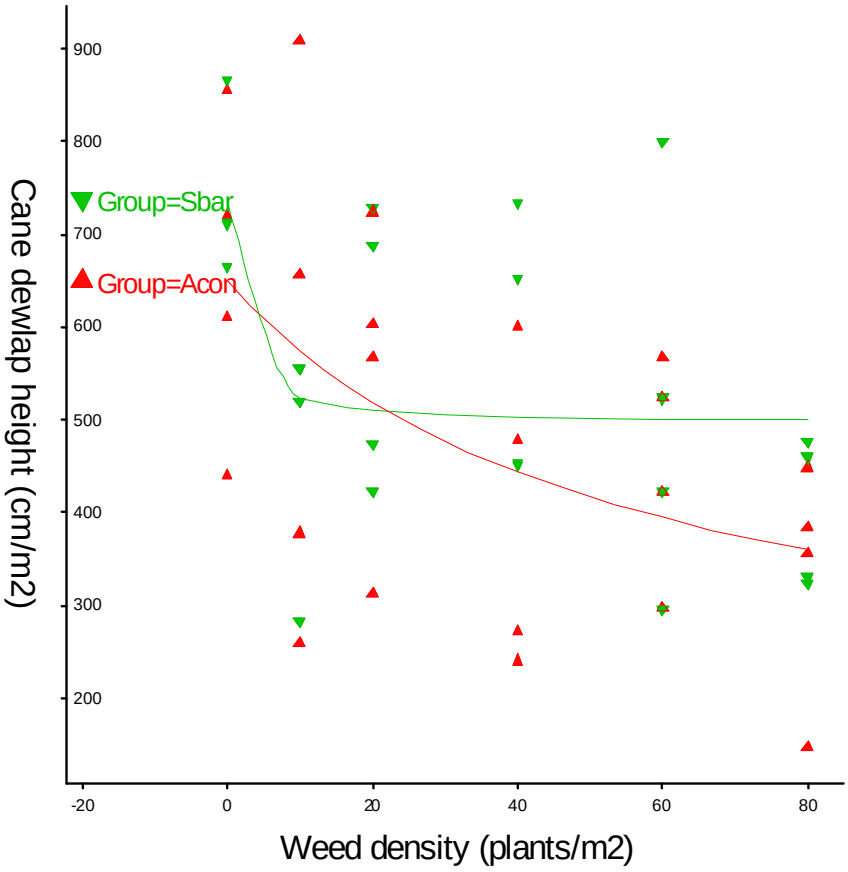


Fig. 3.19 Relationship between cane dewlap height (cm m^{-2}) and density of *A. conyzoides* (red) and *S. barbata* (green). Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density. For *A. conyzoides*, R^2= 0.21 and parameter values D= 0.019 (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*.

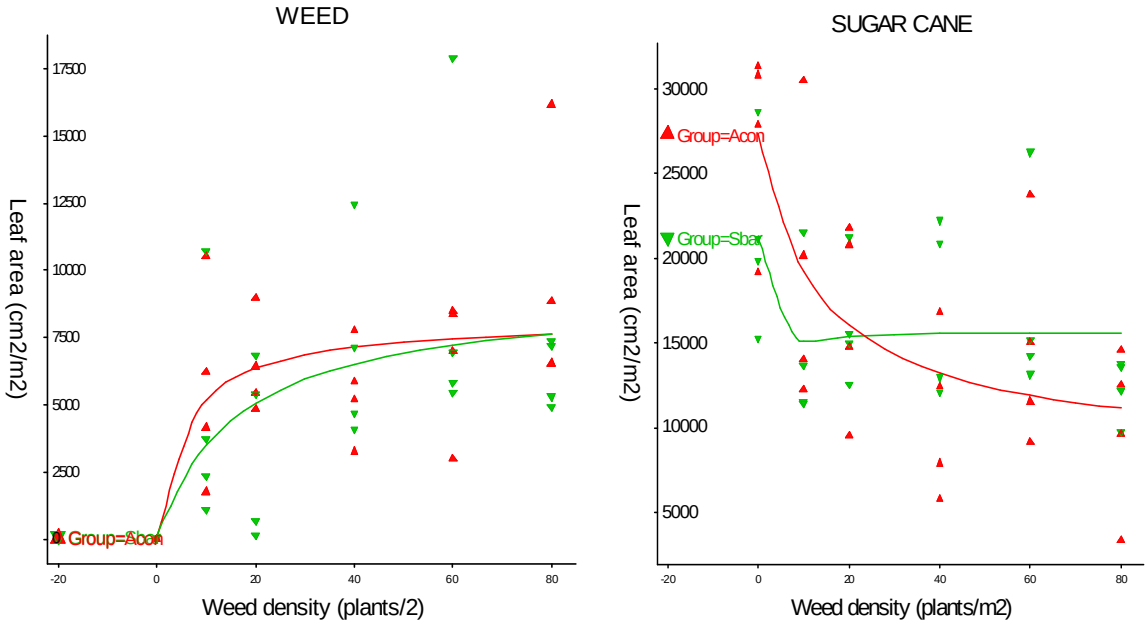


Fig. 3.20 Relationship between the density (plants m^{-2}) of *A. conyzoides* (red) and *S. barbata* (green) and leaf area (cm^2 m^{-2}) of weed (left) and cane (right). Response curves are those from parameters given in Table 3.11.

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*.

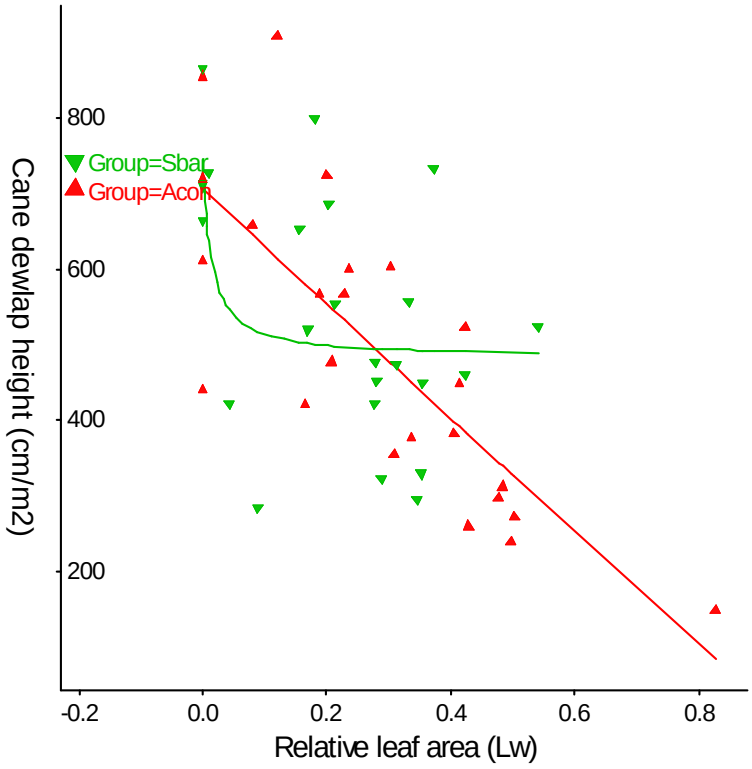


Fig. 3.21 Relationship between cane dewlap height (cm m^{-2}) and the relative leaf area of *A. conyzoides* (red) and *S. barbata* (green). Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where X is weed density. For *A. conyzoides*, R^2= 0.58 and parameter 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.