CHAPTER 4

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

4.1 Introduction

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

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

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

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

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

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

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

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

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

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

where q_0 is the value of q when L_w is observed at t = 0 (the moment of observation for which the relative damage coefficient q has been determined from experimental data) and t indicates the period between t = 0 and the moment of observation (in degree days) for which the relative competitiveness q will characterize the effects. $R_{1(c)}$ and $R_{1(w)}$ are the relative growth rate of leaf area of the crop and the weed respectively. When q_0 is determined for a given crop - weed combination at a certain time period after crop emergence, the value of the relative competitiveness q value at other dates of observations can be estimated using this equation.

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

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

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

4.2 Materials and methods

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

Trial site and plant material

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

Treatments and experimental layout

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

Data collection and analysis

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

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

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

Statistical and regression analysis

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

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

Trial site and plant material

The field experiment to study weed competition from *P. paniculatum* and *P. urvillei* on sugar cane was established in March 2005 at Réduit Experiment Station, L soil group (Parish & Feillafé, 1965). Sugar cane, variety R 570, was initially planted in November 2004 using three-eyed cuttings obtained from a plant cane field on the station and using recommended local cultural practices. Young plants of the two weeds were collected from abandoned fields in the Belle-Rive and Ebène regions and were transplanted on 20 January 2005 after pruning of the upper part of the leaves to reduce transpiration. At the start of this experiment, on 10 March 2005, the now vigorous cane shoots were stubble-shaved, to equalise the initial size of the weeds and cane, and to allow new shoots to sprout (ratooning) again from all plots. The weed infestation were maintained and restored by recruiting some gaps within the first week of April 2005.

Treatments and experimental layout

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

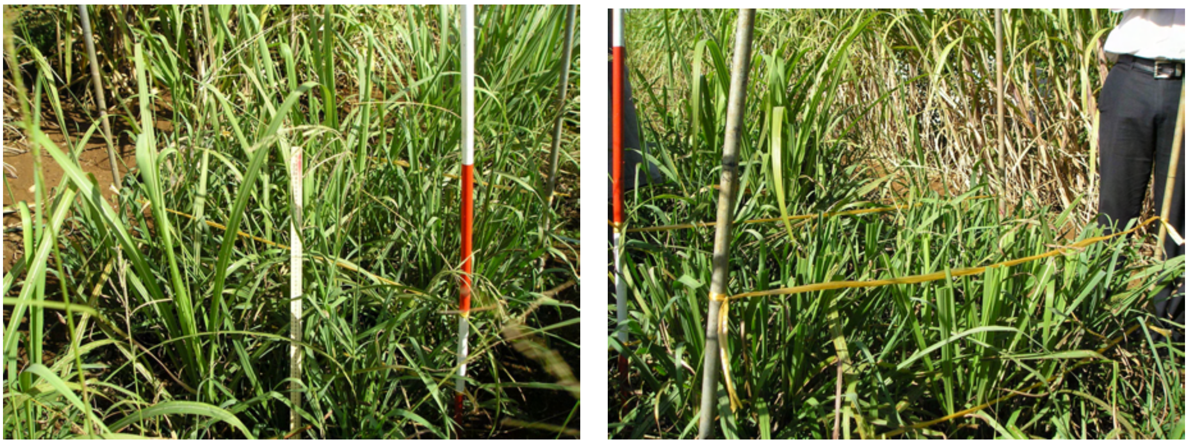
Data collection and analysis

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

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

Statistical and regression analysis

All cane measurements and leaf area data were subjected to ANOVA. The relative leaf area (L_w) was calculated from the cane and weed leaf area data. The effect of competition from the two *Paspalum* species were compared by fitting regression curves of the loss in cane dewlap (total) height compared to the weed-free mean against the relative leaf area using the rectangular hyperbola (linear-by-linear) function in Genstat (Genstat, 2005). Only regressions that were statistically significant ($P < 0.05$) were presented, even though the R^2 values were sometimes low (where fits were not statistically significant the regressions lines were not presented).



(a) **(b)**

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

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

Trial site and plant material

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

Treatments and experimental layout

The weeds were transplanted at two dates, the first between 24 and 26 October 2005 (4 WAP) and the second on 5 and 6 December 2005 (10 WAP). At each date, *P. urvillei* and *P. paniculatum* were both manually transplanted at densities of 4, 8, 16, 32 and 48 plants m^{-2} in each plot; a weed-free plot was also included. Each plot consisted of three cane rows of 2.0 m long and cane planted at a row spacing of 1.5 m. The statistical design used was a split-split plot with the two dates of transplanting weeds as main-plots, weed species (*P. paniculatum* v/s *P. urvillei*) as sub-plot and six weed densities as sub-sub-plot treatments. All treatments were replicated four times. The middle row in each plot was kept for regular cane measurements and was harvested at the end of the experimentation. The two border rows were used for destructive sampling for cane and weed dry weight and leaf area data at each observation date. The field was irrigated regularly and all emerging weeds other than those transplanted were hand-weeded.

Data collection and analysis

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

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

Statistical and regression analysis

Data with respect to cane measurements (dewlap height, no of shoots), dry weight (aboveground biomass), leaf area and cane yields at harvest were subjected to ANOVA. The relative leaf area (L_w) was calculated from the cane and weed leaf area data. Cane yield data were fitted against the weed densities using the rectangular hyperbola (linear-by-linear) function in Genstat (Genstat, 2005). Only regressions that were statistically significant ($P < 0.05$) were presented, even though the R^2 values were sometimes low (where fits were not statistically significant the regressions lines were not presented). Relative leaf area and cane yield loss data were subjected to non-linear regression analysis (weed competition model developed by Kropff and Spitters (1991)) using Genstat (Genstat, 2005) to estimate the relative competitiveness q values for the two weed species.

4.3 Results

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

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

Rate of growth of cane and weeds

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

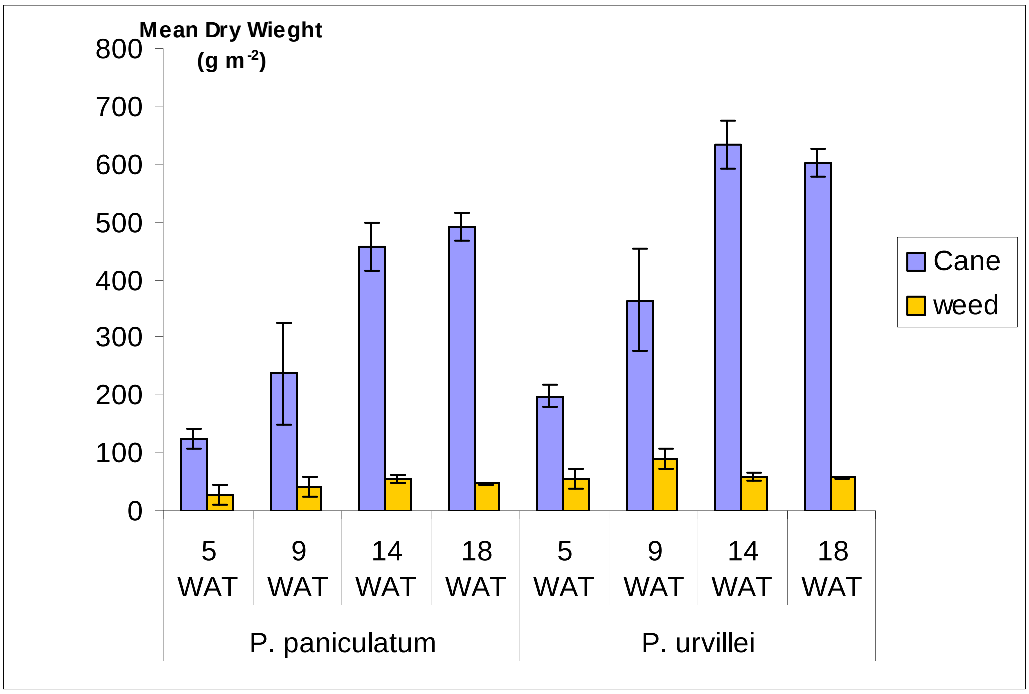


Fig. 4.2 Mean dry weight (g m^{-2}) of cane and weeds 5, 9, 14 and 18 weeks after the first transplanting (TD1) (mean of 6 weed densities for cane and 5 for weeds). Error bars show standard error of mean.

Relative dry weight of cane and weeds

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

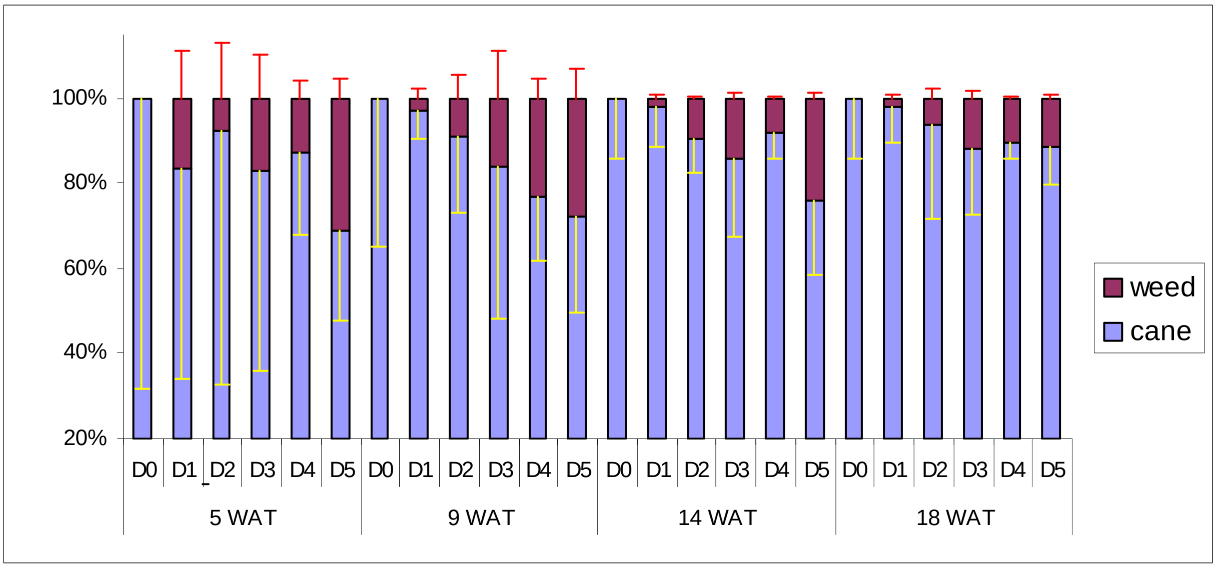


Fig. 4.3a Relative dry weight of cane and *P. paniculatum* at different weed densities (D0= 0, D1= 6, D2= 10, D3= 15, D4= 20 and D5= 33 plants m^{-2}) and observation dates. For each date of observation, the yellow error bars represent 1 x s.e.d. for cane and red error bars represent 1 x s.e.d. for weed.

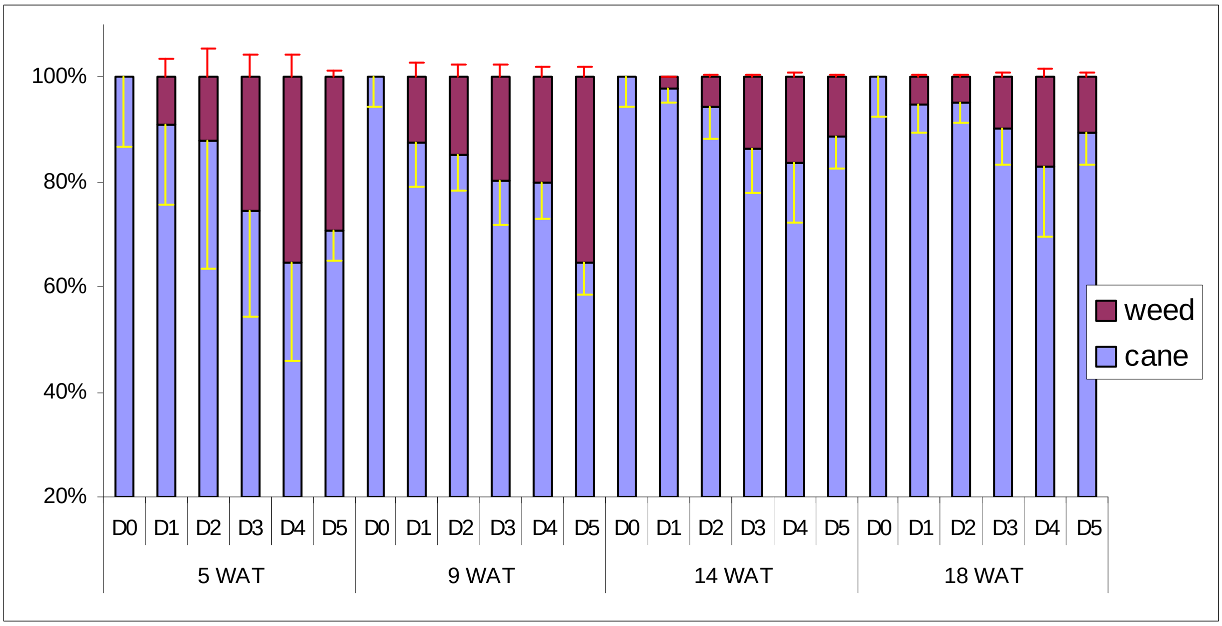


Fig. 4.3b Relative dry weight of cane and *P. urvillei* at different weed densities (D0= 0, D1= 6, D2= 10, D3= 15, D4= 20 and D5= 33 plants m^{-2}) and observation dates. For each date of observation, the yellow error bars represent 1 x s.e.d. for cane and red error bars represent 1 x s.e.d. for weed.

Leaf area of cane and weed

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

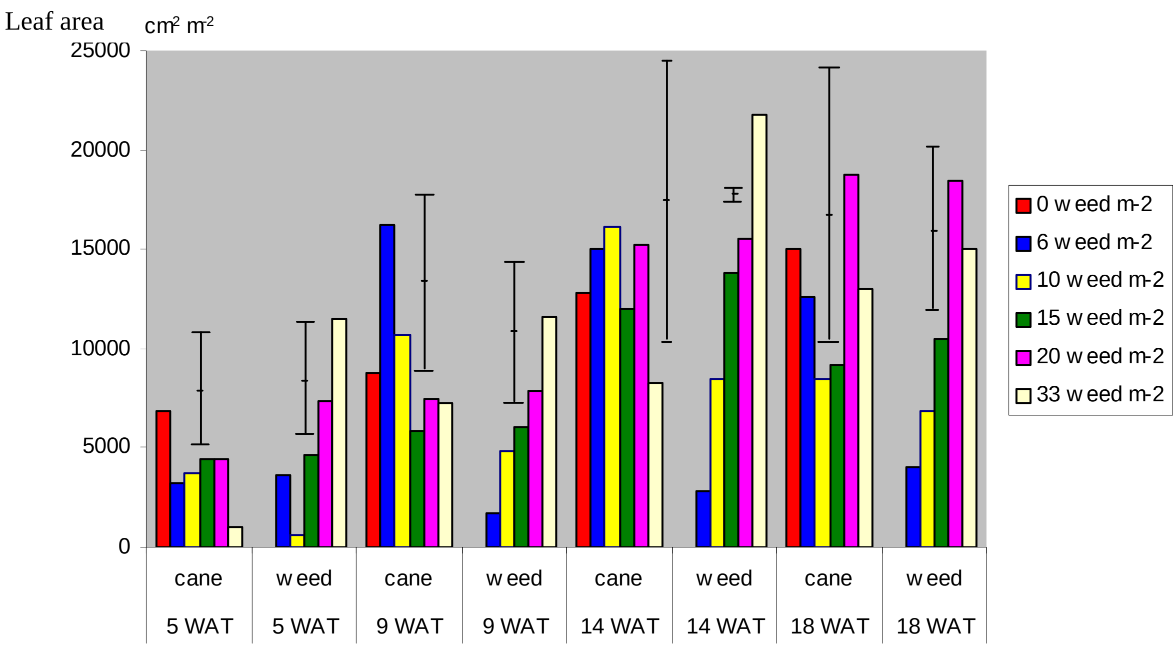


Fig. 4.4a Leaf area of cane and *P. paniculatum* at different weed densities and observation dates. Error bars represent 2 x s.e.d.

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

The mean (of five densities) relative leaf area of *P. paniculatum* was 0.55 (s.e.= 0.125), 0.41 (s.e.= 0.063), 0.48 (s.e.= 0.058) and 0.47 (s.e.= 0.054) at 5, 9, 14 and 18 WAT respectively. For *P. urvillei*, it was 0.45 (s.e.= 0.046), 0.39 (s.e.= 0.049), 0.38 (s.e.= 0.052) and 0.46 (s.e.= 0.053) at 5, 9, 14 and 18 WAT respectively. These results suggest no major drift in the relative growth of cane and the two weeds with time.

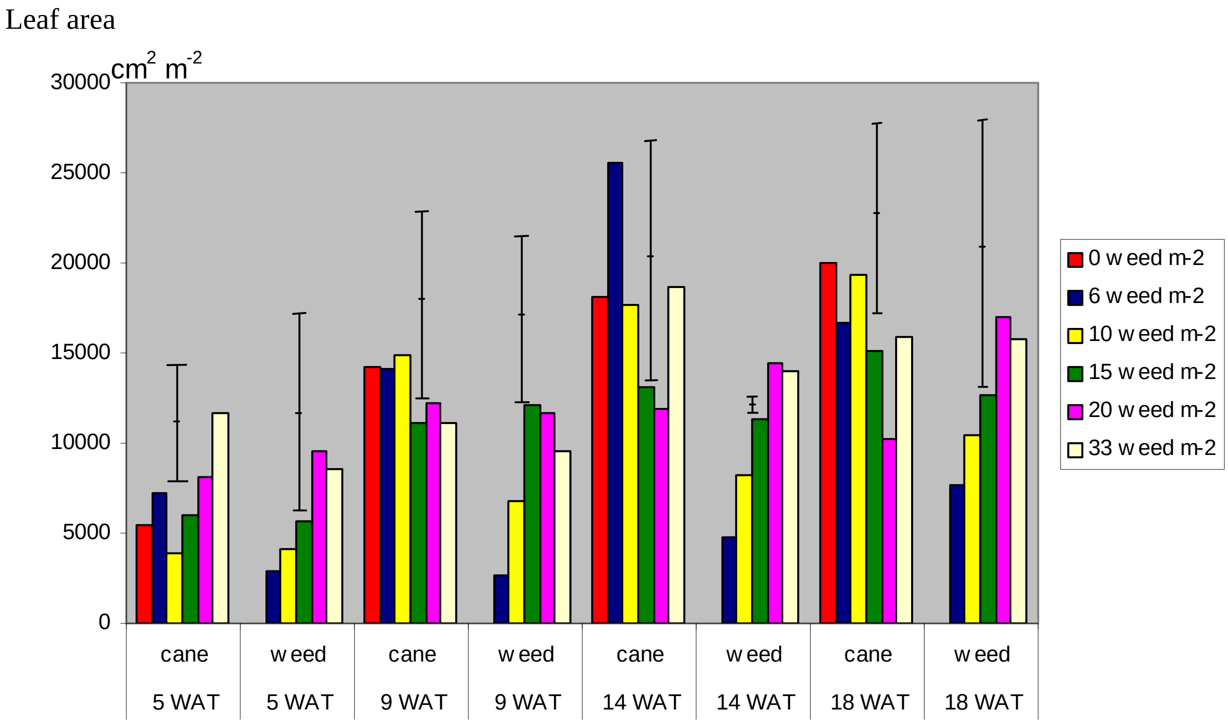


Fig. 4.4b Leaf area of cane and *P. urvillei* at different weed densities and observation dates. Error bars represent 2 x s.e.d.

Effect of weed competition on total dewlap height

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

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

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

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

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

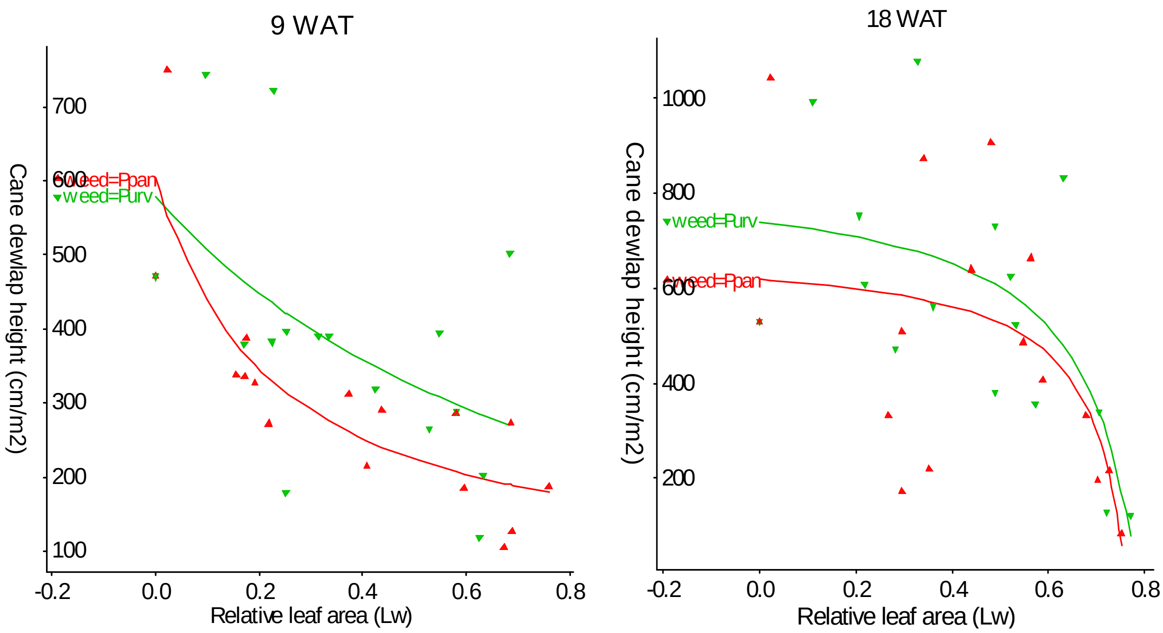


Fig 4.5 Relationship between the relative leaf area (L_w) of *P. paniculatum* or *P. urvillei* transplanted 4 WAP and dewlap height of cane (cm m^{-2}) observed at 9 WAT (left) and 18 WAT (right). Response curve are those from parameters given in Table 4.2.

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

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

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

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

Effect of weed competition on cane yield (TD1)

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

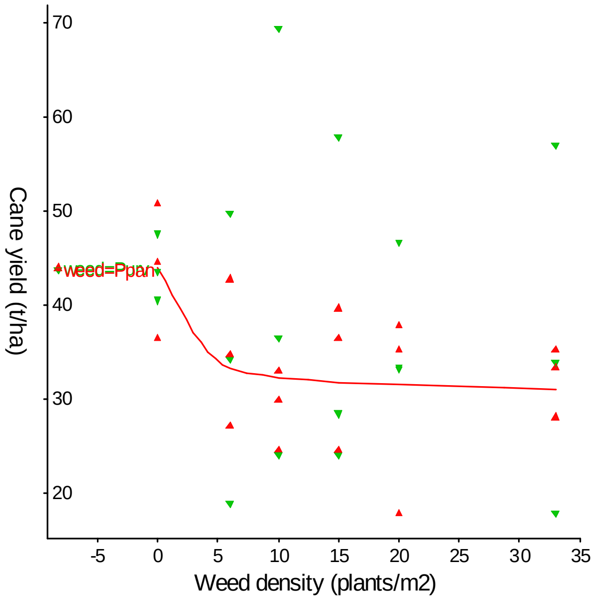


Fig. 4.6 Relationship between cane yield and weed density of *P. paniculatum* and *P. urvillei* transplanted 9 WAP. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where R^2= 0.25 and parameter values D= 0.64 (1.77), B= 13.45 (5.82) and A= 30.44 (4.33) for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

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

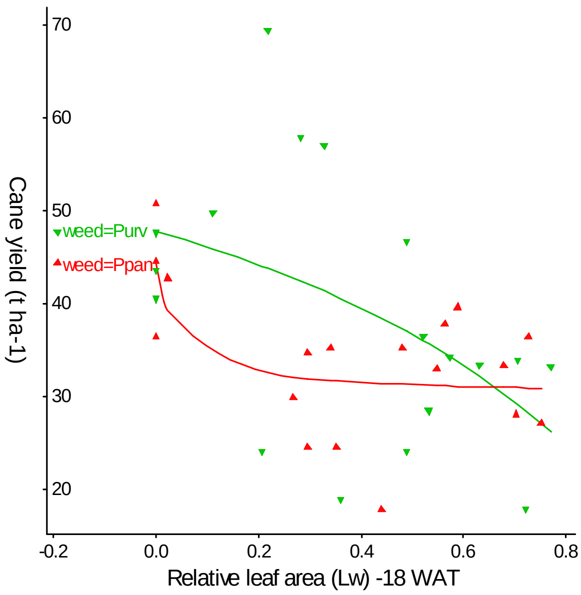


Fig. 4.7 Relationship between cane yield and relative leaf areas (L_w) of *P. paniculatum* and *P. urvillei* transplanted 9 WAP. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where R^2= 0.34 and parameter values D= 23.4 (51.3), B= 14.2 (4.57) and A= 30.1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

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

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

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

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

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

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

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

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

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

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

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

Rate of growth of cane and weeds

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

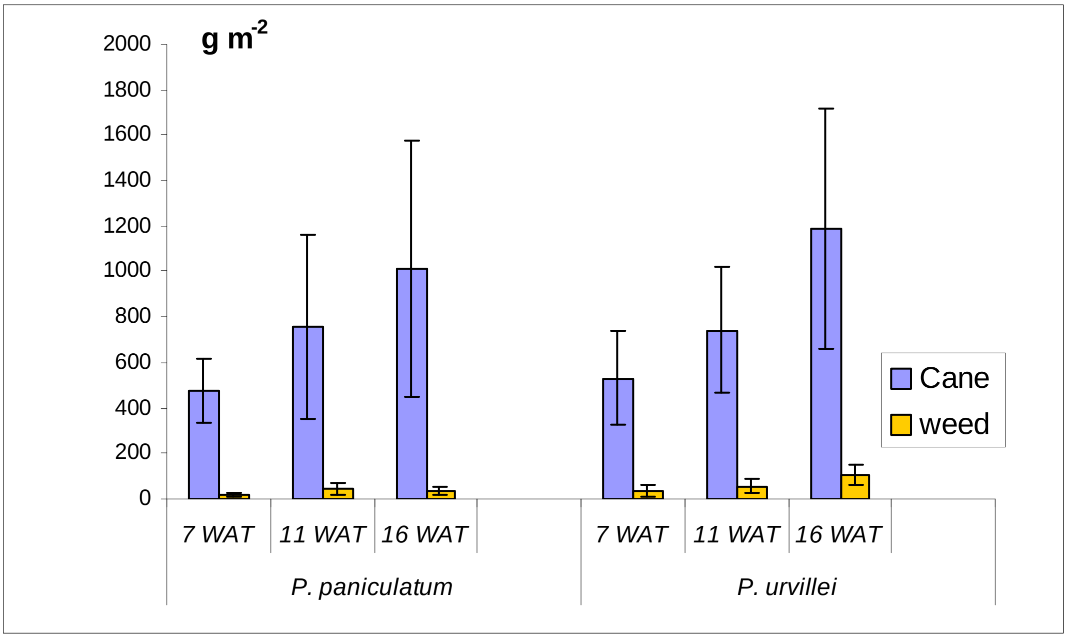


Fig. 4.8 Mean dry weight (g m^{-2}) of cane and weeds 7, 11 and 16 WAT weeds (made 17 WAP - TD2). Error bars show standard error of mean.

Relative dry weight of cane and weeds

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

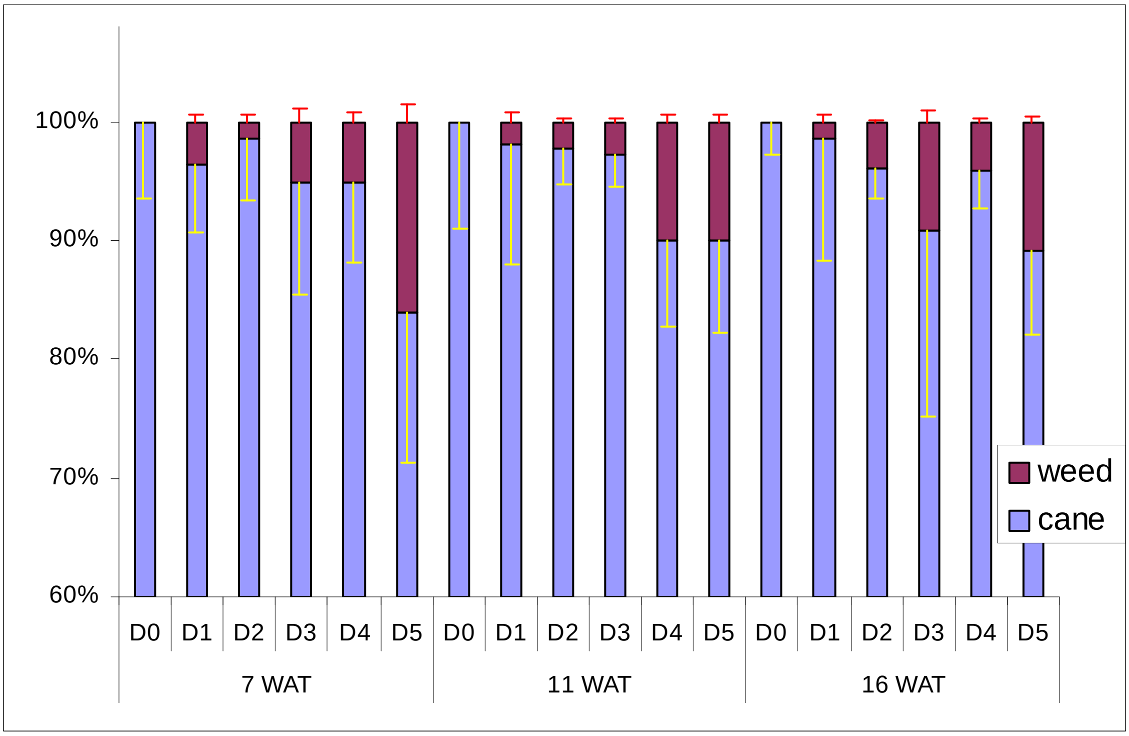


Fig. 4.9a Relative dry weight of cane and *P. paniculatum* at different weed densities (D0= weedfree, D1= 6, D2= 10, D3= 15, D4= 20 and D5= 33 plants m^{-2}) and observation dates. For each date of observation, the yellow error bars represent 1 x s.e.d. for cane and red error bars represent 1 x s.e.d.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

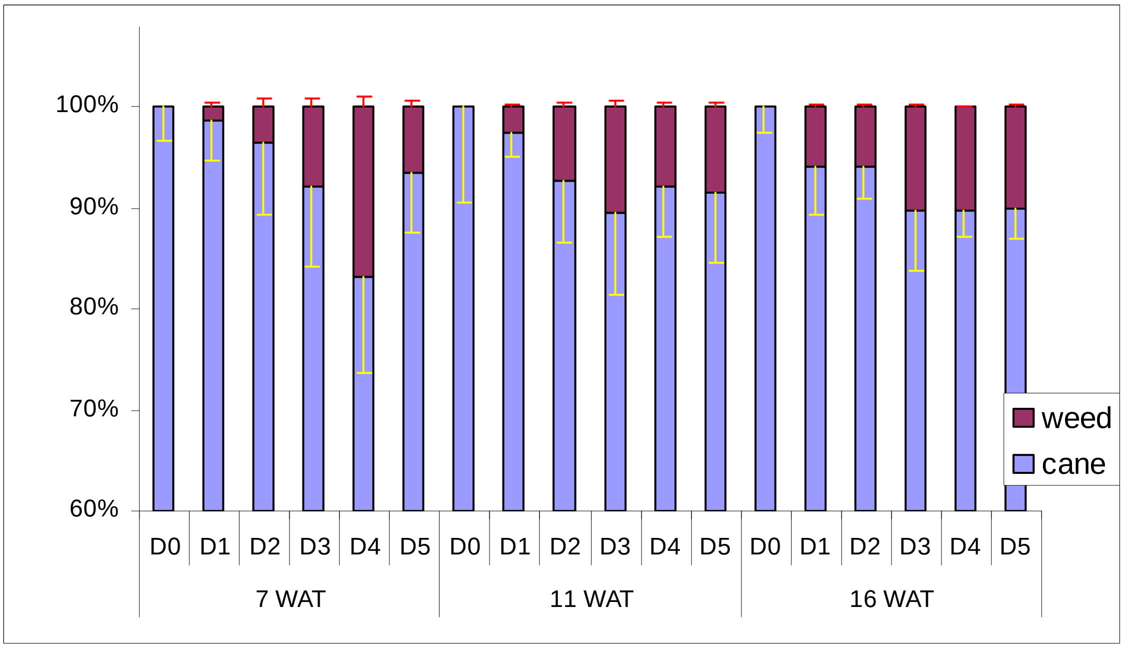


Fig. 4.9b Relative dry weight of cane and *P. urvillei* at different weed densities (D0= weedfree, D1= 6, D2= 10, D3= 15, D4= 20 and D5= 33 plants m^{-2}) and observation dates. For each date of observation, the yellow error bars represent 1 x s.e.d. for cane and red error bars represent 1 x s.e.d. for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

Leaf area of cane and weed

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

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

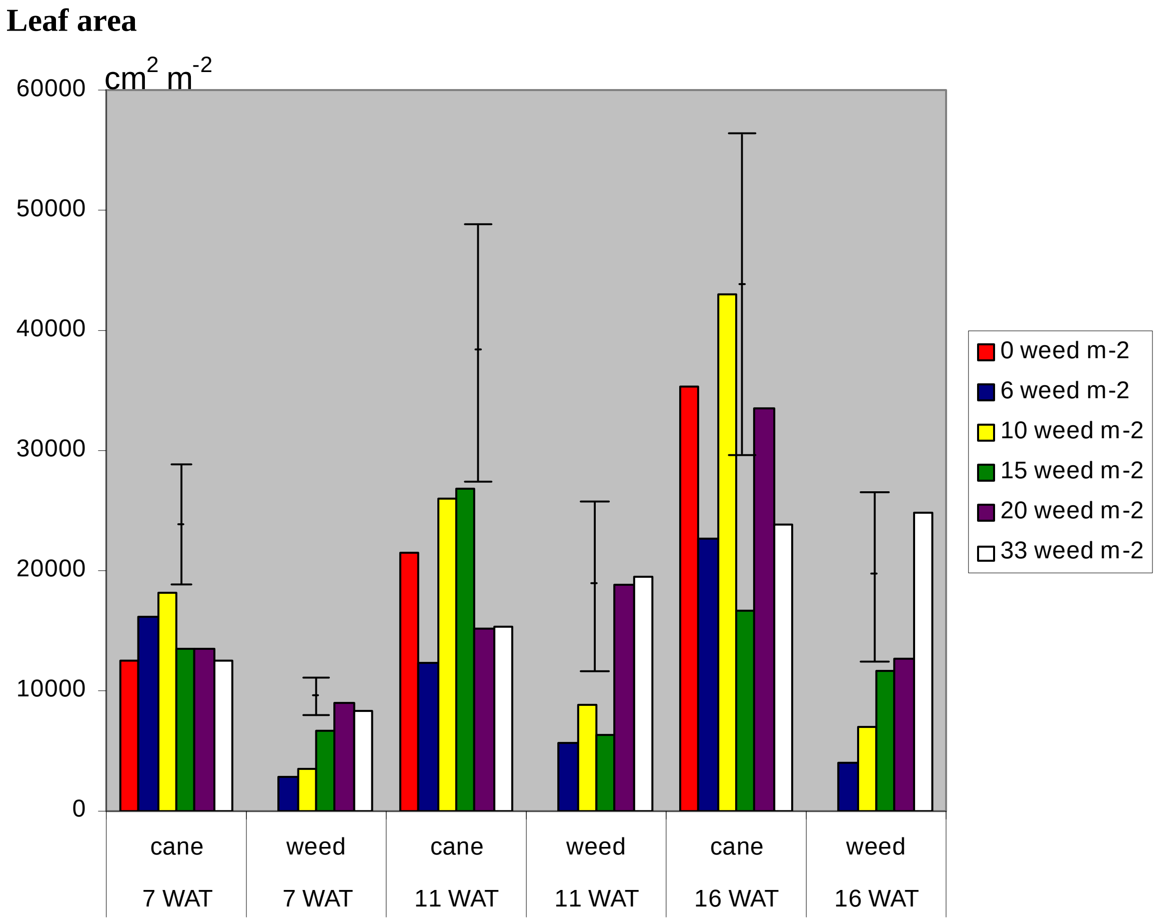


Fig. 4.10a Leaf area of cane and *P. paniculatum* at different weed densities and observation dates (TD2). Error bars represent 2 x s.e.d.

Leaf area

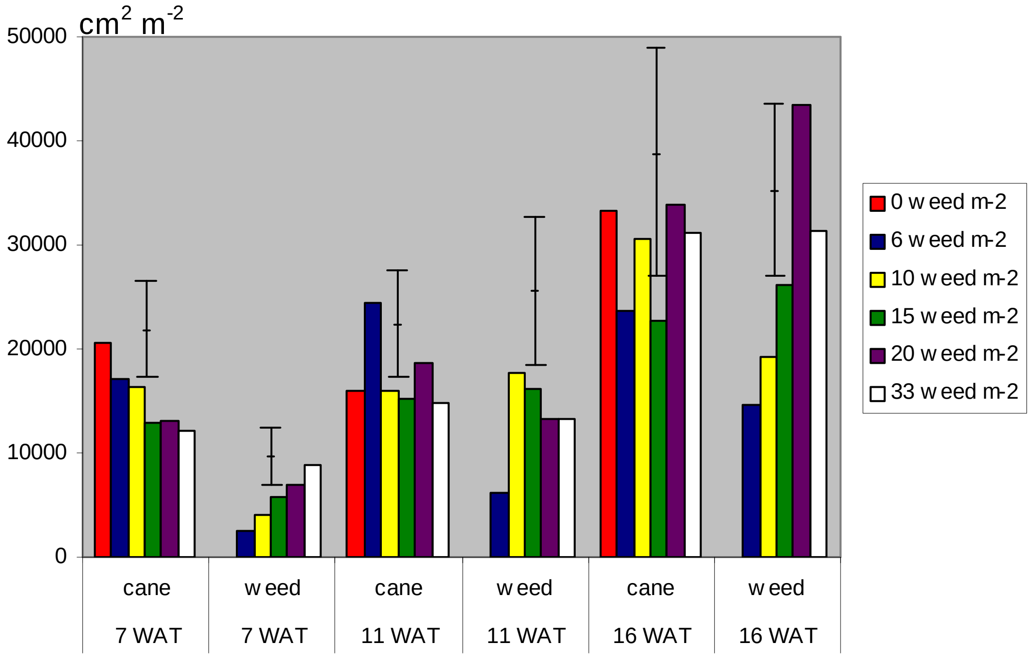


Fig. 4.10b Leaf area of cane and *P. urvillei* at different weed densities and observation dates (TD2). Error bars represent 2 x s.e.d.

Effect of weed competition on total dewlap height

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

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

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

* weed x density x rep

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

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

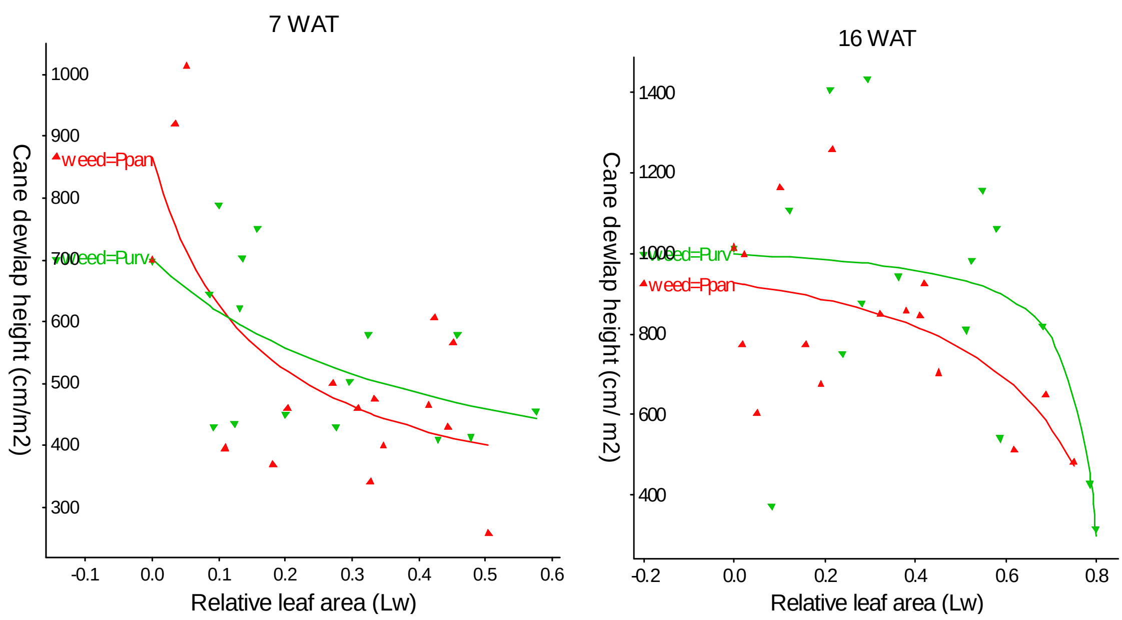


Fig 4.11 Relationship between the relative leaf area (L_w) of *P. paniculatum* or *P. urvillei* transplanted 17 WAP and dewlap height of cane (cm m^{-2}) observed 7 WAT (left) and 16 WAT (right). Response curves are those from parameters given in Table 4.6.

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

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

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

Effect of weed competition on cane yield (TD2)

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

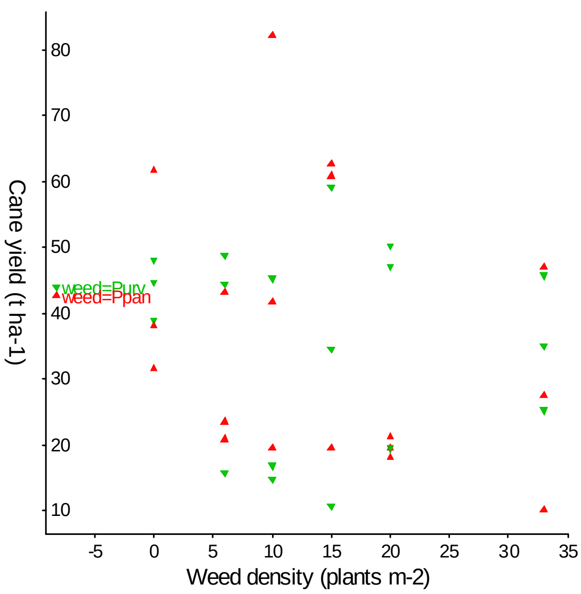


Fig 4.12 Relationship between weed density (plants m^{-2}) of *P. paniculatum* or *P. urvillei* transplanted 17 WAP and cane yield (t ha^{-1}). No fit for both response curves was obtained.

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

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

Stage of cane growth at transplanting of weeds

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

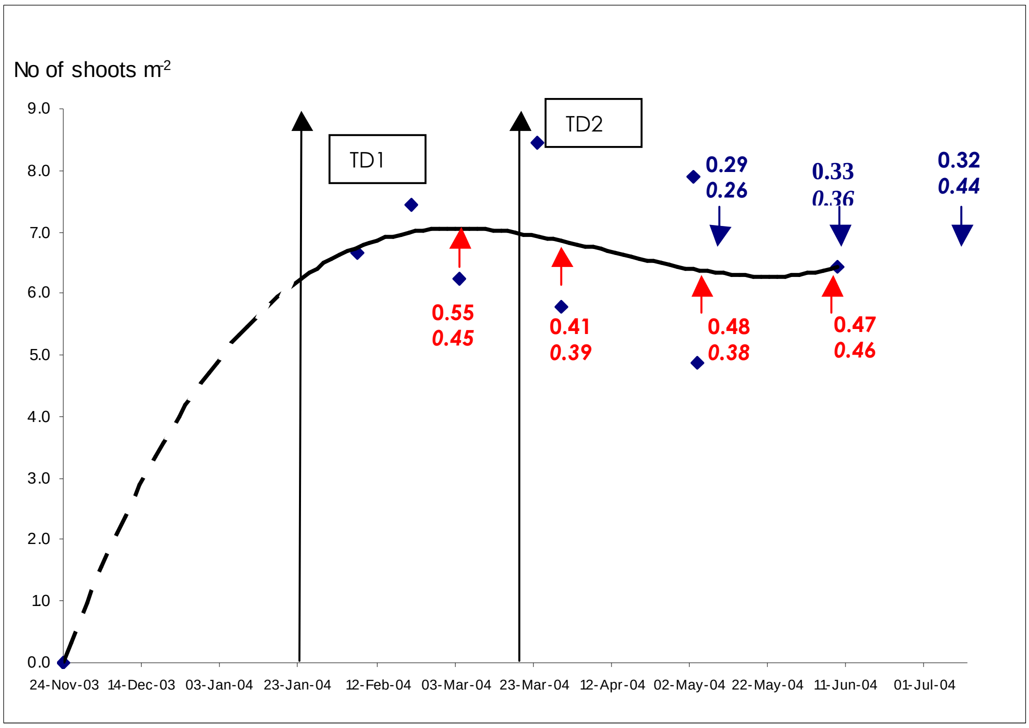


Fig. 4.13 Cane tillering in the weed-free plots and arrows showing first (TD1) and second (TD2) dates of transplanting of weeds (black), date of observations after 1st transplanting (red arrow) and date of observation after 2nd transplanting (blue arrow). The relative leaf areas (L_w) for *P. paniculatum*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

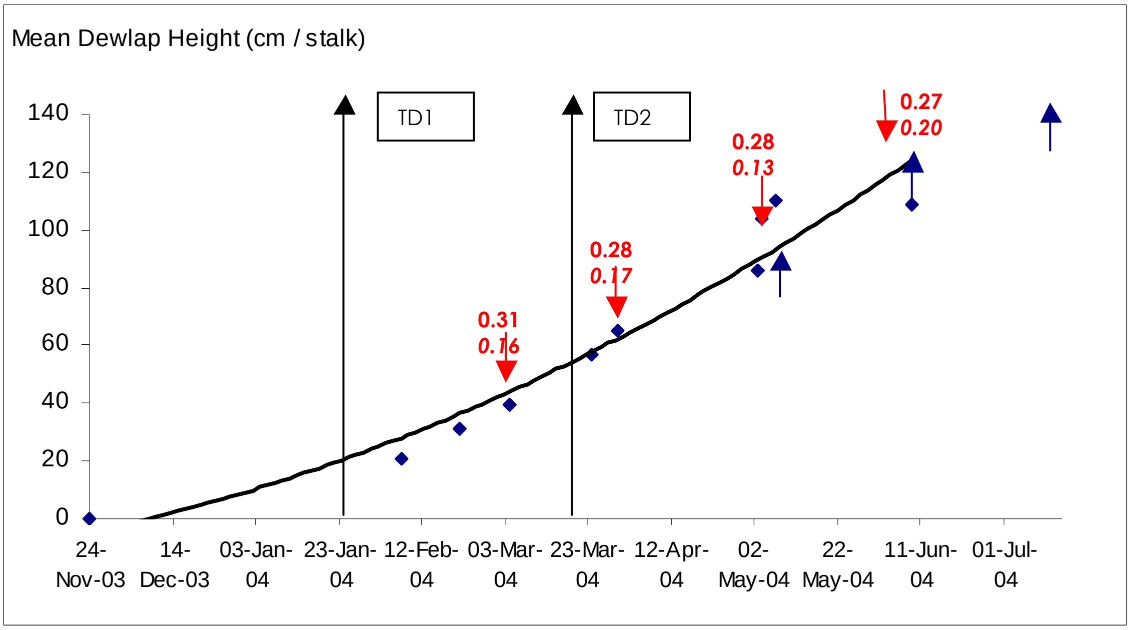


Fig. 4.14 Mean dewlap height of cane stalks in the weedfree plots and arrows showing first (TD1) and second (TD2) dates of transplanting of weeds (black), date of observations after 1st transplanting (red arrow) and date of observation after 2nd transplanting (blue arrow). The q values for *P. paniculatum*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

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

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

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

Effect on cane growth

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

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

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

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

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

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

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

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

Leaf area of cane and weeds

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

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

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

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

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

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

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

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

Relative leaf area and reduction in dewlap height

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

There was an indication that the loss in cane dewlap height by *P. urvillei* was higher than that with *P. paniculatum* (Fig. 4.15); this was partly shown by the parameter A (showing asymptotic loss) in the response curves of the two weeds (Table 4.11). However, *P. paniculatum* exhibited lower L_w than *P. urvillei*.

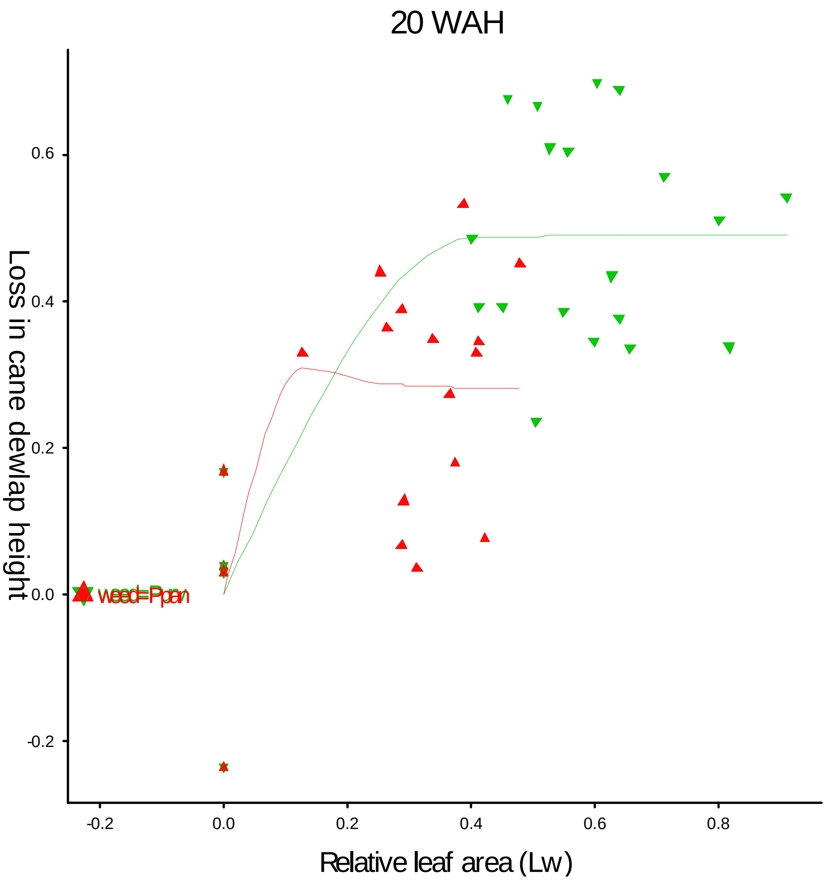


Fig 4.15 Relationship between the relative leaf area (L_w) of *P. paniculatum* (rin red) or *P. urvillei* (in green) and loss in cane dewlap height of cane observed 20 WAH. Response curve are those from parameters given in Table 4.11

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

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

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

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

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

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

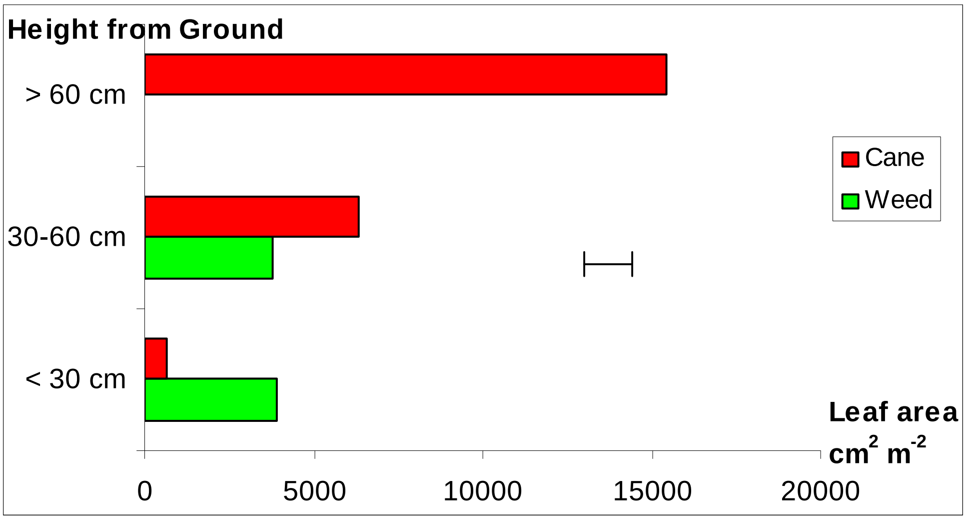


Fig. 4.16a Distribution of leaf area (cm^2 m^{-2}) of sugar cane and *P. paniculatum* at different plant heights measured 18 WAH. Columns are means of five weed densities and four replications. Error bar represents 2 x s.e.d.

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

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

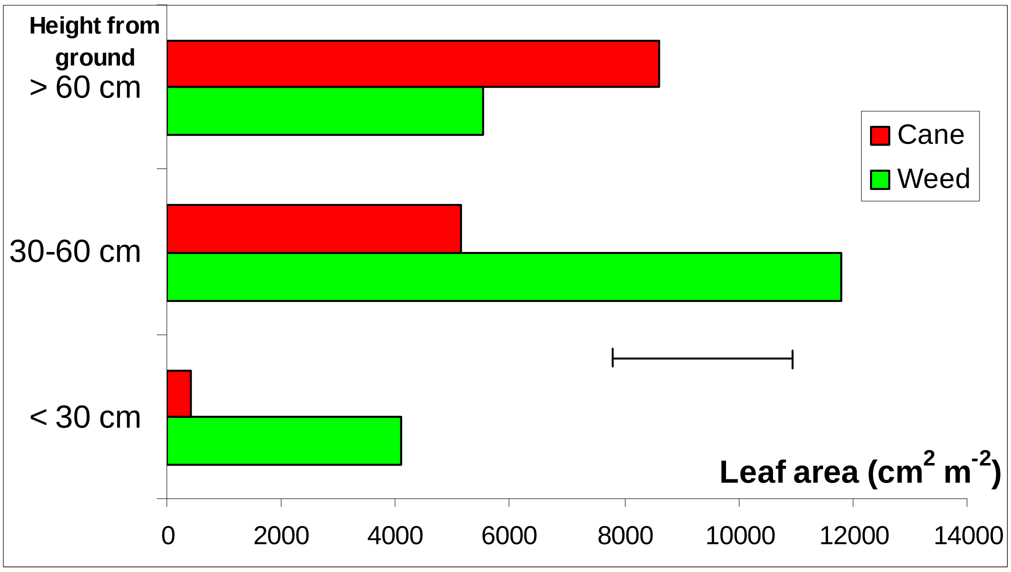


Fig. 4.16b Distribution of leaf area (cm^2 m^{-2}) of sugar cane and *P. urvillei* at different plant heights measured 18 WAH. Columns are means of five weed densities and four replications. Error bar represents 2 x s.e.d.

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

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

Increase in total cane dewlap height and effect of weed competition

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

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

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

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

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

Effect of weed competition on tillering

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

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

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

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

Leaf area of cane and weed

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

Irrespective of the date of observation, the relative leaf area (L_w) of *P. urvillei* was higher than those of *P. paniculatum*. The mean (of all densities) L_w for *P. paniculatum* was found to be highest at 13 WAT; i.e. 0.36 (s.e.= 0.052), 0.34 (s.e.= 0.048), 0.52 (s.e.= 0.069) and 0.46 (s.e.= 0.068) at 6, 9, 13 and 18 WAT respectively. The same trend was observed for *P. urvillei;* the L_w was 0.47 (s.e.= 0.047), 0.52 (s.e.= 0.050), 0.73 (s.e.= 0.061) and 0.65 (s.e.= 0.040) respectively for 6, 9, 13 and 18 WAT. The relative leaf area (L_w) tended to be higher at the last two observation dates than at first two dates.

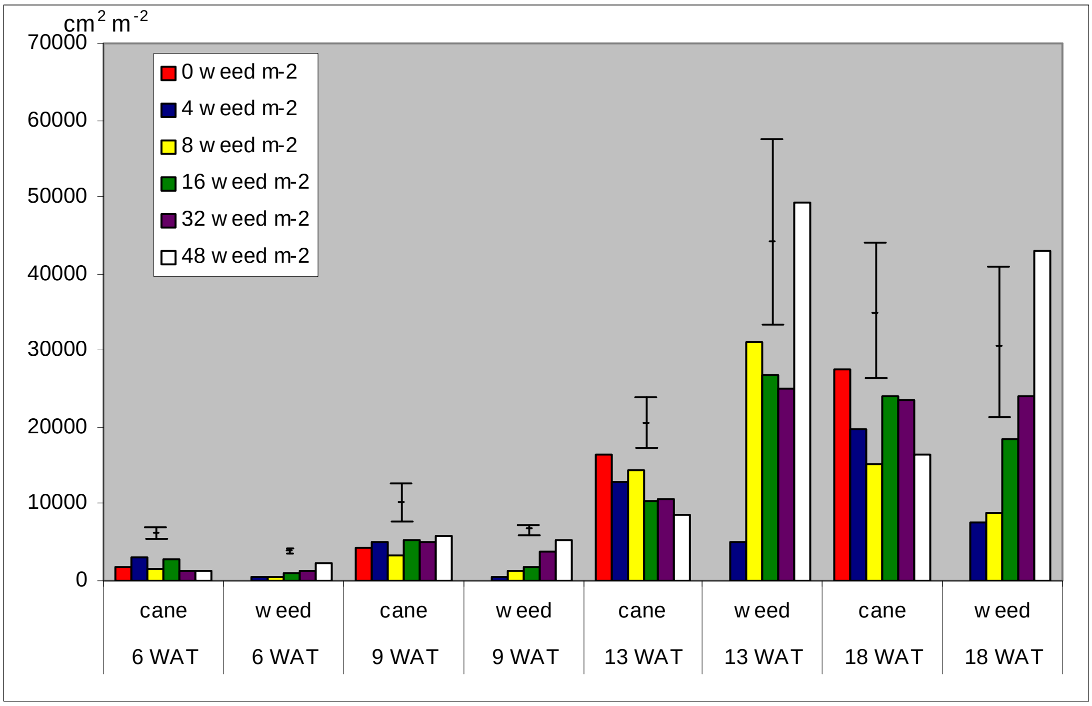


Fig. 4.17a Leaf area of cane and *P. paniculatum* at different weed densities and observation dates. Error bars represent 2 x s.e.d.

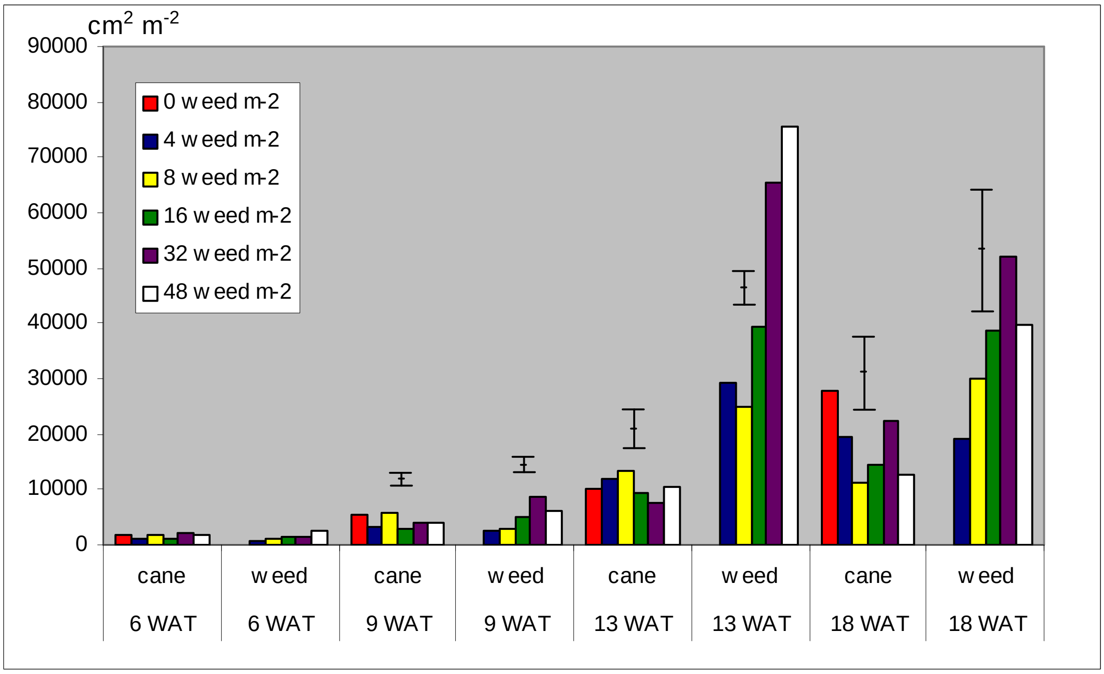


Fig. 4.17b Leaf area of cane and *P. urvillei* at different weed densities and observation dates. Error bars represent 2 x s.e.d.

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

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

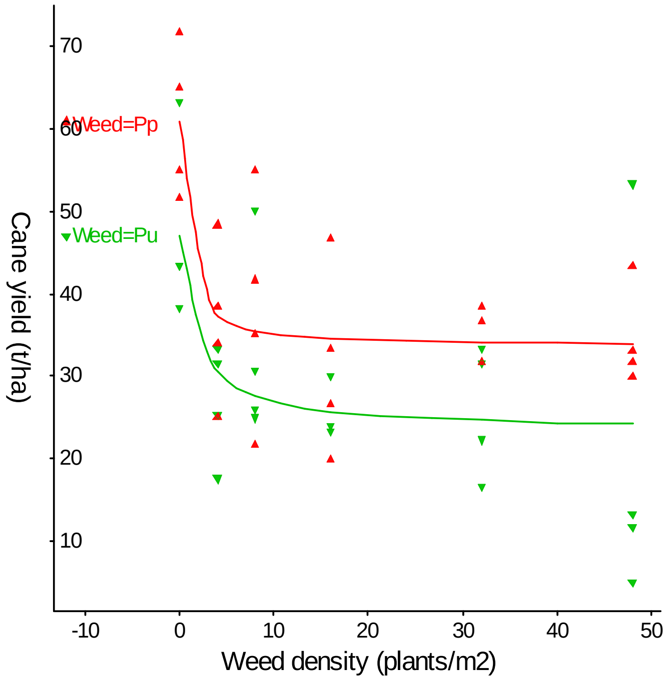


Fig. 4.18 Effect of weed competition on cane yield from *P. paniculatum* and *P. urvillei* transplanted 4 WAP. Response curves represent fitted lines using the rectangular hyperbola model (A + B/(1+D*X)) where the R^2= 0.52 and parameter values D= 1.63 (3.05), B= 27.2 (5.60) and A= 33.62 (3.32) for *P.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

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

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

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

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

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

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

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

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

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

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

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

Increase in total cane dewlap height and effect of weed competition

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

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

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

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

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

Effect of weed competition on tillering

Irrespective of the weed species, weed competition had no adverse effect on cane tillering at the first observation date (6 WAT) and third date (15 WAT). A significant ($P< 0.05$) reduction in the number of shoots was recorded at 9 WAT when the cane was nearer to the peak of its tillering phase (Table 4.17). As the number of shoots reduced naturally after that period, weed competition had no further impact on the tillering. But even at 9 WAT the pattern of responses did not produce a clear link between weed density and tillering.

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

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

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

Leaf area of cane and weed

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

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

Leaf area

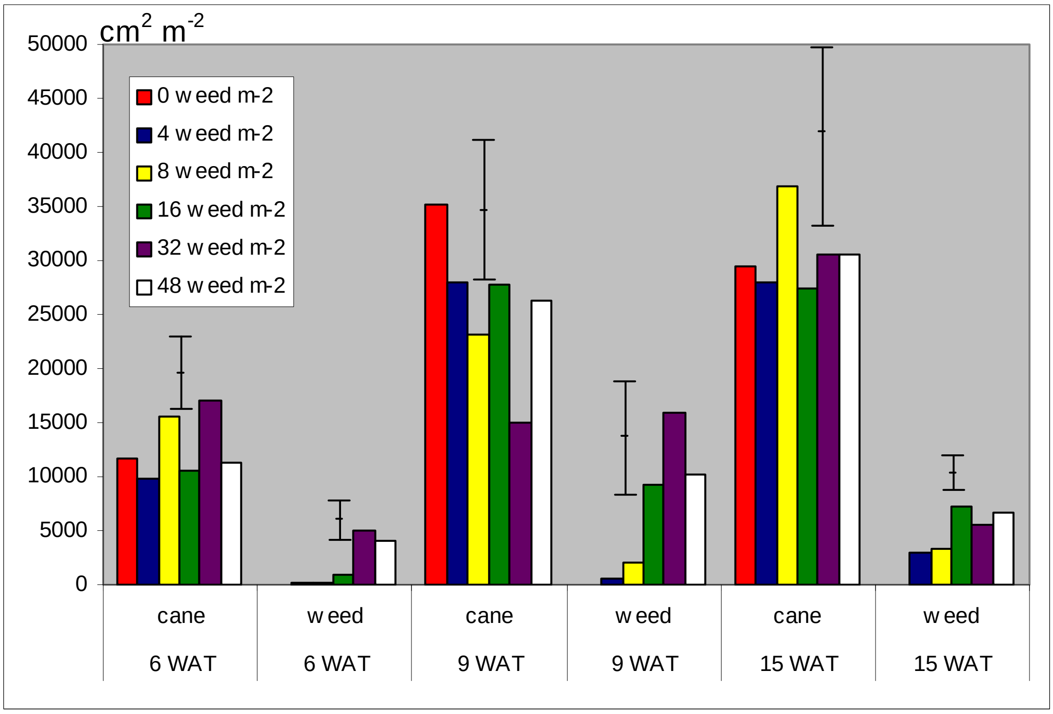


Fig. 4.19a Leaf area of cane and *P. paniculatum* at different weed densities and observation dates. Error bars represent 2 X s.e.d. (mean of all densities).

Leaf area

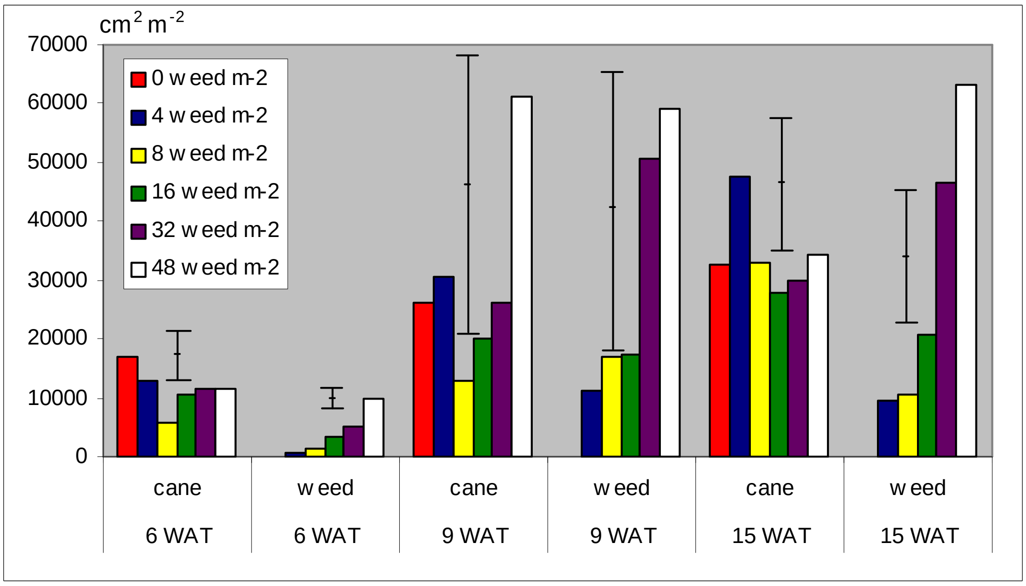


Fig. 4.19b Leaf area of cane and *P. urvillei* at different weed densities and observation dates. Error bars represent 2 x s.e.d. (mean of all densities).

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

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

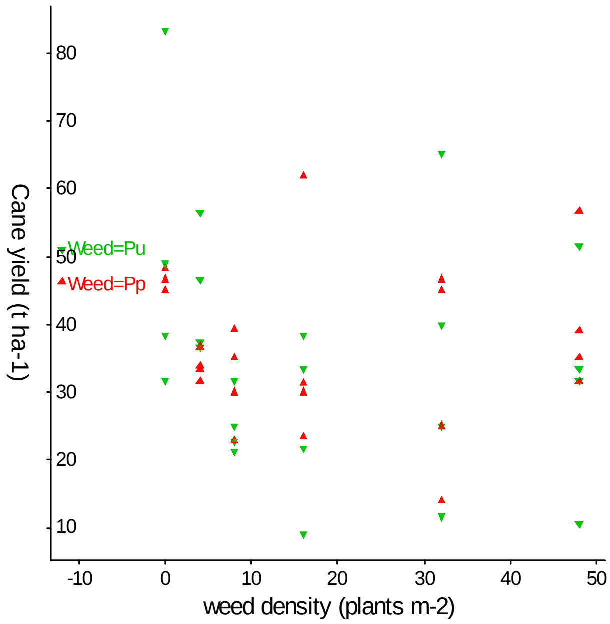


Fig 4.20 Relationship between weed density (plants m^{-2}) of *P. paniculatum* (in red) or *P. urvillei* (in green) transplanted 10 WAP and cane yield (t ha^{-1}). No fit for both response curves was obtained.

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

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

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

Effect of transplanting date of cane yields

No significant difference observed between the yields of the two transplanting dates (main plots) showing that the competition exerted at TD1 was not clearly greater than at TD2. Similarly neither the interactions with the ‘transplanting date’ nor the difference between the two weed species was significant. Only the overall mean densities were found to differ significantly (Table 4.18); the yield of the weedfree treatment was significantly higher than those recorded in the infested plots.

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

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

Stage of cane growth at transplanting of weeds

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

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

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

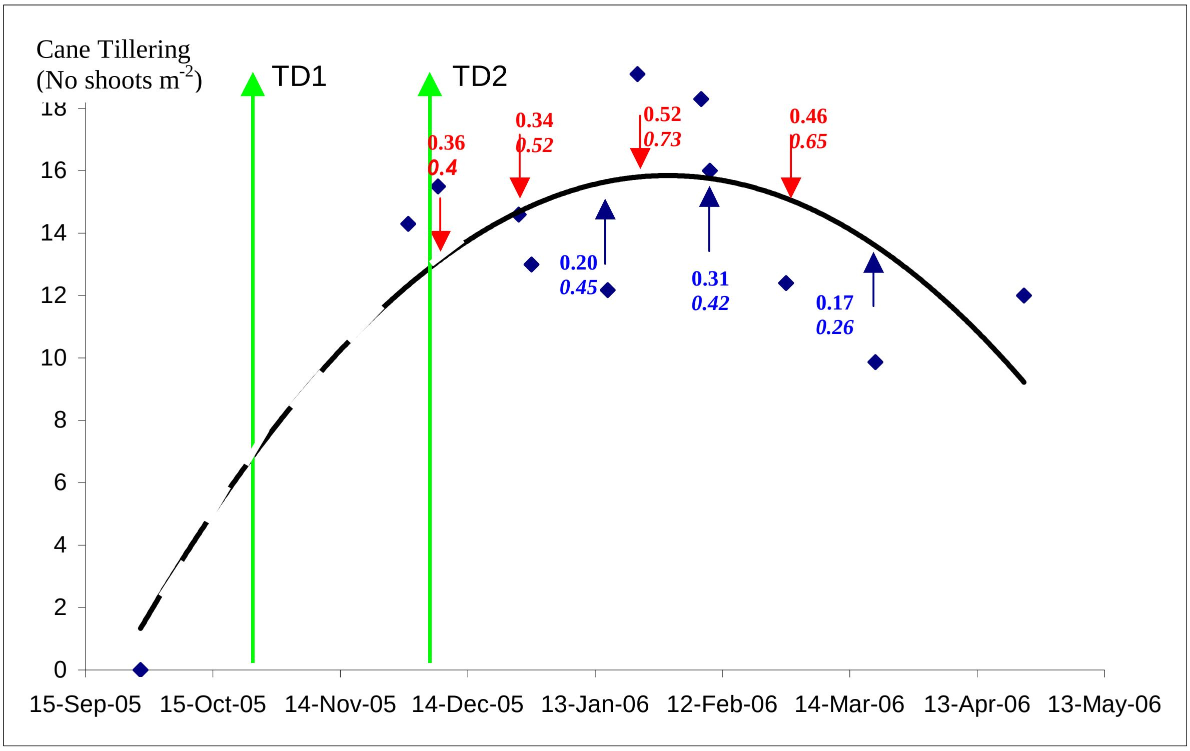


Fig. 4.21 Cane tillering in the weed-free plots and green arrows showing first (TD1) and second (TD2) dates of transplanting of weeds, small arrows show date of observations after 1st transplanting (red) and date of observation after 2nd transplanting (blue). The relative leaf areas (L_w) for *P. paniculatum*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

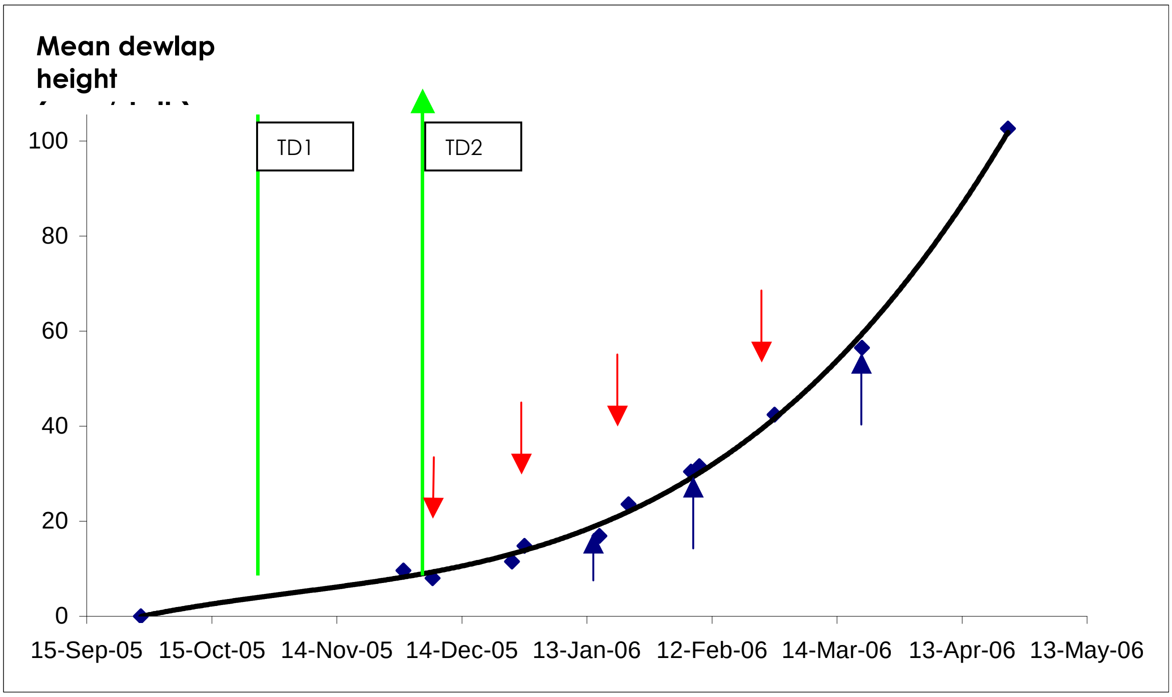


Fig. 4.22 Mean dewlap height of cane stalks in weed-free plots. Green arrows show two transplanting dates, red arrows show observation dates after 1st transplanting and blue arrows observation date after 2nd transplanting. Points show mean of four replications and two weed species.

Leaf area distribution between cane and weeds

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

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

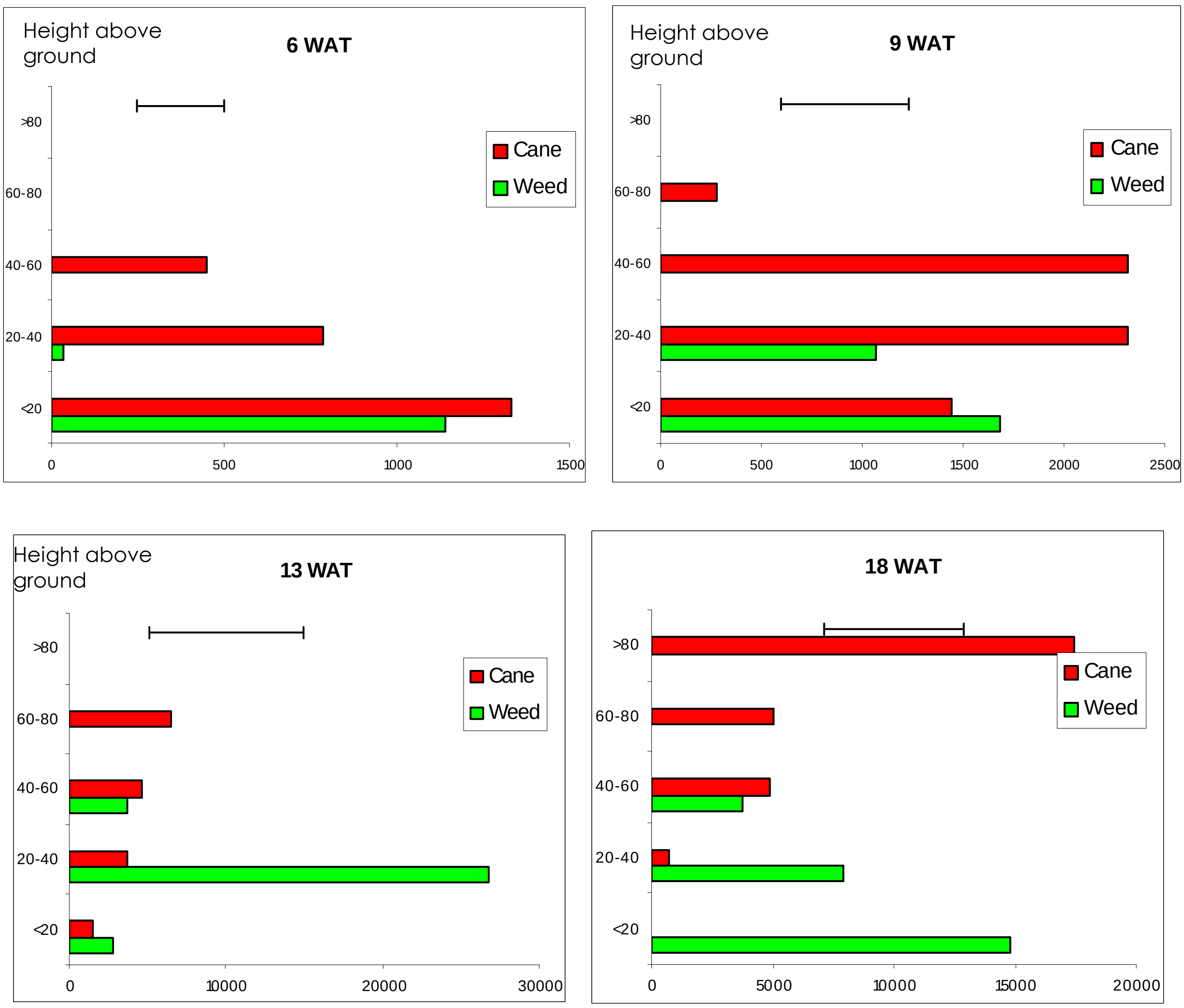


Fig. 4.23 Distribution of leaf area (cm^2 m^{-2}) of sugar cane and *P. paniculatum* at different plant heights (cm from ground) measured at 6 WAT (top left), 9 WAT (top right), 13 WAT (bottom left) and 18 WAT (bottom right) weeds at the first date (TD1). Columns are means of five weed densities and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

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

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

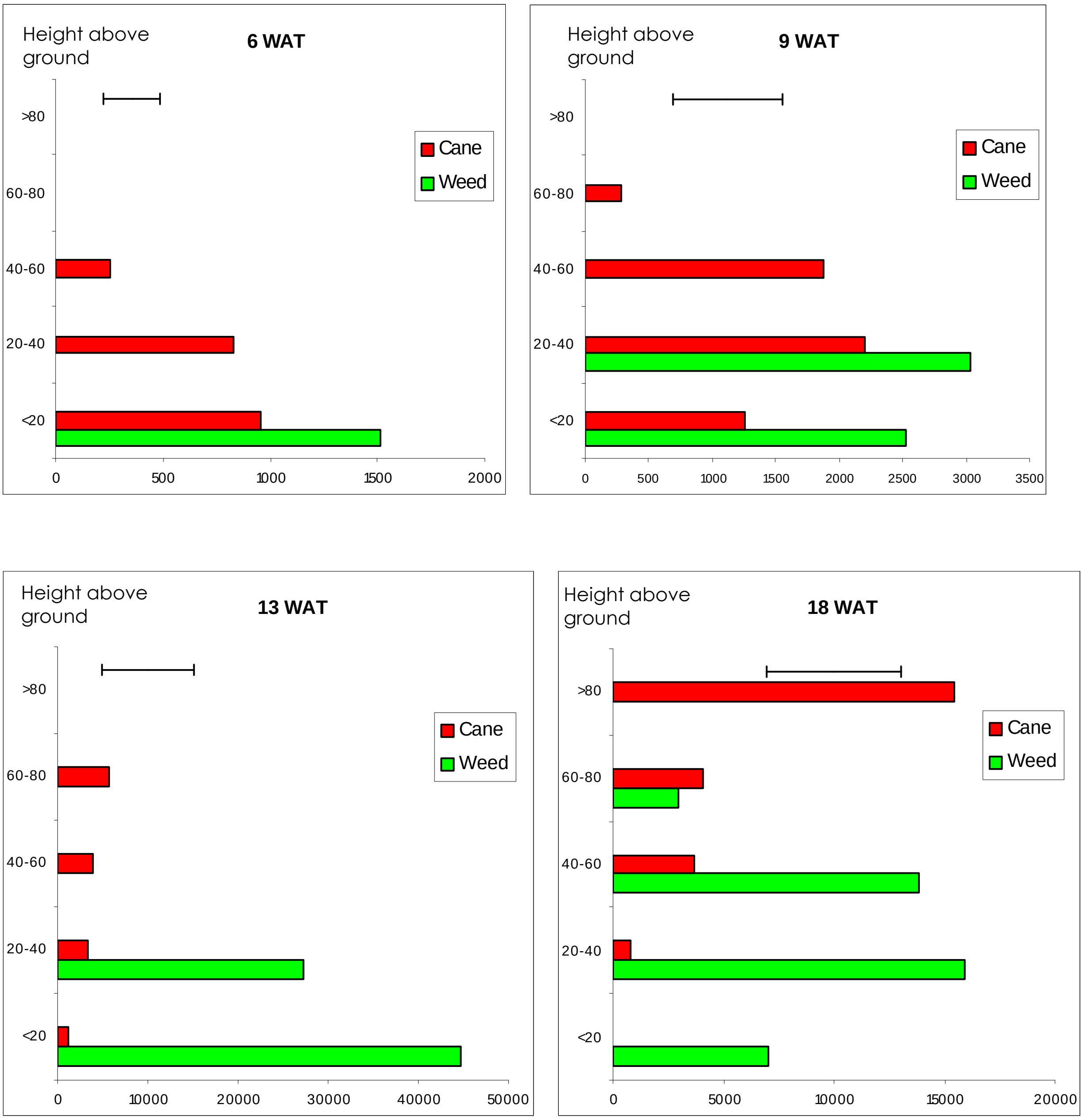


Fig. 4.24 Distribution of leaf area (cm^2 m^{-2}) of sugar cane and *P. urvillei* at different plant heights (cm from ground) measured at 6 WAT (top left), 9 WAT (top right), 13 WAT (bottom left) and 18 WAT (bottom right) weeds at the first date (TD1). Columns are means of five weed densities and four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

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

If the five to eight top leaves contribute to more than 80% of photosynthesis in sugar cane, the competition recorded at the second and third observation dates after the 1st transplanting date should have partly been caused by other means of competition than that for light. The fact that *P. paniculatum* maintains its higher competitiveness over *P. urvillei* despite the latter producing more leaf areas (higher L_w) and more in the higher layers within the crop canopy, adds to the possibility of other means of competition such as competition for underground resources.

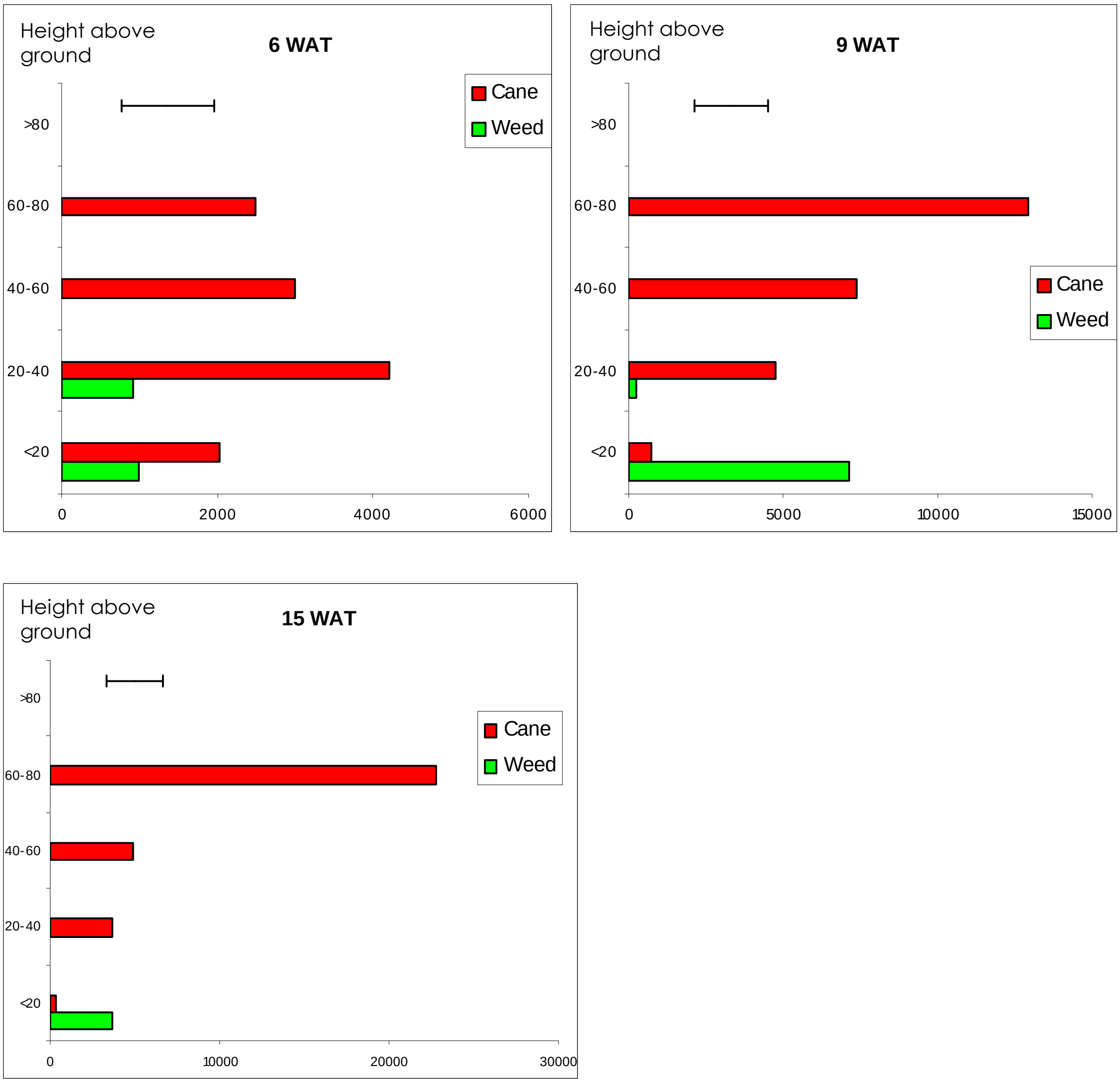


Fig. 4.25 Distribution of leaf area (cm^2 m^{-2}) of sugar cane and *P. paniculatum* at different plant heights (cm from ground) measured at 6 WAT (top left), 9 WAT (top right) and 15 WAT (bottom left) weeds at the second date (TD2). Columns are means of five weed densities and four replications. Error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

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

4.4 Discussion and conclusions

Relative competitiveness of P. paniculatum and P. urvillei

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

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

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

Relative competitiveness with time (duration of infestation)

The relative competitiveness (q value) of both *P. paniculatum* and *P. urvillei* did not change with time in Trial I while it seemed to decrease at later observation dates in Trial II after the first transplanting date. This may have been due to the difference if the stage of growth at transplanting of weeds. Estimating q values with the equation developed by Kropff and Spitters (1991) or Kropff and van Laar (1993) at later growth stages showed higher values for the later q values. This change may partly be due to the base temperature of the weeds being different to that of cane. Furthermore, the equation by Kropff and Spitters (1991) or Kropff and van Laar (1993) is recommended up to canopy closure and when the rate of growth is exponential. This seemed to be different in sugar cane where canopy closure takes longer and there is a significant difference in the vertical distribution of leaf area between the period when cane starts elongation and canopy closure.

Effect of transplanting date on weed competition

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

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

Competition for light and other resources

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