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COMPETITION AND FACILITATION EFFECTS
OF DIFFERENTIAL INTRA- AND INTER-ROW WEED MANAGEMENT IN SUGARCANE

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SUMMARY

Differential intra- and inter-row weed management can be a mean to reduce herbicide use in sugarcane. In 2011, a field experiment was conducted in La Reunion Island to assess inter-row weed competition. Four inter-row weed competition treatments for a duration of one (T1), two (T2), three (T3) and four (T4) months after planting were compared in a randomized complete block design with 5 replicates; treatment plots were paired with non-weeded inter-row control plots. All intra-rows were kept weed-free all season long. Weeds covered 100% of the inter-rows by three months after planting. Sugarcane grew far above the weed canopy, completely closing the canopy between the rows for all treatments. Sugarcane yield decreased by 13 t/ha/month of early weed competition. However, the control yield, expected to be lower than T4, was similar to the T3 treatment. This suggests a late facilitation effect of the inter-rows vegetation in control plots which partially compensates for its early competition effect. This may be due to the particular flora of our experiment, with high populations of N-fixing weeds and broom weeds. The root length density profiles observed in a couple of plots may support the facilitation hypothesis. However, additional research is needed to corroborate this singular result.

Keywords: sugarcane, differential weed management, competition, facilitation, root profile.

RÉSUMÉ

Une gestion rang inter-rang différenciée pourrait générer des économies d'herbicides en culture de canne à sucre. En 2011 à La Réunion, dans un essai de nuisibilité sur canne vierge à rangs maintenus propres, les adventices des inter-rangs ont amputé le rendement en canne à sucre de 10% par mois de concurrence précoce pendant les quatre premiers mois du cycle. Le rendement des témoins à inter-rangs non désherbés a été significativement supérieur au traitement ayant subi quatre mois de concurrence. Une compensation partielle et tardive de la concurrence précoce est donc intervenue, ce qui suggère des phénomènes de facilitation de la part des adventices confinées dans les inter-rangs sous la canne jusqu'en fin de cycle. La flore atypique de l'essai dominée par des fixatrices d'azote et des malvacées connues pour la puissance de leur enracinement pivotant pourrait être en cause ; les profils de densités de longueur racinaire réalisés sur un couple de parcelles ne sont pas incohérents avec cette hypothèse qui reste à vérifier.

Mots-clés : canne à sucre, désherbage différencié, concurrence, facilitation, profil racinaire.

Advertising: this paper provides a root distribution analysis by Dr. Chopart in addition to the paper previously presented to the XXVIII ISSCT Congress held in São Paulo (BR), 24-27 Jun 2013.

Avertissement : article présenté au congrès ICSST de juin 2013 à Sao Paulo (BR) enrichi pour la conférence COLUMA par l'étude de deux profils racinaires (contribution de J.-L. Chopart).

INTRODUCTION

Differential intra- and inter-row weed management can be a mean to reduce herbicide use in sugarcane. For example, herbicides could be applied as a stripe over the rows and mechanical cultivation implemented between the rows. Inter-cropping of non-creeping legumes as cover-crops or managing the spontaneous vegetation between the rows can be further options.

Most studies show that the critical period of weed competition for sugarcane is the period of crop establishment, from spiking to the “out-of-hand stage” (McMahon *et al.*, 2000), i.e. mainly between one and four months after planting for plant-cane crops (Marion et Marnotte, 1991; Azania *et al.*, 2010). During this period before canopy closure, yield losses commonly ranged between 10 and 12% per month of weed competition. These results were obtained from conventional trials with mixed weed populations and without separation of intra- and inter-row competition.

A field experiment was designed in La Reunion Island to assess inter-row weed competition on sugarcane. The weediness and weed flora of sugarcane fields in Reunion Island are quite well known (Le Bourgeois *et al.*, 2004 ; Lebreton *et al.*, 2009). Weed management relies mainly on chemical control (Marnotte *et al.*, 2010 ; Martin *et al.* , 2013).

MATERIALS AND METHODS

The experiment was conducted in 2011 in sub-humid lowlands to assess sugarcane yield losses from inter-row weed competition by keeping the intra-rows free of weeds. The experiment was established in a field left as a weedy fallow for 10 years, submitted to moderate grazing and periodic crushing-mowing, where broadleaves weeds became dominant. Conventional cultivation was used for soil preparation. NPK fertilizers were pre-plant applied in the furrows according to soil testing recommendations. The sugarcane cultivar used was ‘R579’. The field was sprinkler-irrigated as needed throughout the growing season. Four treatments T1, T2, T3, and T4 were compared, with inter-row weed competition occurring for (and stopped at) one, two, three and four months after planting, respectively in a randomized complete block design with 5 replicates. Each of these 20 plots was paired at random with an adjacent control plot, whose inter-rows were not weeded for the entire season.

Just after planting, a broadcast application of a non residual, contact herbicide killed the first emergence of weed seedlings before planting, in order to measure the effect of weed competition from planting to harvest. Row spacing was 1.5 m and space allocated to intra- and inter-rows was equally divided. All intra-rows (including those of the control plots) were kept weed-free all season long, using labeled PRE and POST herbicides in stripe applications over the rows (three applications at 14, 43 and 65 days after planting). By mid-season, intra-row colonization by weeds coming from inter-rows in T4 and control plots – mainly vines - was prevented by pushing them back to the inter-rows (up to three times on control plots). For T1 to T4 treatments, inter-rows weed competition was stopped at the respective treatment time and kept weed-free by hand hoeing and hand pulling after weed removal.

Weeds species present in the field are listed in Table I. The percentage of ground covered by weeds in the inter-rows and the percentage of each weed species were assessed visually in each plot, every month until the seventh month (with the exception of the sixth month). The weed biomass in the inter-rows was assessed by harvesting and measuring the dry weight of 3.75 m² areas for T2, T3 and T4 treatments at the end of their respective time of weed competition for cane. Regarding the control plots, dry weight of weeds was also assessed in a lateral inter-row at five, six and seven months after planting. The most abundant species were weighted separately as far as possible.

Tillering and stalk elongation were measured monthly; sugarcane was harvested 9.5 months after planting and cane yields were assessed by weighing the two central rows of each plot. Tillering, stalk elongation, cane yield (and difference with control plots) were statistically analyzed with linear models (analysis of variance or covariance and regression analysis), using the GLM procedure of SAS software (SAS Institute Inc. 2002-2011).

Table I: Botanical names and family of weeds present at the study location. Functional groups are relative to their contribution to global coverage (Figure 1) and global biomass (Table II).

Les adventices de l'étude. Les groupes fonctionnels renvoient à leur contribution au recouvrement global (figure 1) et à leur biomasse (tableau II)

	Botanical name	Family	Functional groups
1	<i>Cyperus rotundus</i>	Cyperaceae	Geophyte plant (as sedge)
2	<i>Brachiaria nana</i>	Poaceae	Grasses
3	<i>Cenchrus biflorus</i>	Poaceae	Grasses
4	<i>Digitaria ciliaris</i>	Poaceae	Grasses
5	<i>Eleusine indica</i>	Poaceae	Grasses
6	<i>Melinis repens</i>	Poaceae	Grasses
7	<i>Panicum maximum</i>	Poaceae	Grasses
8	<i>Paspalum dilatatum</i>	Poaceae	Grasses
9	<i>Rottboellia cochinchinensis</i>	Poaceae	Grasses
10	<i>Sorghum verticilliflorum</i>	Poaceae	Grasses
11	<i>Commelina benghalensis</i>	Commelinaceae	<i>Commelina benghalensis</i>
12	<i>Achyranthes aspera</i>	Amaranthaceae	Amaranthaceae + Solanaceae
13	<i>Amaranthus dubius</i>	Amaranthaceae	Amaranthaceae + Solanaceae
14	<i>Amaranthus viridis</i>	Amaranthaceae	Amaranthaceae + Solanaceae
15	<i>Bidens pilosa</i>	Asteraceae	Asteraceae + others broadleaf weeds
16	<i>Parthenium hysterophorus</i>	Asteraceae	Asteraceae + others broadleaf weeds
17	<i>Sigesbeckia orientalis</i>	Asteraceae	Asteraceae + others broadleaf weeds
18	<i>Cleome viscosa</i>	Brassicaceae	<i>Cleome viscosa</i>
19	<i>Ipomoea eriocarpa</i>	Convolvulaceae	Vines
20	<i>Ipomoea hederifolia</i>	Convolvulaceae	Vines
21	<i>Ipomoea nil</i>	Convolvulaceae	Vines
22	<i>Ipomoea obscura</i>	Convolvulaceae	Vines
23	<i>Acalypha indica</i>	Euphorbiaceae	Euphorbiaceae
24	<i>Croton bonplandianus</i>	Euphorbiaceae	Euphorbiaceae
25	<i>Euphorbia heterophylla</i>	Euphorbiaceae	Euphorbiaceae
26	<i>Euphorbia hypericifolia</i>	Euphorbiaceae	Euphorbiaceae
27	<i>Phyllanthus amarus</i>	Euphorbiaceae	Euphorbiaceae
28	<i>Cajanus scarabaeoides</i>	Fabaceae	N-fixing Fabaceae
29	<i>Centrosema pubescens</i>	Fabaceae	N-fixing Fabaceae
30	<i>Crotalaria retusa</i>	Fabaceae	N-fixing Fabaceae
31	<i>Desmanthus virgatus</i>	Fabaceae	N-fixing Fabaceae
32	<i>Desmodium intortum</i>	Fabaceae	N-fixing Fabaceae
33	<i>Desmodium tortuosum</i>	Fabaceae	N-fixing Fabaceae
34	<i>Indigofera hirsuta</i>	Fabaceae	N-fixing Fabaceae
35	<i>Mimosa invisa</i>	Fabaceae	N-fixing Fabaceae
36	<i>Mimosa pudica</i>	Fabaceae	N-fixing Fabaceae
37	<i>Senna occidentalis</i>	Fabaceae	within others broadleaf weeds
38	<i>Hibiscus surattensis</i>	Malvaceae	Vines (as creeping plant)
39	<i>Malvastrum coromandelianum</i>	Malvaceae	Broomweeds Malvaceae
40	<i>Melochia pyramidata</i>	Malvaceae	Broomweeds Malvaceae
41	<i>Sida acuta</i>	Malvaceae	Broomweeds Malvaceae
42	<i>Sida glutinosa</i>	Malvaceae	Broomweeds Malvaceae
43	<i>Oxalis corniculata</i>	Oxalidaceae	Geophyte plant
44	<i>Argemone mexicana</i>	Papaveraceae	Asteraceae + other broadleaf weeds
45	<i>Passiflora foetida</i>	Passifloraceae	Vines
46	<i>Portulaca oleracea</i>	Portulacaceae	Asteraceae + other broadleaf weeds
47	<i>Cardiospermum halicacabum</i>	Sapindaceae	Vines
48	<i>Solanum americanum</i>	Solanaceae	Amaranthaceae + Solanaceae
49	<i>Solanum lycopersicum</i>	Solanaceae	Amaranthaceae + Solanaceae
50	<i>Solanum nigrum</i>	Solanaceae	Amaranthaceae + Solanaceae
51	<i>Striga asiatica</i>	Scrofulariaceae	none (parasitic plant, scarce)
	51 species	17 families	10 functional groups

Root mapping and distribution were assessed 5.4 months after planting in two adjacent plots including a T1 treatment and its adjacent control using the trench-profile method (Chopart *et al.*, 2008 ; Azevedo *et al.*, 2011). Roots interceptions (RI) were counted using a grid with a 5 x 5 cm mesh, down to a depth of 1.2 m over 1.5 m wide soil profiles. Sugarcane roots and weed roots were not distinguished at counting. RI values were processed using RACINE2 software application in order to assess root length densities (RLD) (Chopart *et al.*, 2009).

RESULTS

Weeds covered 96% of the inter-rows two months after planting, reaching 100% cover at around 3 months and then declining to 96% at 7 months in non-weeded treatments (Figure 1). Weed composition was quite diverse (Table I), but at 4 months N₂-fixing weeds (9 among 10 Fabaceae) and broomweeds (4 among 5 Malvaceae) became dominant, accounting for approximately 30 and 32% of total coverage at 7 months, respectively (Figure 1). Weed biomass (dry matter) reached a maximum of 1.8 kg/m² in the inter-rows of the control plots five months after planting; when adjusted to a curvilinear model and extrapolated, this maximum value becomes 7.1 t/ha (Table II). At 6 months, broom weeds and *Crotalaria retusa* accounted for 62 and 19% of weed biomass, respectively (Table II). N₂-fixing Fabaceae other than *C. retusa* were not separated from other weeds because of their voluble, spiny or sticky traits.

Figure 1: Inter-row weed coverage (%) and number of species (red bars) of treatment plots before their weeding at 1, 2, 3 and 4 months plus control plots. All intra-rows, including those of control plots, were kept weed-free using chemical plus manual control. Recouvrement moyen (en %) et nombre d'espèces (barres rouges) dans les inter-rangs avant leur désherbage à 1, 2, 3, 4 mois et des parcelles témoins. Tous les rangs de canne, y compris ceux des témoins, ont été maintenus propres par voie chimique ou manuelle.

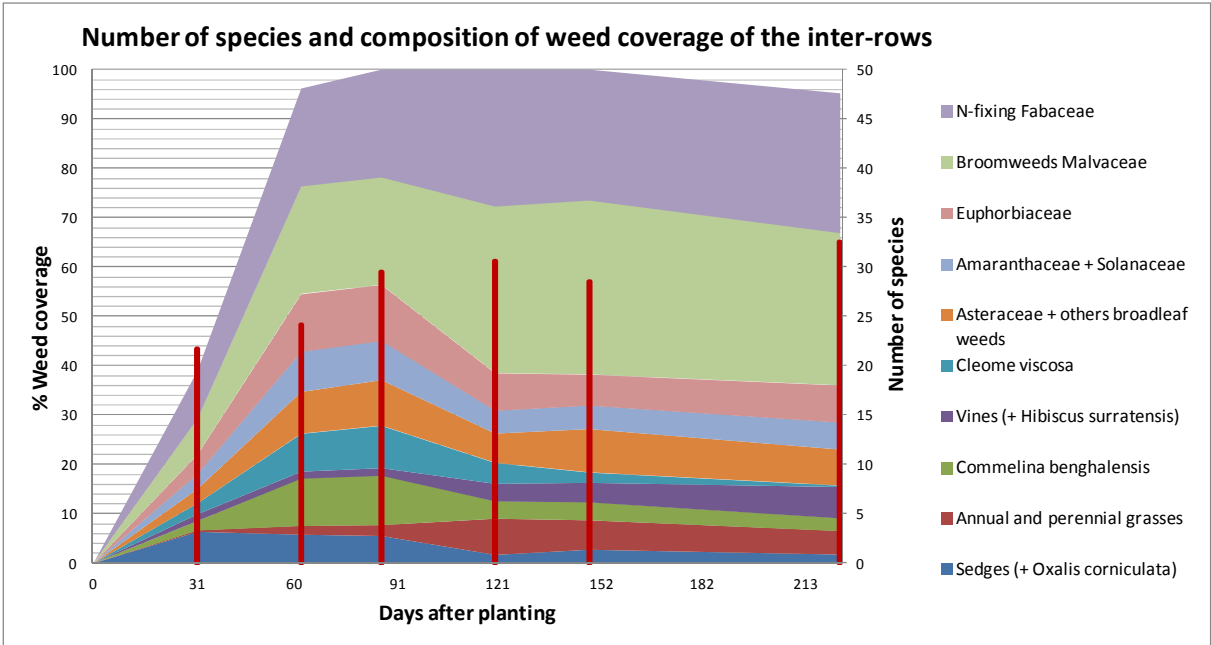


Table II: Total biomass of weeds in the inter-rows and contribution of some specific weeds or group of weeds to the total biomass (%). Missing values correspond to an apparent declining contribution of the referred species or groups.
 Biomasse d'adventices dans les interlignes et contribution de certaines espèces ou groupes d'espèces à la biomasse totale (%). Les valeurs manquantes correspondent à une contribution apparemment en baisse de l'espèces ou groupe considéré.

	Days after planting					
	62	90	121	149	185	220
Measured weed biomass (kg/m ²)	0.30	0.89	0.75	1.85	0.52	0.18
Adjusted weed biomass to full area (t/ha)	1.5	4.6	6.6	7.1	5.9	2.7
Broomweeds <i>Malvaceae</i> (%)	19	13	25	28	62	54
<i>Crotalaria retusa</i> (%)	12	6	10	15	19	-
<i>Amaranthus dubius</i> + <i>A. viridis</i> (%)	11	6	11	21	-	-
<i>Bidens pilosa</i> (%)	4	9	-	-	-	-
<i>Commelina benghalensis</i> (%)	4	12	21	21	-	-
<i>Cleome viscosa</i> (%)	3	13	-	-	-	-
Grasses (%)	-	22	16	-	-	-
Other weeds (%)	47	20	18	16	19	46

Sugarcane height was far above weed canopy by mid-season, completely closing the canopy between the rows for all treatments. Overall, sugarcane tillering (Table III) and production were significantly reduced by weed competition. Stalk elongation and sugar content were not affected by weed competition (results not shown).

The effect of the duration of weed competition was highly significant on sugarcane tillering ($p < 0.0001$ at 3 and 6 months after planting) despite one significant effect of the initial shoot emergence rate on tillering ($p = 0.006$ and $p = 0.015$). Effects other than initial shoot emergence rate and duration of weed competition were not significant (not shown).

Table III: Sugarcane tillering at 3 and 6 months after planting.
 Tallage de la canne à sucre 3 et 6 mois après plantation.

Time after planting	Average (number of tillers / m)	Initial shoot emergence rate effect (covariance analysis)	Duration of weed competition effect
3 months	17.8	$P = 0.006$	$P < 0.0001$
6 months	13.6	$P = 0.015$	$P < 0.0001$

Sugarcane yield was 131 t/ha for T1 and significantly decreased by 13.5 t/ha/month for consecutive months of early competition through T4 ($p = 0.0015$, Figure 2-A). The differences observed between the treatments and their respective control plots ranged from +33 t/ha for T1 to -23 t/ha for T4; a significant decrease ($p = 0.0029$) of 17.2 t/ha/month was recorded for consecutive months of early competition from T1 to T4 (Figure 2-B). The checking of treatments minus control yield differences showed (Table IV) that T1 was significantly superior to control (T4-control > 0) and T4 was significantly inferior to control (T4-control < 0) whereas T3 minus control and T2 minus control were not significantly different from zero.

Figure 2: A - Average sugarcane yields (blue bars) and linear regression of treatment yields over the 20 plots (y, t/ha) against time of weed control (x, months); B - Average yield differences between treatments and their control plots (red bars) and linear regression of the 20 yield differences (y, t/ha) against time of weed control (x, months). MAP: months after planting. A - Rendements moyens en canne à sucre (barres bleues) et régression linéaire des rendements individuels (20 parcelles) (y, t/ha) sur la durée de concurrence des adventices (x, mois); B – moyennes des différences de rendements entre les traitements et leurs témoins adjacents (barres rouges) et régression linéaire des 20 différences de rendements (y, t/ha) sur la durée de concurrence des adventices (x, mois). MAP : mois après la plantation.

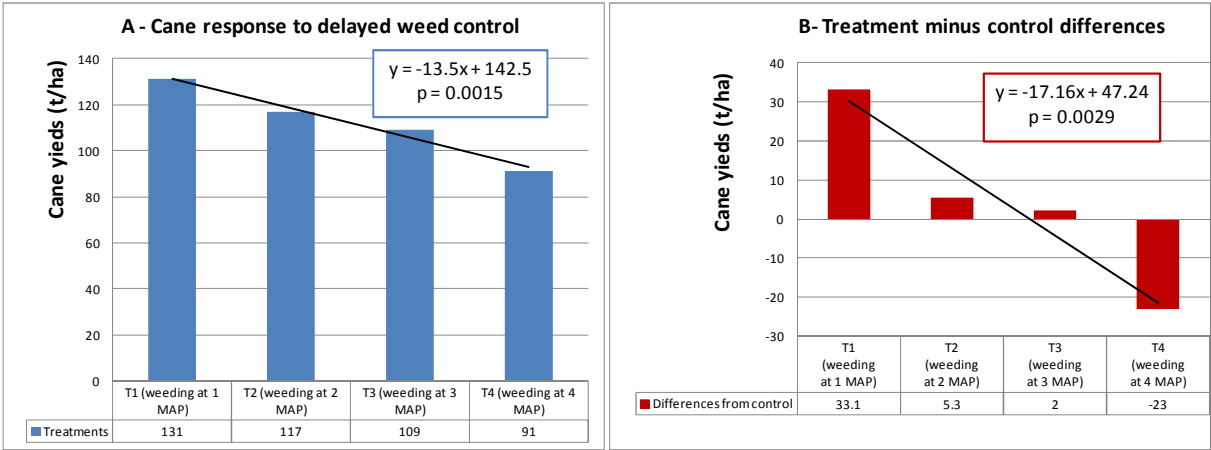


Table IV: Confidence intervals at $p=0.05$ for the yield differences predicted by the equation of regression from figure 2-B [y (yield difference, t/ha) = $-17.16x$ (months) + 47.24]. Intervalles de confiance à $p=0.05$ des différences de rendement calculées avec l'équation de régression de la figure 2-B [y (différence de rendement, en t/ha) = $-17.16x$ (en mois) + 47.24].

Predicted yield differences (sugarcane, t/ha)				
differences	predicted value	standard error	confidence interval ($p=0.05$)	
T1 - control	30.1	9.3	10.5	49.7
T2 - control	12.9	6.1	0.1	25.8
T3 - control	-4.2	6.1	-17.1	8.6
T4 - control	-21.4	9.3	-41.0	-1.8

RLD profiles observed in a single T1 plot (as weeded sugarcane) and its adjacent control plot (unweeded inter-rows) at 5.4 months after planting are shown in Figure 3. The mean RLD values for the T1 plot were 1.20, 0.42 and 0.06 cm/cm^3 in the 0-20, 20-40 and 40-120 cm layers, respectively. In contrast, the control plot (sugarcane plus weeds roots) exhibited higher RLD values over the profile, with +156%, +150% and +236% in the 0-20, 20-40 and 40-120 cm layers, respectively. However, these differences are not supported by statistical analysis (no replicated lectures). These differences can obviously be due to the weeds, particularly those with strong taproots dominant in this trial (N-fixing weeds and broomweeds). However, this assumption is not supported by differential counting of sugarcane roots versus weeds roots.

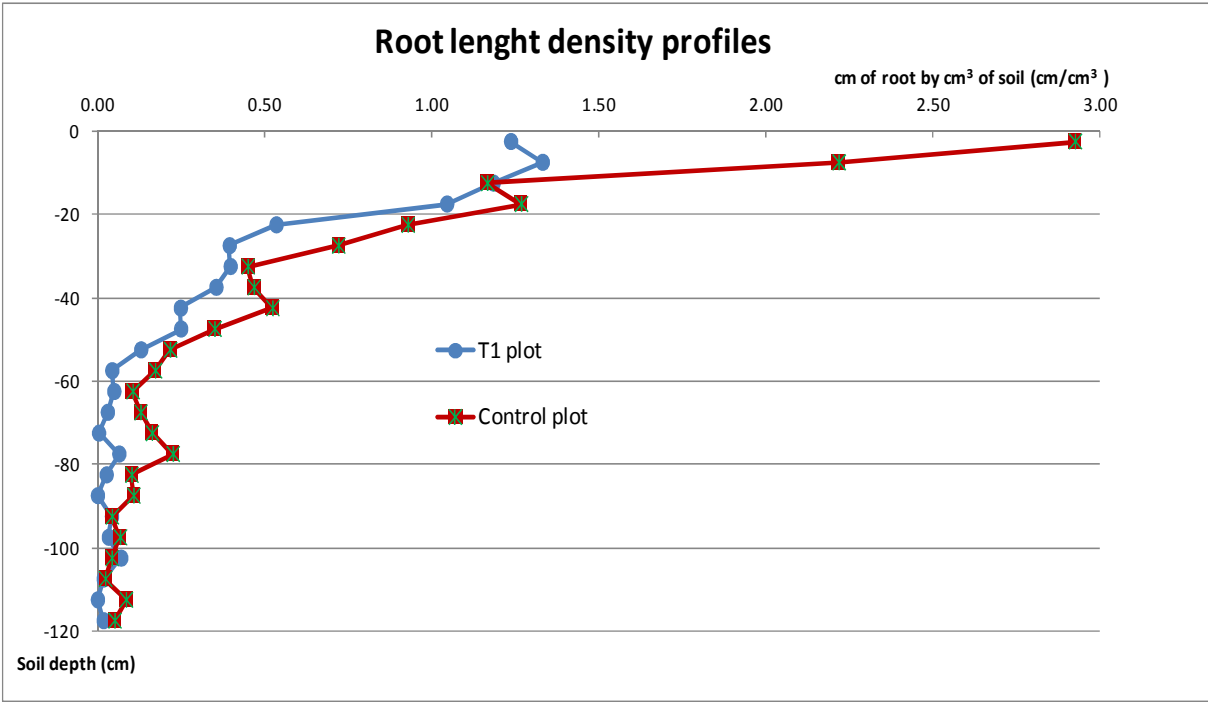
The RLD of the control plot reached +200% when compared with the T1 plot in the 0-10 cm layer (Figure 3), with a maximum value of 2.92 cm/cm³ in the upper 5 cm layer. This contrasted distribution pattern in the upper soil supports the existence of a strong early weed competition for sugarcane in this surface layer. This assumption is also consistent with the depth of the furrows opened for sugarcane plantation (around 15 cm): sugarcane cannot develop significant rooting upon this depth. In contrast, sugarcane roots could have a stronger development in depth, as a response to the strong early weed competition in the surface layer.

RLD values decreased rapidly in depth, with values lower than 0.5 cm/cm³ at 25 cm depth in the T1 plot, and at 50 cm depth in the control plot. Thus, competition relations between roots, either belonging to sugarcane or weeds in the case of the control plot, probably decreased too.

Finally, the main trait resulting from this comparison of RLD profiles in a couple of trenches by mid-season is that the association of strong sugarcane in the intra-rows with limited weeds in the inter-rows probably originated a higher density of mixed roots over the profile.

Figure 3: Profiles of root length density (RLD) expressed as cm of roots by cm³ of soil, in a couple of adjacent plots belonging to T1 treatment (weeded sugarcane in the intra-rows plus weeded inter-rows) and the control treatment (weeded sugarcane in the intra-rows plus unweeded inter-rows) at 5.4 months after planting. For the control plot, RLD included both sugarcane and weed roots without distinguishing them.

Profils de longueur de racines (RLD, en cm de racines par cm³ de sol) observés sur un couple de parcelles adjacentes, correspondant à la modalité T1 (propre) et à son témoin adjacent (rangs de canne propres et inter-rangs non désherbés) 5,4 mois après la plantation. Sans distinction des racines de canne et d'adventices pour le témoin.



DISCUSSION AND CONCLUSION

Results from this study were similar to those of Marion and Marnotte (1991) in terms of weed and maximum cane biomass accumulation, despite the fact that their study was conducted in quite different conditions and harvested at 12.7 months *versus* 9.5 for this study. The cane yield reduction documented with total intra-row weed control in this study is almost as high as Marion and Marnotte (1991) recorded without intra-row weed control (-13.5 *versus* -14.5 t/ha/month of exposure to weed competition). Thus, mitigation of weed competition by intra-row weed control above ground is probably less than proportional to the space allocated to the intra-row: we observed in some soil profiles evidence that weed roots coming from inter-rows colonize intra-row space and meet sugarcane roots.

However, the average yield of our control plots (whose inter-rows were kept unweeded over the cycle), logically expected to be lower than T4 (whose inter-rows were weeded at four months after planting), were significantly higher than T4 ($p = 0.05$), reaching the yield level of T3. This finding suggests a late facilitation effect of the inter-row vegetation in control plots which partially compensated for an early competition effect. This may be due to the particular flora of our study, with high populations of N_2 -fixing weeds and broomweeds, probably associated with a higher global root length density over the soil profile, as observed in this study by the observation of a single couple of trench-profiles by mid-season. Could this higher density of mixed roots over the profile be involved in and responsible for the partial yield compensation significantly recorded in the control plots?

Additional research is needed (i) to corroborate the results in terms of yields over several cropping seasons, (ii) to assess the root distribution and the potential root extraction ratio for water and nutrients for sugarcane and weeds separately, and (iii) to investigate the diversity of facilitation processes involved.

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