Available online at http://ajol.info/index.php/ijbcs

Int. J. Biol. Chem. Sci. 8(5): 2244-2257, October 2014

ISSN 1997-342X (Online), ISSN 1991-8631 (Print)

International Journal of Biological and Chemical Sciences

Original Paper http://indexmedicus.afro.who.int

Determination of critical period for weed control in intensive and non-intensive sugarcane (*Saccharum officinarum* L., Poaceae) production systems in center Côte d'Ivoire

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ABSTRACT

Field experiments were conducted in Zuenoula and Yamoussoukro for determining Critical Period for Weed Control (CPWC) in sugarcane. The treatments consisted in two sets of weed interference. In the first set, the crop was kept weed-free until 31, 61, 92, 123 days after planting (DAP) in Zuenoula and until 32, 69, 98 and 162 DAP in Yamoussoukro. In the second set, weeds were permitted to grow within the crop until the above-mentioned DAP. The CPWC was determined for 5, 10, 15 and 20% acceptable yield loss levels by fitting Logistic and Gompertz nonlinear equations to relative yield data. In both locations, increasing the duration of weed interference decreased sugarcane yield significantly. In Zuenoula, the CPWC was from 28 to 117, 30 to 93, 32 to 75 and 34 to 59 DAP to prevent yield losses of 5, 10, 15 and 20%, respectively. In Yamoussoukro, the CPWC ranged from 38 to 163, 39 to 112, 40 to 99 and from 40 to 91 DAP to prevent yield losses of 5, 10, 15 and 20%, respectively. Results suggest weed control between 28 and 117 DAP in Zuenoula and between 38 and 163 DAP in Yamoussoukro to provide maximum yield.

Keywords: Weed interference, Gompertz, Logistic, weed control, yield.

INTRODUCTION

Weeds are major constraints to sugarcane production. Weeds, primarily, reduce yield and sucrose content in sugarcane due to their competition with the crop for limited resources such as light, soil water and soil nutrients. For example, pigweed is a luxuriant extractor of soil nitrogen that causes nitrate deficiencies in the sugarcane plant. Khan et al. (2004) reported that cane yield is reduced to the extent of 20-25% due to weed infestation. Secondly, weeds host pathogens and nematodes. Specifically, weedy grasses serve as alternate hosts and reservoirs for viruses, and they harbor insects that carry diseases to sugarcane. Similarly, rats find shelter in weedy fields.

DOI : http://dx.doi.org/10.4314/ijbcs.v8i5.27

They also impose other losses on growers, millers, and surrounding communities. Heavy weed infestation hinders sugarcane harvesting by adding unnecessary harvesting expenses (Cheema et al., 2010). Field workers may be injured by weeds with spiny or thorny protrusions, burs, or needles that penetrate the skin. Examples include starbur (*Acanthospermum* Schrank.), spiny amaranth (*Amaranthus spinosus* L.), itchgrass (*Rottboellia cochinchinensis* (Lour.) Clayton), smooth prickly poppy (*Argemone glauca* (Nutt. ex Prain) Pope), and other weedy species with burs or spines. Some weeds may cause allergies in some workers resulting in lost productivity. As a result, weeds may reduce harvesting efficiency by 5-20% and excessive weeds may cause some fields to be abandoned (Dudley et al., 2008). Unsuccessful control of guinea grass and vines, for example, can lead growers to destroy and replant some fields of sugarcane.

Consequently, weed control prior to crop canopy spread is crucial. Integrated weed management (IWM) involves a combination of cultural, mechanical, biological, genetic, and chemical methods for effective and economical weed control (Swanton and Weise, 1991). The principles of IWM should provide the foundation for developing optimum weed control systems and efficient use of herbicides. The critical period for weed control (CPWC) is a key component of an IWM program. It is a period in the crop growth cycle during which weeds must be controlled to prevent yield losses. Swanton and Weise (1991) defined the CPWC as the time interval when it is essential to maintain a weed-free environment to prevent crop yield loss. Knezevic et al. (2002), have described the CPWC as a ‘‘window’’ in the crop growth cycle during which weeds must be controlled to prevent unacceptable yield losses. Therefore, interference from weeds before or after the CPWC will not result in unacceptable reductions in yield. The CPWC is useful for making decisions on the need for weed control and the timing of this weed removal. Determining the appropriate timing of weed control tactics is valuable in developing integrated weed management systems (Rajcan and Swanton, 2001; Knezevic et al., 2002) and has been the subject of extensive research in agronomic crops (Zimdahl, 2004). The CPWC is determined by characterizing functional relationships between two separately measured competition components: crop yield as a function of the duration of weed interference to identify the beginning of CPWC, and crop yield as a function of the duration of the weed-free period to identify the end of CPWC.

Determining the CPWCs in intensive and non-intensive conditions will provide better understanding of weeds sustainable management in sugarcane. For that reason, our objectives were to determine the CPWC in those two production systems.

MATERIALS AND METHODS

Sites description

Field experiments were conducted in 2001-2002 at the Agricultural Integrated Unit of Sucrivoire Zuenoula (Commercial sugarcane fields of an Ivorian Sugar Company) and in 2010-2011 at the National School of Agronomy in Yamoussoukro, in the center of Côte d’Ivoire. In Zuenoula, the soil type was sandy clay loam, moderately desatured, with an acid pH. At the experimental farm of National School of Agronomy, the soil type was sandy with 0.6% organic matter. The value of pH was 5.3. Carbon and nitrogen contents of the soil were, respectively 1.2% and 0.10% while the C/N ratio was of 12%. At the adsorption complex’s level, the cation exchange capacity (CEC), total amount of charges that can be held in exchangeable form, the contents of ions Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} were, respectively, 8.72 meq/100 g, de 1.722 meq/100 g, 0.801 meq/100 g, 0.225 meq/100 g and 0.096 meq/100 g. The Fe, Mn, Cu and Zn contents were, respectively, 437 ppm, 126 ppm, 2 ppm and 1 ppm.

Experimental design and procedures

A randomized complete block design was used with four replications in 2001-2002 and 3 replications in 2010-2011. In 2010-2011 each plot was composed of three inter-furrows of 1.5 m and 4.2 m width (1.5 meter between furrows). The plot's area was 18.9 m^2 (4.5 m x 4.2 m). In 2001-2002 each plot was composed of four furrows (1.5 meter between furrows) of 5 m long. The plot's area was 22.5 m^2 (4.5 m x 5 m). Thirty subplots were carried out in 2010-2011 and forty in 2001-2002. Two sets of treatments were imposed to represent both increasing duration of weed interference and the length of the weed-free period measured after planting. The first set of treatments established four levels of increasing duration of weed interference by delaying weed control from the time of crop planting up to predetermined dates after planting (weedy up to 31, 61, 92, 123 days after planting (DAP) in 2001-2002 and up to 32, 69, 98 and 162 DAP in 2010-2011) at which weed control was initiated and maintained for the remainder of the growing season. The second set of treatments established four levels of increasing length of the weed-free period by maintaining weed control from the time of crop planting up to the above-presented crop growth stages before subsequently emerging weeds were left uncontrolled for the remainder of the season. In addition, season long weedy and weed-free controls were included. Naturally occurring weed populations were used in trials. Weeds were removed by hand pulling and hoeing.

Cultural management practices

In Yamoussoukro, land preparation consisted in ploughing and harrowing. First ploughing was made on the 13th of May 2010 followed by the harrowing on the 19th May 2010. A second ploughing was carried out on the 4th of July 2010 with a harrowing the same day. The furrows were made with hoes on the 16th July 2010. Planting intervened on the 17th July 2010 in single rows at 1.5 m spacing. The cuttings of variety C_O 997 (from Sucrivoire Zuenoula) were planted in plant cane cycle. There was no previous cropping; sugarcane was planted after a savannah fallow of 5 years.

In Zuenoula, on the other side, at the experimental site, located at the plot C 57, land preparation consisted in ploughing and making the furrows. Fertilizers, NPKSMg (18.5-9-24-2.5-2), applied at about one month and half after planting, were used at the rate of 650 kg/ha (N: 120.25 kg/ha, P: 58.5 kg/ha, K: 156 kg/ha, S: 16.25 kg/ha and Mg: 13 kg/ha). Water was applied by irrigation reel sprinkler to the plot area throughout the crop growing season. Amount of irrigation was adjusted to meet crop water needs. The irrigation brought 613 mm to the sugarcane while the rainfall brought 501.04 mm that gives a total water supply of 1114.04 mm. Planting was done on the 1st October 2001 in single rows at 1.5 m spacing. The cuttings of the variety Co 997 were planted in plant cane cycle. The previous cropping was sugarcane.

Weed and crop measurements

In Zuenoula, an inventory was made first and it was followed by rating the abundance-dominance of main species regarding the sampling area. The scale to rate abundance-dominance is the one used by Le Bourgeois (1993). This scale is an adaptation to Braun-Blanquet (1932) (Table 1).

In Yamoussoukro, two quadrats of 1 m^2 were placed in the two inter-furrows within each experimental plot. At the day of each weed removal floristic studies were carried out to identify all the weeds of the plot in the sampling areas of each subplot. Secondly, weeds were harvested from the sampling areas. At each harvest, weeds were clipped at the soil surface, and dried at 70 °C for 48 hours to constant moisture content to obtain a measure of aboveground dry weed biomass. Final sugarcane harvest dates were the 20^{th} of June 2002 and the 18^{th} June 2011. In 2002, irrigation was stopped 1 month before cane harvest. For quantification of yield in both experiments, plants in the 2 central rows in each plot were harvested by hand. In Yamoussoukro, at the end of growing cycle, the weeds of the set of weed-free were harvested in the two 1 square meter quadrats on the 2^{nd} of June 2011 air-dried and weighted on the 8^{th} of July 2011. The end-of-season weed total biomass for the weed-free treatments was determined.

Data analysis

Yield data of individual plots were computed as the percentage of their corresponding weed-free plot yields. Relative yield data were subjected to analysis of variance with the use of the PROC MIXED function of Statistical Analysis System (SAS), to assess the effect of the length of the weed-free period and increasing duration of weed interference on relative sugarcane yields (Knezevic et al., 2002). The statistical significance of treatment was evaluated at 5% level of probability. Nonlinear regression analyses with the PROC NLMIXED function of SAS were used to estimate the relative yield of sugarcane as a function of increasing duration of weed interference or as a function of the length of the weed-free period, according to the procedure outlined by Knezevic et al. (2002). A three-parameter logistic equation, proposed by Hall et al. (1992) and modified by Knezevic et al. (2002) was used to describe the effect of increasing duration of weed interference on relative yield. The following logistic equation was used:

$$Y = \left(\left(\frac{1}{e^{c*(x-d)}+f}\right) + \left(\frac{f-1}{f}\right)\right) * 100 \quad (1)$$

where Y is the relative yield, x is the duration of weed interference measured from the time of sugarcane planting in DAP, d is the point of inflection in DAP, and *c* and *f* are constants. The Gompertz model has been shown to predict the relationship between relative yield, as influenced by the length of the weed-free period (Hall et al., 1992; Knezevic et al., 2002). The model has the following form:

$$Y = a * e^{-b*e^{(-k*x)}} \quad (2)$$

where Y is the relative yield, a is the yield asymptote or maximum yield in the absence of weed interference, band care constants, and *T* is the length of the weed-free period after sugarcane planting in DAP. Goodness of fit was studied in terms of minimum root mean square error (RMSE) and by calculating the model efficiency index (EF). The EF was calculated as follows:

$$EF = 1 - \frac{\sum_{i=1}^{n}(Y_i - \widehat{Y_i})^2}{\sum_{i=1}^{n}(Y_i - \overline{Y})^2}$$

where Y_i is the measured value for situation *i*, $\widehat{Y_i}$ is the corresponding value calculated by the model and $\overline{Y_i}$ is the average of the Y_i values. EF values range from 0 to 1; the nearer the value to 1, the better the goodness of fit of the model.

The logistic equation (equation 1) was used to determine the beginning of the CPWC, and the Gompertz equation (equation

2) was used to determine the end of the CPWC for acceptable yield loss levels (AYL) of 5%, 10%, 15% and 20%.

Analysis of variance of weed biomass means, was performed using PROC GLM of SAS software. The level of significance is indicated by the least significant difference between the means (LSD) at 5% probability. Additionally, the relationship between weed dry weight and the treatments was described using PROC REG in SAS (SAS Institute, 2002). To determine the type of relationship between weed dry weight and the treatments, an exponential equation (3) was fitted to the series of weed–free treatments (Sit and Costello, 1994; Mondani et al., 2011):

$$Y = a * e^{bx} \qquad (3)$$

where, Y is the weed dry weight (g m^{-2}), *a* and *b* are constants of curve and X is the length of weed-free period (in DAP).

Schumacher's (1939) model, also used by Mondani et al. (2011), was fitted to the weed-infested treatments and weed biomass accumulation using the NLIN PROC of SAS (SAS Institute, 2002).

$$Y = e^{a+b/x} \qquad (4)$$

where, Y is the weed dry weight (g m^{-2}), *a* and *b* are constants of curve and X is the duration of weed infested period (in DAP).

RESULTS

Weed measurements

Floristic diversity

Weed floristic diversity in Zuenoula is shown by Table 2 and Table 3. In Zuenoula, the weed flora of the field experiments is constituted of 93 species. These species were distributed into 32 families and 72 genera. The most representative botanical families, constituting 58% of the identified species, are Poaceae (8 species), Cyperaceae (3 species), Solanacaeae (3 species). The number of genera per family ranges between 1 and 8. The major weeds in Zuenoula were horse purslane (*Trianthema portulacastrum* L.), itchgrass (*Rottboellia cochinchinensis* (Lour.) Clayton), crowfootgrass (*Dactyloctenium aegyptium* (L.) Willd.), purple nutsedge (*Cyperus rotundus* L.), *Brachiaria lata* (Schum.) C.E. Hubb. Horse purslane (*Trianthema portulacastrum* L.) is the most abundant.

In Yamoussoukro, the weed flora of the field experiments was composed of 34 species. Table 4 shows the weed families, genera and species.

These species were distributed into 14 families and 28 genera. The most representative botanical families, constituting 62.5% of the identified species, are Poaceae (8 species), Cyperaceae (3 species), Euphorbiaceae (3 species), Tiliaceae (3 species), Fabaceae (3 species). The number of genera per family ranges between 1 and 8. The dominant weed species were *Mimosa pudica* L., *Brachiaria* Griseb., *Croton hirtus* L'Hér., *Spermacoce ruelliae* DC., *Dactyloctenium aegyptium* (L.) Willd. and *Ipomoea heterotricha* Didr.

Weed biomass evolution

The analysis of variance revealed a significant effect ($p < 0.0001$) of the imposed sets of weed interference on weed biomass. The season-long weedy treatment presents the highest weed biomass (1866.57±79.16 g). The analysis of variance also revealed that keeping the crop weed-free until 32 DAP provides the second highest weed dry weight (1442.2±89.50 g). Starting weed control at that date provoked only 22.74% reduction of weed biomass (compared to weedy treatment). Similarly, keeping sugarcane weed-free until 162 DAP induced 96.52% reduction of weed dry weight. On the contrary, when weeds were permitted to grow within the crop until 32 DAP weed biomass reduction is of 98.90% (compared to weedy treatment). That reduction is of 97.51% for allowing weeds to compete with sugarcane until 69 DAP.

The parameters estimates, for the exponential and Schumacher's model fitted to the data, are shown in Table 5.

The results on weed biomass, as influenced by the weedy and weed-free treatments, are shown in Figure 1.

Total weed dry weight increased with increasing duration of weed-infested period. In contrast, total weed dry weight in all growing season, decreased with increasing duration of weed-free period (Figure 1).

Critical period for weed control in sugarcane

In intensive conditions (Zuenoula) and non-intensive conditions (Yamoussoukro) the yields of sugarcane declined with increasing duration of weed presence (Figures 2 and 3). Average yields were reduced with prolonged delays in weed removal at two locations. Conversely, the mean of sugarcane weight increased with increasing duration of weed-free period in both cropping systems (Figures 2 and 3).

The presence of weeds during the entire growing season decreased sugarcane yield more than 50% and 61% in intensive and non-intensive cropping systems, respectively.

Besides that, the average yield of sugarcane in the weed-free treatments was 115.8±4.64 t/ha in intensive and 32.86±4.51 t/ha in non-intensive cropping systems, respectively. On the contrary, weed interference during the entire growing season provoked a sugarcane yield of 57.03±5.19 t/ha in Zuenoula and 12.77±5.02 t/ha in Yamoussoukro.

In both locations, the treatments (timing of weed removal and length weed-free period) have a significant effect on the relative yield ($p < 0.0001$), indicating that regression analysis may be appropriate. The parameters estimates, of the three-parameter logistic and the Gompertz model (Equations 1 and 2) fitted to the data, are shown in Table 6.

In the intensive production system of Zuenoula, the beginning of the CPWC was 28 DAP at 5% AYL, 30 DAP at 10% AYL, 32 DAP at 15% AYL and 34 at 20% AYL (Table 7). The end of the CPWC was 117 DAP at 5% AYL, 93 DAP at 10% AYL, 75 DAP at 15% and 59 DAP at 20% AYL (Table 7). The end of the CPWC increased as the AYL decreased from 20% to 5% (Table 7, Figure 2). Results showed that in the beginning of the growing season weeds have no economic damage. Thus, to provide less than 5% yield losses, there is no need to control weeds before 28 days. Similarly, weed control achieved after 117 days cannot provoke yield losses greater than 5%. Thus, it is recommended that after this period, farmers do not apply weed control methods (in similar field conditions). After the CPWC, sugarcane dominates on weeds because of its canopy extension and high competitiveness. The length of the CPWC was 90, 64 days for 5 and 10% AYL, respectively. That length of CPWC was 44 and 26 days for 15 and 20% AYL, respectively.

In non-intensive conditions of Yamoussoukro, using a 5%, 10%, 15% and 20% AYL, gives a beginning of CPWC of 38, 39 and 40 DAP (Table 7). The end of the CPWC was 163 DAP at 5% AYL, 112 DAP at 10% AYL, 99 DAP at 15% and 91 DAP at 20% AYL (Table 7). The end of the CPWC increased as the AYL decreased from 20% to 5% (Table 7, Figure 3). These results also revealed that in the beginning of the growing season weeds have no economic damage. As a result, to provide less than 5% yield losses, there is no need to control weeds before 38 days. Likewise, weed control achieved after 163 days cannot provoke yield losses greater than 5%. Thus, it is recommended that after this period, farmers do not apply weed control methods (in similar field conditions). After the CPWC, sugarcane dominates on weeds because of its canopy extension and high competitiveness. The length of the CPWC was 126 and 74 days for 5 and 10% AYL, respectively. That length of CPWC was 60 and 52 days for 15 and 20% AYL, respectively.

Table 1: The rating scale for weeds (Le Bourgeois, 1993).

Index	Meaning
5	Individuals covering more than ¾ of the sampled area, some abundance
4	Individuals covering from ½ to ¾ of the sampled area, some abundance
3	Individuals covering ¼ to ½ of the sampled area, some abundance
2	Very abundant individuals, covered 1/20 of the sampled area
1	Rare individuals, less abundant or abundant but weak covering

Table 2: Weed flora families in the sugarcane field in Zuenoula.

Family	Genus (number)	Species (number)
Aizoaceae	1	1
Amaranthaceae	3	3
Araceae	1	1
Asteraceae	10	10
Bombacaceae	1	1
Caesalpiniaceae	2	2
Capparidaceae	1	1
Commelinaceae	1	3
Convolvulaceae	1	3
Cucurbitaceae	1	1
Cyperaceae	3	5
Dioscoreaceae	1	2
Euphorbiaceae	5	9
Fabaceae	4	4
Loganiaceae	1	1
Molluginaceae	1	1
Malvaceae	3	4
Moraceae	1	1
Nyctaginaceae	1	2
Passifloraceae	1	1
Poaceae	14	17
Portulacaceae	2	2
Rosaceae	1	1
Rubiaceae	2	3
Solanaceae	2	6
Sterculiaceae	1	1
Tacaceae	1	1
Tiliaceae	1	1
Ulmaceae	1	1
Urticaceae	1	1
Verbenaceae	2	2
Zygophyllaceae	1	1
Total	**72**	**93**

Table 3: Abundance-dominance average of main weeds in Zuenoula.

Species	**Family**	**AD average**
Trianthema portulacastrum L.	Aizoaceae	5
Cyperus rotundus L.	Cyperaceae	3
Rottboellia cochinchinensis (Lour.) Clayton	Poaceae	2
Brachiaria lata (Schum.) C.E. Hubb.	Poaceae	2
Dactyloctenium aegyptium (L.) Willd.	Poaceae	3

Table 4: Weed flora families in the sugarcane field in Yamoussoukro.

Family	**Genus (number)**	**Species (number)**
Poaceae	8	7
Fabaceae	4	4
Caesalpiniaceae	2	1
Mimosaceae	3	2
Tiliaceae	3	2
Euphorbiaceae	3	2
Cyperaceae	2	2
Asteraceae	1	1
Solanaceae	2	2
Rubiaceae	1	1
Convolvulaceae	2	1
Passifloraceae	1	1
Loganiaceae	1	1
Malvaceae	1	1
Total	**34**	**28**

Table 5: Parameters values for response curves based on exponential model (a) and Schumacher's (1939) model (b).

Equation model	**a**	**b**	**R^2**
(a) $Y =$	4084.97	-0.02525	0.9467
(b) $Y =$	8.1328	-215.8	0.988

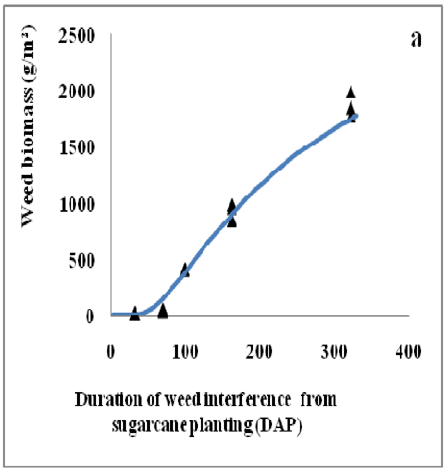
Table 6: Parameters estimates of the three parameter logistic model used to determine the critical timing of weed removal and the Gompertz model used to determine the critical weed-free period for sugarcane in 2002 and 2011 (Equations 1 and 2).

Location	Year	Gompertz					Logistic				
		a	b	k	RMSE	EF	c	d	f	RMSE	EF
Zuenoula	2002	108.78	0.7144	0.01422	4.14	0.389	0.3581	29.5722	3.0284	4.13	0.997
Yamoussoukro	2011	95.3768	22.0326	0.05277	3.38	0.982	1.3177	40.0730	1.9233	3.25	0.971

RMSE: root mean square error EF: model efficiency index

Table 7: Critical period for Weed Control (CPWC) for sugarcane determined through Logistic and Gompertz equations at four acceptable yield losses (AYL) during two years and expressed in days after (DAP).

AYL	Beginning of CPWC (DAP)		End of CPWC (DAP)	
	2002	2011	2002	2011
5%	28	38	117	163
10%	30	39	93	112
15%	32	40	75	99
20%	34	40	59	91



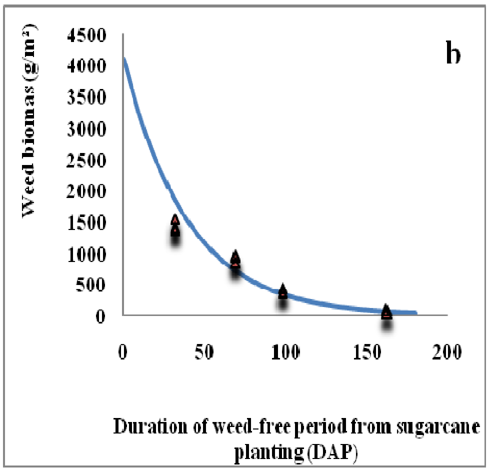


Figure 1: Weed biomass as a function of lengths of (a) weed interference and (b) and weed-free duration from sugarcane planting date in Yamoussoukro. Symbols indicate observed data (see Table 5 for coefficients).

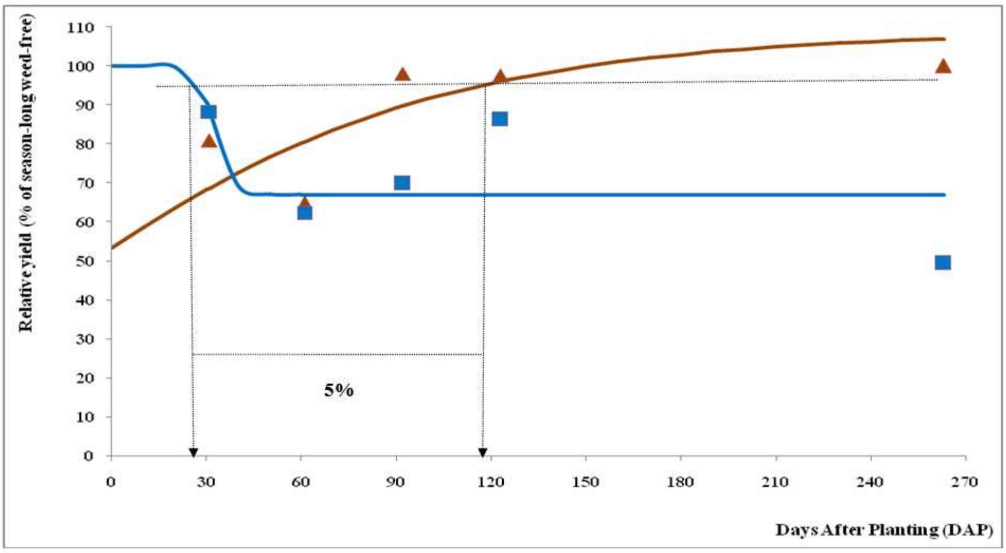


Figure 2: Effect of weed interference on total yield of sugarcane. Increasing duration of weed interference (■) and fitted curves as calculated by the logistic equation; increasing weed-free period (▲) and fitted curves as calculated by the Gompertz equation. Dots represent observed data averaged over 2001-2002. Horizontal dashed lines indicate the 5%, 10%, 15% and 20% acceptable yield loss levels used to determine the CPWC, whereas vertical dashed lines indicate the beginning and end of CPWC. Parameters for fitted curves are given in Table 6.

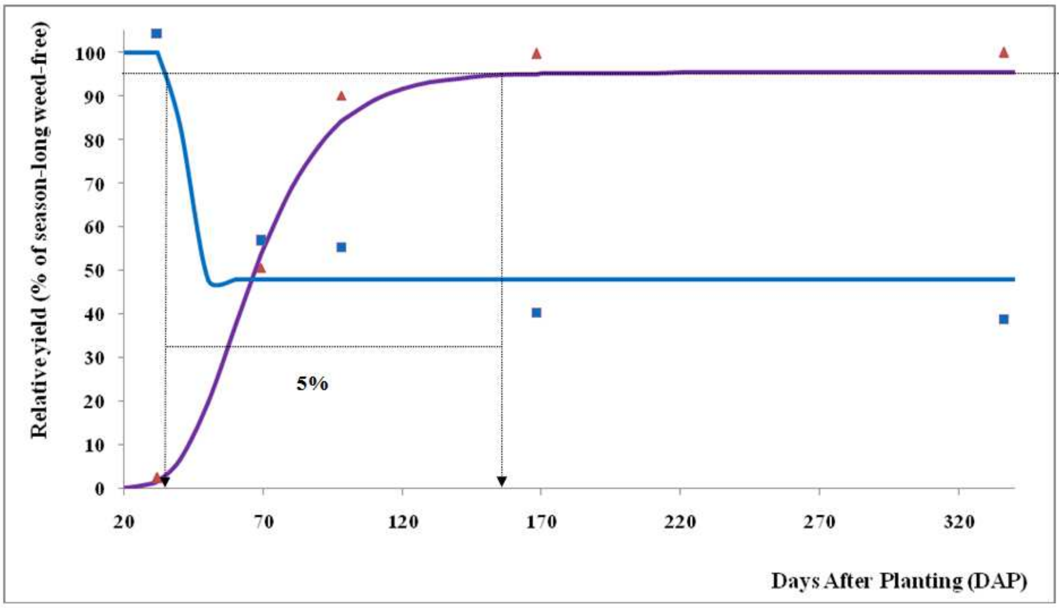


Figure 3: Effect of weed interference on total yield of sugarcane. Increasing duration of weed interference (■) and fitted curves as calculated by the logistic equation; increasing weed-free period (▲) and fitted curves as calculated by the Gompertz equation. Dots represent observed data averaged over 2010-2011. Horizontal dashed lines indicate the 5%, 10%, 15% and 20% acceptable yield loss levels used to determine the CPWC, whereas vertical dashed lines indicate the beginning and end of CPWC. Parameters for fitted curves given in Table 6.

DISCUSSION

Weed species composition and biomass evolution

According to Akobundu (1987), 10 families comprise the most species considered as « major world weeds ». Those families are Euphorbiaceae, Malvaceae, Asteraceae, Poaceae, Cyperaceae, Convolvulaceae, Fabaceae, Polygonaceae, Amaranthaceae and Solanaceae. Among those 10 aforementioned families, 4 dominant families were found during our field experiment: Euphorbiaceae, Poaceae, Cyperaceae, and Fabaceae. These results are also close to those of Aman-Kadio et al. (2004), who noted the dominance of 5 families (Euphorbiaceae, Asteraceae, Poaceae, Cyperaceae, Rubiaceae) in the crops' weed flora. Generally, the floristic diversity of the experiments shows a likeness with the ivorian flora (Aké-Assi, 2002) characterized by 7 dominant families of Angiosperms that are Leguminoseae, Rubiaceae, Poaceae, Orchidaceae, Cyperaceae, Euphorbiaceae and Asteraceae.

Total weed dry weight in all growing season, decreased with increasing duration of weed-free period. This phenomenon is in agreement with Mondani et al. (2011) who stated that total dry weight of weeds was the highest in the unweeded control. It is followed by weeding at 162 days after planting. As the total weed biomass reveals weeds growing ability and is a good predictor of their competitive ability against crops (Sarwar, 1994), the competitive ability of plants for resources such as light, nutrients and soil water is linked to biomass allocation (Aerts et al., 1991). For Tilman (1988), light interception and soil nutrients absorption are proportional to leaves and roots biomass respectively because resources are captured by plants to produce dry matter that is redistributed to various organs (stems, roots, leaves, fruits). Consequently, weeds emerging earlier in the growing season of sugarcane are the ones that will have the greatest biomass. Therefore, they have an important role in time of weed removal and choosing an appropriate method for weed control in sugarcane fields.

Critical period for weed control in sugarcane

Sugarcane yields decreased in Yamoussoukro. In Zuenoula, yields varied from 57.03±5.19 t/ha to 115.82±4.64 t/ha while in Yamoussoukro they ranged from 0.80± 0.244 t/ha to 34.32±5.02 t/ha. The highest yield in Yamoussoukro was less than the lowest yield (weedy control) in Zuenoula. The high yielding in Zuenoula can be explained by the intensive management of sugarcane at that location (fertilization, irrigation, pest management). In fact, according to Anonymous (1985), comparatively to rainfed sugarcane, the irrigation increases the yields of 30%. In the North of Côte d'Ivoire (Ferkessedougou) for instance, it permits to double and even to multiply by 3 the yields, compared to those in rainfed crop (Diomande, 1989). According to Péné (1999), water is the first limiting factor for sugarcane yield in Côte d'Ivoire.

The results of the experiments suggest that increasing the duration of weed interference decreased sugarcane yield significantly. In Zuenoula in 2002, the CPWC was from 28 to 117 DAP to prevent yield losses of 5%. This period to prevent yield losses of 10, 15 and 20% was from 30 to 93 DAP, from 32 to 75 DAP and from 34 to 59 DAP, respectively. In 2011, at the experimental farm of National School of Agronomy of Yamoussoukro, the CPWC ranged from 38 to 163 to prevent yield losses of 5%. This period to prevent yield losses of 10%, 15% and 20% ranged from 39 to 112, from 40 to 99 DAP and from 40 to 91 DAP, respectively. Results from this experiment suggest that weed control should be carried out between 28 and 117 DAP in intensive conditions and between 38 and 163 in non-intensive conditions to provide maximum sugarcane yield. The cultural practices and environmental conditions of the two locations modified the CPWC in sugarcane. In fact, previous research has suggested that the exact outcome of crop–weed interference is dependent on many site-specific factors, particularly the availability of essential nutrients (Di Tomaso, 1995; Tollenaar et al., 1994; Vengris et al., 1955; Weaver et al., 1992). Therefore, nutrient management has been identified as a likely strategy for weed management (Walker and Buchanan, 1982). In Zuenoula, because of the intensive production conditions, canopy closure is earlier than in Yamoussoukro. Knowledge of the CPWC and the factors that affect it is essential for making decisions on the appropriate timing of weed control and in achieving the efficient use of herbicides (Knezevic et al., 2002; Mulugeta and Boerboom, 2000).

In its early stages, sugarcane germinates and grows very slowly, while weeds show a rapid growth due to the lack of competition from the crop. If not checked timely, early tillering and growth of sugarcane is likely to be affected by weed competition. Singh et al. (1980) reported that critical period for weed control was between 30 and 120 days after planting sugarcane in Spring. Punzelan and Cruzz (1981) obtained maximum yield of cane when the crop was kept weed free from one to three months after planting, controlling weeds for longer periods did not enhance yields. It was further observed that weeds competition for one month from planting had no adverse effect on cane yields, whereas competition for two months reduced yield by 15% and for the whole season by 55%. In India for example, it was reported that critical period of weed crop competition in sugarcane ranged between 27 and 50 days (Srivastava et al., 2003). Critical period of weed-crop competition was also found 45 days after sowing (Zafar et al., 2010).

Conclusion

The critical period for weed control represents the time during which weeds must be controlled to avoid an assigned level of crop yield loss, which is often 5%. Difference in CPWC due to intensive and non-intensive cropping systems documented in this experiment highlights the need for a better understanding of the effects of environmental conditions (rainfall, solar radiation, wind speed, temperature) and intensification factors (irrigation, fertilisation) on crop-weeds competition for limited resources. The development of an Integrated Weed Management (IWM) System requires a deeper understanding of the behaviour of weeds in agro-ecosystems. The practical application of this study is that weeds must be controlled from 28 to 117 days and from 38 to 163 days after planting in intensive and non-intensive production systems, respectively, to prevent more than 5% unacceptable yield losses. If these critical periods for weed control are adopted by farmers and practitioners, they have the potential to influence their decision making on timing of POST herbicide application. And as Ivorian farmers usually tackle weed problems after weed emergence, these CPWC help them optimise POST herbicide doses.

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