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A review on weed management in sugar cane: Critical periods of *Paspalum paniculatum* and *Paspalum urvillei*

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Abstract

The adverse effect of weed competition in sugar cane is not experienced before several weeks following weed emergence. Weeds transplanted 10 WAP caused no significant change in cane yield response as compared to those transplanted 4 WAP. *Paspalum paniculatum* was often found to be more competitive than *P. urvillei*, although the latter produced more leaf area and grew taller to intercept more light within the canopy. This indicated that other mechanisms of weed interference were involved and competition for light was more important during the earlier (tillering) growth stages. Root competition was shown to be as important as shoot competition. Root competition effects were observed several weeks after imposing competition, suggesting that it was more important than competition for light in the post-tillering phase. The application of root exudates from the two types of grass to sugar cane confirmed an allelopathic effect on the root biomass of sugar cane. One chemical identified in the leachates from both *Paspalum* species for the allelopathic effects was 2-propenoic acid, 3-(4-methoxyphenyl). The main implications of the above findings for the Indian sugar industry would involve a change in the timing of the application of herbicides. A new tank-mix consisting of trifloxysulfuron + ametryn and amicarbazone has been found to meet this objective. In ratoon cane, CPWC with natural weed infestations started between 228 and 916 growing degree days (GDD), and ended between 648 and 1311 GDD, depending on the site and cane variety. These results represented a maximum CPWC of 12 to 28 weeks after harvest (WAH). In-plant cane, the CPWC started earlier (6WAP) and was longer than those in ratoon cane.

Keywords: Weed competition, root competition, allelopathy, *Paspalum* species

Introduction

Sugarcane (*Saccharum* spp. hybrids) is a perennial crop and in India two harvests are typically made from a single planting. Under Indian growing conditions, sugarcane is planted in August and September to allow the crop to establish before the winter dormant period. New growth occurs usually in March of the following year. Weed problems are addressed before planting with pre-plant application of glyphosate and/or timely tillage operations to control weeds during the spring and summer fallow period (Anonymous 2009). At planting, the preemergence herbicide is applied to prevent weed establishment and competition with the crop. Sugar cane was first brought to India in 1639 by the Dutch who established two sugar processing plants in 1641 (Koenig, 1988). By 1652, however, the manufacture of sugar was abandoned but the cultivation of sugar cane was continued for the production of 'arrack' (an alcoholic beverage similar to rum). The Dutch left the island in 1710 and during the French occupation (1721–1810), a great impetus was given to sugar cane production and the first sugar factories were created; some 3 000 tonnes of sugar and 300 000 gallons of arrack were produced by the beginning of the 19th century. The British captured the island in 1810 and realized that sugar production could be the greatest asset of India; as a result, the area under cane increased steadily and reached 11 000 ha in 1825. The island was already producing some 107 000 tonnes of sugar in 1854. The sugar industry has since undergone further expansion through increased acreage of sugar cane and significant technical progress due to research and development. The country recorded its maximum sugar production in 1973 when 718 464 tonnes were yielded from a cultivated area of 87 384 ha (Koenig, 1988). Since then, owing to the conversion of cane land to other uses and small-growers abandoning their production due to increasing costs, production has been falling on average; from 706 839 tonnes in 1986 to 504 900 tonnes in 2006 (Msiri, 2006) [11]. The current area under cane is less than 67 000 ha (Msiri, 2006) [11].

The decrease in area and production has been faster within the last five years as more lands have been converted to other new emerging sectors such as manufacturing (mainly textile), information and telecommunication technologies (ICT) and integrated resort schemes (IRS). India is a small volcanic island situated some 850 km east of Madagascar in the south-west Indian Ocean at latitude 20°32' South and longitude 57°04' East. The island covers an area of 1860 km² and consists of a coastal plain rising gradually towards a central plateau bordered by mountain ranges, with the highest peak 826 m above sea level. Much of the research on sugarcane as a crop is now carried out by entities financed by commercial cane growers. Their interest in plant physiology, and particularly in growth and development, is principally directed to acquiring knowledge that can contribute to improved varieties and management of the crop. Recently Duvick and Cassman (1999) [2] referring to maize in the United States lamented the scarcity of funds for research on the understanding of physiology and noted that the limited amount is directed mostly toward molecular approaches to increase productivity. They went on to observe that molecular approaches without a deeper understanding of physiological determinants of yield potential that seek empirically to concentrate "yield genes are likely to fail. Although Duvick's and Cassman's comments refer to maize, they are directly appealing, cable to the sugarcane situational present. There is little funding for physiological research on sugar cane: the small amounts dedicated to physiology are mainly at the cellular and molecular levels with virtually no research, outside of Australia, on growth and development at the crop art plant level. *Paspalum paniculatum* and *P. urvillei* have been focused on in this paper to study and describe weed competition in sugar cane, as they are listed among the five most common weeds in the humid and super humid areas, representing more than 60% of the cane-growing area, and because the cane growers include them in their list of more intractable weeds (see above). Other reasons for their selection in this study include their diverse morphological characteristics, despite them being closely related, plus the relative ease with which they can be established.

Paspalum paniculatum

Botanical classification

Paspalum paniculatum Walt. is from the Poaceae (Grass) family and synonyms include *Paspalum compress caulis* Raddi, *Paspalum multispica* Steud., *Paspalum polystachium* Salzm., *Paspalum strictum* Pers. It's the common or vernacular name in India. *Paspalum paniculatum* is a coarse tussocky perennial, 0.3-2.2 m high with culms erect or geniculately ascending, moderately stout, and glabrous. The leaf-sheaths are keeled with the nodes densely bearded, usually stiffly hairy to nearly glabrous; ligule is truncate and very short. The leaf blades are linear to narrowly lanceolate, acute, 9-50 cm long, 6-25 mm wide, flat, stiffly hairy to almost glabrous (Hubbard & Vaughan, 1940) [3]. The inflorescence is 5-30 cm long and is made up of numerous racemes (7-60). The latter is 2.5-12 cm long, very slender, dense and finally spreading with their axes 0.5 mm wide. The spikelets occur in pairs and are rotundate-elliptic, obtuse, measuring 1.2-1.5 mm long. They are straw-colored to purplish-brown and minutely hairy, the upper glume and lower lemma being 5-nerved.

Ecology and distribution

Paspalum paniculatum produces large quantities of fertile

seeds which germinate rapidly under favorable conditions to invade new areas. It can also propagate from split tussocks as a result of certain cultural practices carried out in the fields. It grows well even in shaded places. *Paspalum paniculatum* is a dominant species of the humid and super humid areas of India, growing mostly along roadsides and in fallow fields from where it encroaches onto sugar cane fields. Today, it is quite common in sugar cane fields.

Paspalum urvillei

Botanical classification

Paspalum urvillei Steud. is from the Poaceae (Grass) family and synonyms include *Paspalum griseum* Hack., *Paspalum dilatatum* var. *parviflorum* Doell and *Paspalum velutinum* Trin. Its common or vernacular name in India is 'Herbe cheval'. *Paspalum urvillei* is an erect perennial, growing in dense tussocks about 30 cm in diameter and 0.75- 2.5 m high. The culms are moderately stout and glabrous. The base of the stalks and leaf sheaths is hairy and bluish. The leaf-sheaths are keeled upwards with the lower ones being coarsely hairy whereas those found on the upper parts are less hairy or are glabrous. The ligules are 3- 5 mm long; leaf blades are erect, linear, acute, 12-50 cm long and 3-15 mm wide. They are flat and long-hairy at the base, otherwise glabrous (Skerman & Riveros, 1990) [16]. The inflorescence is erect or slightly nodding, 10-40 cm long, and is composed of 6-25 dense, mostly erect racemes. The flower racemes are 6-14 cm long, whereas the upper ones become gradually shorter, each with their axis about 0.8 mm width. The spikelets are paired, broadly ovate-elliptic, abruptly acute and are 2-3 mm long. They are green or purplish, the upper glume and lower lemma are 3-5 nerved and are fringed with long silky hairs (Skerman & Riveros, 1990) [16].

Ecology and distribution

Paspalum urvillei is a perennial plant that spreads fairly quickly under favorable moist conditions with its heavy seed production; it can also regenerate from split tussocks. It prefers full sunlight and does not grow well in shade. Its vigorous, erect growth allows it to compete successfully with other plants and crops. *Paspalum urvillei* is a high rainfall grass occurring mostly in the humid and super-humid areas of India, along roadsides and in fallow fields from where it extends its range to cultivated fields. It is commonly found in sugar cane fields nowadays.

Weed control in sugar cane

Since the early 1950s, the introduction of selective herbicides has been one of the main factors enabling the intensification of agriculture in developed countries (Kropff & Lotz, 1992a; Kropff & Walter, 2000) [6, 7]. In India, before the introduction of the herbicides MCPA and 2,4-D in the late 1940s, weed control in sugar cane was achieved mainly by manual weeding. Some cultural practices such as trash lining ("relevance") and ridging ("butting") also helped to suppress weeds (De Sornay, 1926) [1]. The availability of residual herbicides from the 1950s and research showing the advantages of chemical control resulted in a major shift in methods of control; use of herbicides increased significantly thereafter to reach a peak with more than 700 tonnes of active ingredient applied to approximately 80 000 ha of cane in the 1980s. The residual action of the first herbicide treatment usually lasts between 10-14 weeks, thus necessitating a second application consisting of one or two pre-emergence herbicides tank-mixed with a post-emergence one to control

emerged weeds and, at the same time, to prevent others from emerging. Under certain circumstances, when canopy closure is retarded for reasons such as climate, cane variety and row spacing, a third herbicide application may be necessary usually as a full or spot treatment. This application is sometimes replaced by manual weeding depending on the availability of labor (especially during the intercrop period). Manual weeding is also resorted to when certain weed species are not controlled by the standard treatments. In sugar cane fields, the presence of more than 15 weed species consisting of broad-leaved weeds, grasses and sedges is quite common. For this reason, tank-mixing of two or more herbicides to achieve a broader spectrum of control is a common practice in sugar cane production. Pre-emergence herbicides represent more than 60% of the total amount (active ingredients) of herbicides used in sugar cane. The most important ones are diuron, atrazine, tebuthiuron, acetochlor, metolachlor and oxyfluorfen. The two main post-emergence herbicides applied in sugar cane in the last 30 years have been 2,4-D amine salts and ioxynil+2,4-D ester.

Strategies of weed management

The traditional weed management practice has been to eradicate practically all weeds from sugar cane fields irrespective of the species present, their levels of infestation, and the stage of growth of the cane. To achieve this level of control and to cope with the reduction in, or non-availability of, labor in the sugar industry in the 1980s, cane producers have resorted to more pre- and post-emergence herbicides. Although a slight reduction in the total amount of active ingredients had been noted during the last decade due to new molecules/formulations using less active ingredients, as well as the adoption of trash blanketing in the sub-humid areas, the total costs of herbicides have increased significantly. This is mainly due to the exchange rate of the Indian rupee the US dollar and the pound Sterling; all herbicides used locally being imported. The average cost of herbicides exceeds and the total costs for weed control in the sugar industry were estimated at more than 45 lakh in 2004. Costs for weed control vary between 4% and 8% of the total cost of production. The optimization of herbicides to reduce environmental effects and to minimize costs has led to the development of strategies for Weed Management or Integrated Weed Management (IWM) and the use of alternative methods for weed control. IWM involves a combination of cultural, mechanical, biological, genetic, and chemical methods for effective and economical weed control (Swanton & Weise, 1991) [18]. The new approach is aimed at the management of weed populations and includes a better understanding of crop-weed(s) interactions, identifying critical periods of weed competition concerning crop growth and weed emergence and infestation, improved agronomic practices, etc. Any weed management system developed for a particular crop should not be geared towards yield losses only in the current year but should consider longer-term issues including consequences for the level of weed infestation that is likely to arise in subsequent years. The latter includes the impact on the weed seed bank of seeds produced from surviving weeds.

Critical periods of weed control in sugar cane in India

The development of weed management strategies to reduce the number of herbicides used for weed control in sugar cane, for both economical and environmental reasons, is now even more of a priority than it has been in the recent past. An

integrated approach to weed management is needed. Integrated Weed Management (IWM) involves a combination of cultural, mechanical, biological, genetic, and chemical methods for effective and economical weed control (Swanton & Weise, 1991) [18]. This approach focuses on the management of weed populations following economic threshold levels, rather than their total elimination. To achieve this there is a need for a better understanding of crop-weed interactions, identification of critical periods of weed competition concerning crop growth, weed emergence and infestation level, as well as improved agronomic practices. The critical period for weed control (CPWC) is defined as the specified minimum period during which the crop must be free from the adverse effects of weeds to prevent crop yield loss (Zimdahl, 1993) [20]. Knezevic *et al.* (2003) [4] reported the CPWC as a key component of any IWM program. The CPWC represents the time interval between two separately measured components: the maximum weed-infested period – the length of time that the weeds emerging with the crop can remain before they begin to interfere with crop growth, and the minimum weed-free period – the length of time a crop must be free of weeds after planting to prevent yield losses. These components can be experimentally determined by measuring crop yield loss as a function of successive times of weed removal or weed emergence, respectively (Weaver *et al.*, 1992). The CPWC has been found to vary with location, year, cultivar, nitrogen application rate, row spacing, etc. (Cousens, 1988; Knezevic *et al.*, 2003; Van Acker *et al.*, 1993) [4, 19]. Critical periods of weed competition in sugar cane have been reported from experiments carried out in plant cane only. Lamusse (1965) [8] reported, from a field experiment carried out in Trinidad, that weed competition from *Paspalum fasciculatum* Wild (bamboo grass) had a little adverse effect on the sugar content and yield of sugar cane when infestation started as late as 12 weeks after planting; however those beginning earlier were detrimental to final yields. Promkun (1984, cited by Suwanarak, 1990), in an irrigated area of Thailand, showed that delaying the first removal of weeds by 3 and 4 months may decrease yield by 44% and 65% respectively while Suwanarak (1982) [17] observed that nonirrigated sugar cane required a weed-free period of 4-5 months after planting. From a field trial carried out in Ivory Coast, Marion and Marnotte (1991) [9] showed that a weed-free period between the first and third months after planting was required to restrict maximum yield loss to 5%. As India conditions are different, and because ratoon cane represents more than 85% of the cultivated area, the objectives of this part of the project were to study the CPWC mainly in ratoon cane (plus one trial in plant cane) in the super-humid and humid areas of India, where cane canopy closure takes longer and weed competition is expected to be higher. It is expected that results obtained under such difficult conditions may be extrapolated for the development of weed management strategies for other regions of the island.

Weed infestation treatments

A naturally occurring population of mixed weed species was present at all sites; they were either kept for increasing periods or were removed for weed-free treatments for corresponding periods. The treatments were imposed only when the first homogeneous flush of weeds started to emerge; this resulted in different treatment start dates as weed emergence varied across the six trials. In ratoon cane, weed infestation or weed-free periods started from 8 to 14 weeks after harvesting (WAH) of the previous crop and were

maintained for up to 23-31 weeks depending on the trial, whereas treatments in plant cane were imposed as from the first week after planting and continued up to 30 weeks. The interval between different treatments (weed-free or weedy) was usually three or four weeks for trials in ratoon cane while a five-week interval was established for the trial in plant cane. For the weed-free treatment and at the end of each weed infestation period, the plots were sprayed manually with a knapsack sprayer using double cone-jet nozzles delivering 450 L ha⁻¹ of spray volume at a working pressure of 300 kPa. The herbicide treatments were a tank-mix of diuron (2.5 kg a.i. ha⁻¹) + 2,4-D amine salt (2.0 kg a.e. ha⁻¹). Diuron was replaced in the treatment by hexazinone + atrazine (0.6 + 2.0 kg a.i. ha⁻¹) at Olivia due to the susceptibility of the variety grown. Where the weed infestation was planned to start later (10 to 20 weeks after harvest/planting), reduced rates (25% of the full rate) of the diuron or hexazinone + atrazine were applied at the beginning of the experiment to keep the plots weed-free initially. The few weeds not controlled by the herbicides were removed manually.

Weed species and infestation levels

The main weed species present in Trials I, IV, and VI some grass weeds, namely *P. paniculatum*, *P. urvillei* and *D. horizontalis* were recorded as the cane variety is grown (M 3035/66) was harvested late in the season (October/November) when the temperatures were higher and more conducive for germination of these grasses. Variety M 52/78 (Trials II & V) was harvested in June/July, a period of the year when broad-leaved weeds such as *A. conyzoides* and *Solanum nigrum* L. were predominant. Although Trial III (Olivia) was also initiated late in the season, only *Phyllanthus* spp. and *A. conyzoides* were common, as the site was at a lower altitude and is less humid than the other sites. *Paspalum urvillei*, *Paspalum paniculatum*, *Solanum nigrum*, *Digitaria horizontalis*, *Drymaria cordata*, *Ageratum conyzoides*, *Kyllinga* sp, *Youngia japonica*, *Kyllinga bulbosa*, *Phyllanthus* sp, *D. horizontalis*, *Lactuca indica*, *Conyza canadensis*, *Bidens Pilosa*, *K. elata*, *Oxalis corniculata*.

Effect of weed infestation periods on cane yield and critical periods of weed control: Cane yield in the weed-free treatments were 61.6, 106.3, 85.0, 56.1, 82.9, and 89.1 t ha⁻¹ in Trials I to VI, respectively. Yield differences can be explained by variation in cropping year, crop cycle, cane, variety and agroclimatic conditions. At all sites, with one exception (Trial I – 50% infestation level), cane yield was found to decrease with increasing weed infestation periods and to increase with the extension of weed-free periods. An example of the cane response to different weed interference and weed-free periods for Trial VI. Nayamuth *et al.* (1999)^[12] showed that an early variety differs agronomically and physiologically from a late variety, the early variety produced fewer tillers and a lower leaf area index (LAI) but formed cane stalks earlier. The slower initial development of the early variety (M 52/78) explains the earlier onset of the CPWC due to more competition from weeds present; the winter period is predominated by broad-leaved weeds such as *S. nigrum* which can grow quickly and produce a relatively high leaf area. But as the early varieties also start stalk formation quicker than the late varieties, and exhibit a more efficient partitioning of above-ground dry matter into cane (Nayamuth *et al.*, 1999)^[12], this means that they can grow faster beyond that stage and are less susceptible to weed competition. The latter results in early varieties reaching the end of the CPWC at lower GDDs.

In-plant cane, the CPWC was longer than in ratoon as it is known that germination, tillering and start of the elongation phase take more time. The results obtained for the onset of the CPWC in plant cane, i.e. six and eight weeks for the 50% and 100% infestations respectively, are similar to those reported by Suwanarak (1990) and Marion and Marnotte (1991)^[9].

Weed management based on critical periods

The above results show that the classical weed control approach, i.e. applying herbicide treatments immediately after planting, or after the previous harvest in ratoon cane, is not justified and the first herbicide treatment may be delayed according to the cane variety grown and the temperatures (GDD) expected during the growing phase. Rochecouste (1967) reported that weeds adversely affect young cane and thus applying a herbicide treatment pre-emergence of cane and weeds was important. This was mainly due to the early post-em treatments available in those days (e.g. diuron + 2,4-D amine salt or ioxynil + 2,4-D ester) not being selective to young cane shoots and their spectrum of control was limited. This approach of applying a treatment pre-emergence of cane has remained as a standard practice and had been the focus of research in the late 1980s with the screening of treatments exhibiting longer residual activity. For example, the tank-mix oxyfluorfen + diuron was recommended in 1989 as it provided the residual activity of 14 to 16 weeks after planting (Mc Intyre & Barbe, 1995)^[10]. The latter approach would succeed only if herbicide treatments can knock down all weeds present before the onset of the critical periods and can provide a fairly long residual activity until the end of critical periods are reached. In 2005, a new herbicide containing trifloxysulfuron and ametryn (one product) tank-mixed with amicarbazone at 1.5 + 1.075 kg a.i. ha⁻¹ has been recommended for such purpose, as it was found to be well tolerated by young cane shoots (from four to six weeks after planting or harvest) and provided a wide spectrum of control when applied both pre-and post-emergence of weeds (Seeruttun *et al.*, 2007)^[15]. This new treatment permits the delay of the first application nearer to the onset of the CPWC and with its residual activity varying between 14 and 16 weeks, one herbicide application may be sufficient to reach the end of the CPWC.

Conclusion

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

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