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Article

# USE OF HERBICIDES IN SUGARCANE IN THE SÃO PAULO STATE

## *Uso de Herbicidas na Cultura de Cana-de-Açúcar no Estado de São Paulo*

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ABSTRACT - Sugarcane is one of the main agricultural cultivations of Brazil, and one of the crops in which herbicides are most applied. In the 2017/2018 season, the estimated sugarcane production was 694.54 million tons, with an estimated increase of 0.9% in yield for this season. In order to evaluate the use of herbicides in this crop in the São Paulo State during a five-year period, a survey was carried out with sugarcane farmers. The use of herbicides applied alone and in a formulated mixture, according to their mechanism of action, were evaluated from 2010 to 2014. Photosystem II inhibitor herbicides were the most used in this period and the total amount of herbicides of almost all mechanism of action increased from 2010 to 2014, except for photosystem I inhibitors herbicides. The use of formulated mixtures also increased during this period. The area treated with carotenoid biosynthesis and photosystem II inhibitor herbicides was the largest for the control of monocotyledonous species (Poaceae, Cyperaceae and Commelinaceae). In relation to the dicotyledonous species, the area treated with PROTOX inhibitor herbicides was the largest in all evaluated years.

**Keywords:** marketing, mechanism of action, research, pesticides, *Saccharum officinarum*.

*RESUMO - A cana-de-açúcar é um dos principais produtos agrícolas do País, sendo uma das culturas em que mais se utilizam herbicidas. Na safra de 2017/2018 a produção estimada é de 694,54 milhões de toneladas, e se estima um incremento de 0,9% na produtividade para a safra de 2017/2018. Com o objetivo de avaliar o uso de herbicidas nessa cultura no Estado de São Paulo durante cinco anos, foi realizado levantamento junto aos produtores do Estado. A utilização dos herbicidas aplicados isoladamente e em mistura formulada, de acordo com seu mecanismo de ação, foi avaliada entre os anos de 2010 e 2014. Os herbicidas inibidores do fotossistema II foram os mais usados neste período, e a quantidade total dos herbicidas de praticamente todos os mecanismos de ação, exceto inibidores do fotossistema I, aumentou entre os anos de 2010 e 2014. O uso de misturas formuladas de herbicidas também aumentou nesse período. A área tratada por herbicidas inibidores da biossíntese de carotenoides e fotossistema II foi a maior para o controle de espécies da classe das monocotiledôneas (Poaceae, Cyperaceae e Commelinaceae). Em relação à classe das dicotiledôneas, a área tratada por herbicidas inibidores da PROTOX foi a maior em todos os anos avaliados.*

**Palavras-chave:** marketing, mecanismo de ação, pesquisa, pesticidas, *Saccharum officinarum*.

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## INTRODUCTION

In the 2017/2018 season, sugarcane production was estimated to be 694.54 million tons, with an increase of 0.9% in yield. However, a reduction of 4.6% was observed in the overall sugarcane yield between the 2013/2014 and 2014/2015 seasons. Among the reasons for this reduction are unfavorable climate conditions during 2014 and 2015 in southern Brazil (Marengo et al., 2015; Conab, 2017).

In addition to unfavorable climate conditions, other factors may affect sugarcane yield, including soil conditions, planted varieties, pest and disease incidence, weed competition, and plant phytotoxicity due to herbicide application (Victória-Filho and Christoffoleti, 2004). A study carried out by Kuva et al. (2001) reported that sugarcane yield could be reduced up to 80% according to the degree of competition with weeds.

Weed management in production systems, in general, is based on the integration of cultural, mechanical, physical, and chemical control. The chemical control of weeds in sugarcane cultivation areas is undoubtedly the most used practice due to the lower cost and practicality of the use of herbicides (Kuva and Salgado, 2014). Currently, several herbicide molecules are registered for weed control in sugarcane (Rodrigues and Almeida, 2011), but only 15 to 20 molecules are commonly used.

In addition, herbicides commercialized with a single active ingredient in formula, there are also options of double and triple formulated herbicides mixtures, which could belong to different chemical groups, mechanism of action and have different physicochemical characteristics (Kuva and Salgado, 2014). Therefore, this study aimed to evaluate the use of herbicides in the sugarcane crop in the São Paulo State for a period of five years (2010 to 2014).

## MATERIAL AND METHODS

Data from market surveys conducted by the Kleffmann Group between 2010 and 2014 were used in the analyses. The data were provided with confidentiality and do not have free access. The results of herbicide use are presented according to the mechanism of action to ensure the confidentiality of the data. According to information from Kleffmann Group employees, the survey started by preparing questionnaires and determining the most representative regions of sugarcane production. After elaborating the questionnaire and training the interviewers, personal or telephone interviews were carried out with interviewees chosen randomly. Thus, the survey was conducted with 510 interviews per year, which allowed a safe margin of error of 3%. Data from official agencies (IBGE, CONAB, and CANASAT) were used to estimate the area planted with sugarcane per municipality.

The following topics were addressed in the questionnaire: applied sugarcane area, applied herbicides, period and number of applications, and weed to be controlled. Only the herbicides applied during the period were considered in this study; those purchased by the producer and not used were excluded. The herbicides applied were cited by the trade name or active ingredient. However, the herbicides were grouped into their mechanism of action to evaluate their use in the sugarcane cultivation in the period.

The calculation of the response variable treated area was performed according to that described by Franconere (2010), considering that in this area at least one application of herbicides was carried out. The treated area was determined by multiplying the surface treated by the number of applications, taking into account if the product was applied in a mixture. Data analysis was performed with the presentation of figures and tables. Initially, the total amount of herbicide applied in the sugarcane from 2010 and 2014, divided by mechanism of action, as well as the total amount of formulated mixtures, was calculated by the graphical analysis. Then, the area treated with herbicides of different mechanism of action applied to control monocotyledonous and dicotyledonous weeds was calculated. The percentage of the planted area of sugarcane in which herbicides were applied and how much of them are recommended for monocotyledonous, dicotyledonous, Cyperaceae, and desiccation were shown in the tables. The error due to the extrapolation of data was 10%.

## RESULTS AND DISCUSSION

The mechanism of action of the herbicides cited during the field research, active ingredients, and chemical groups within each class are presented in Table 1. Herbicides belonging to ten mechanism of action and a total of five mixtures were cited by the interviewees (Table 2). The herbicides were cited by the interviewees by commercial name or active ingredient but were grouped by mechanism of action.

Both the area planted with sugarcane and that applied with herbicides increased by approximately 16% from 2010 to 2014 (Table 3). However, in 2010, the percentage of adoption was 98.56%, reaching 99.43% in 2014, indicating a small increase in the adoption of areas applied with herbicides in relation to the area cultivated with sugarcane in this period, showing that in almost 100% of sugarcane cultivation areas occur herbicide applications.

The total amount of herbicides (t) used in the State of São Paulo increased by 38% from 2010 to 2014, while the increase of herbicide used per hectare was 26% (Table 4). This indicates that the increased use of herbicides in sugarcane cultivation in the state was due to higher applied volume per hectare as well as the expansion of cultivated area.

***Table 1*** - Identification of chemical groups and active ingredients within each mechanism of action of the herbicides applied alone in sugarcane cultivation areas from 2010 to 2014

| Mechanism of action | Chemical group | Active ingredient |
|---|---|---|
| Synthetic auxins | Phenoxy carboxylic acid | 2,4-D |
| | Pyridine carboxylic acid | Picloram |
| Carotenoid biosynthesis inhibitors | Isoxazole | Isoxaflutole |
| | Triketone | Mesotrione |
| | Isoxazolidinone | Clomazone |
| ALS inhibitors | Pyrimidinyl(thio)benzoate | Bispyribac-sodium |
| | Imidazolinones | Imazapic |
| | Imidazolinones | Imazapyr |
| | Triazolopyrimidine | Diclosulam |
| | Sulfonylurea | Ethoxysulfuron |
| | Sulfonylurea | Flazasulfuron |
| | Sulfonylurea | Halosulfuron-methyl |
| | Sulfonylurea | Iodosulfuron-methyl |
| | Sulfonylurea | Metsulfuron-methyl |
| | Sulfonylurea | Trifloxysulfuron-sodium |
| Fatty acid and lipid biosynthesis inhibitors | Chloroacetamide | Alachlor |
| | Chloroacetamide | S-metolachlor |
| EPSPS inhibitors | Glycine | Glyphosate |
| Photosynthesis II inhibitors | Triazine | Ametryn |
| | Triazine | Atrazine |
| | Triazinone | Hexazinone |
| | Triazinone | Metribuzin |
| | Urea | Diuron |
| | Urea | Tebuthiuron |
| PROTOX inhibitors | N-phenylphthalimide | Flumioxazin |
| | Diphenyl ether | Oxyfluorfen |
| | Oxadiazole | Oxadiazon |
| | Triazolinone | Amicarbazone |
| | Triazolinone | Carfentrazone-ethyl |
| | Triazolinone | Sulfentrazone |
| Mitosis inhibitors | Dinitroaniline | Pendimethalin |
| | Dinitroaniline | Trifluralin |
| Photosynthesis I inhibitors | Bipyridylium | Paraquat |
| Unknown | Organoarsenical | MSMA |

***Table 2*** - Identification of chemical groups and active ingredients within each mechanism of action of the herbicides applied in mixtures in sugarcane cultivation areas from 2010 to 2014

| Mechanism of action | Chemical group | Active ingredient |
|---|---|---|
| Synthetic auxins + synthetic auxins | Phenoxy-carboxylic acid + Pyridine carboxylic acid | 2,4-D + picloram |
| Photosynthesis II inhibitors + ALS inhibitors | Triazine + sulfonylurea | Ametryn + trifloxysulfuron-sodium |
| Photosynthesis II inhibitors + carotenoid biosynthesis inhibitors | Isoxazolidinone + triazinone | Clomazone + hexazinone |
| Photosynthesis II inhibitors + photosynthesis II inhibitors | Triazine + urea<br>Urea + triazinone | Ametryn + diuron<br>Diuron + hexazinone |
| Photosynthesis II inhibitors + photosynthesis II inhibitors + ALS inhibitors | Urea + triazinone + sulfonylurea | Diuron + hexazinone + sulfometuron-methyl |

***Table 3*** - Sugarcane cultivation area (1,000 ha), area applied with herbicides (1,000 ha), and percentage of adoption of the area applied with herbicide in the São Paulo State from 2010 to 2014

| Year | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| Cultivated area | 4916.77 | 5254.84 | 5400.82 | 5734.41 | 5837.51 |
| Applied area | 4845.77 | 5183.13 | 5331.90 | 5672.64 | 5804.44 |
| % of adoption | 98.56 | 98.64 | 98.72 | 98.92 | 99.43 |

***Table 4*** - Total amount (t) and amount per hectare (kg) of herbicides as commercial product applied to the crop and area (in 1,000 ha) cultivated with sugarcane in the São Paulo State from 2010 to 2014

| Year | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| Total amount (t) | 18115.36 | 21520.81 | 24948.04 | 28596.22 | 29207.95 |
| Cultivated area (1.000 ha) | 4916.77 | 5254.84 | 5400.82 | 5734.41 | 5837.51 |
| Amount per hectare (kg) | 3.68 | 4.10 | 4.62 | 4.99 | 5.00 |

This increased use of herbicides per hectare may be due to changes in sugarcane cultivation in this period. The adoption of sugarcane harvest without previous burning and maintenance of straw on the soil after harvesting although favoring the control of some weeds with small seeds (Correia et al., 2006), was not enough to control other species (Leal et al., 2013). In addition, straw maintenance on the soil can increase the sorption of some herbicides, decreasing their effectiveness, as occurs for alachlor and diuron (Giori et al., 2014).

The increased use of herbicides from 2010 to 2014 occurred despite the country's financial crisis and climate adversities, pointing out a positive scenario for the pesticide industries. On the other hand, there is currently concern of society regarding the excessive use of these products and possible environmental contamination. Thus, sugar and alcohol sector may face the pressures of society due to the increased use of these compounds.

Herbicide use of almost all mechanism of action increased from 2010 to 2014, except for those that act on the photosystem I (Figure 1). Both the total amount (t) and herbicides used per hectare including those that inhibits carotenoid biosynthesis, EPSPS, photosystem II, and PROTOX increased in all evaluated years.

An increase (23%) in total use of auxin mimic herbicides was observed, but the increase of the application per hectare was lower (9%) (Figures 1 and 2). This suggests an increase in the market of these herbicides due to an expantion of the cultivated sugarcane area.

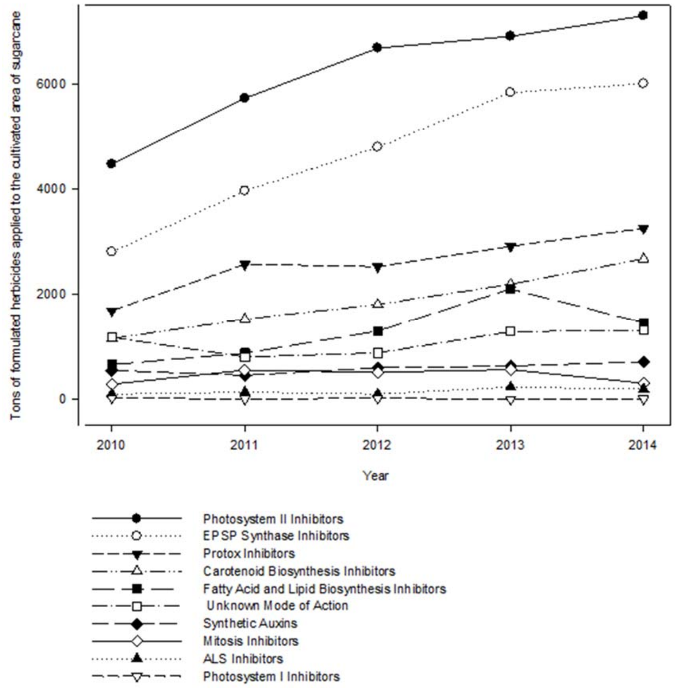
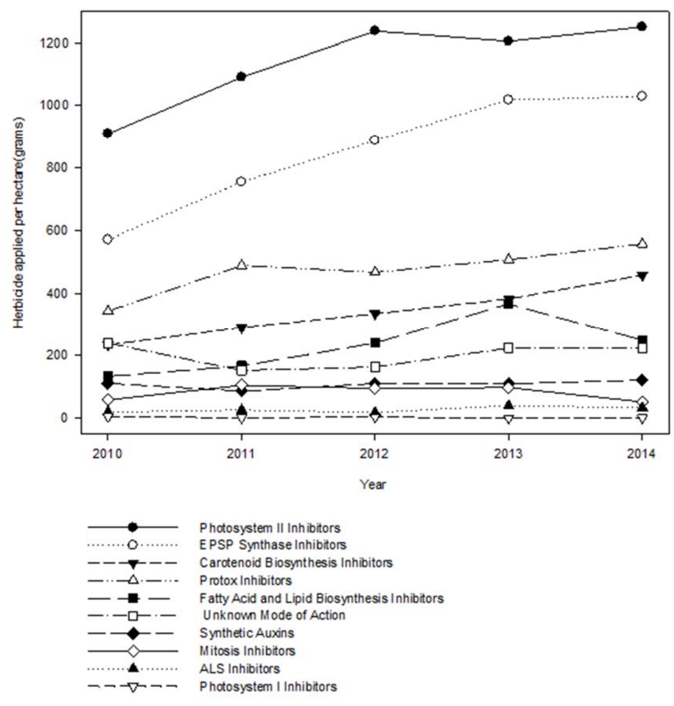



***Figure 1 -*** Amount of herbicides (tons of formulated product) by mechanism of action used in sugarcane cultivations in the São Paulo State from 2010 to 2014.




* Values obtained by the division of the used amount and the cultivated area (Table 3) do not refer to the recommended dose per hectare.

***Figure 2 -*** Amount of commercial herbicides applied (g) per hectare in sugarcane cultivation areas of the State of São Paulo from 2010 to 2014 by mechanism of action.

The use of ALS inhibitor herbicides (t) and the amount applied per hectare decreased in 2014 when compared to 2013, with reductions of 18 and 21%. The same occurred in 2012 when compared to 2011, with a reduction of 38% in the total use and 42% per hectare, respectively. These herbicides represent one of the most important mechanism of action in agriculture due to the high number of active ingredients available and of great utility (Vidal et al., 2014). The decreased use of these herbicides in 2014, when compared to the previous year, may be due to a negative outlook for sugarcane production in the 2014/2015 season caused mainly by the drought in the Southeast region in this period.

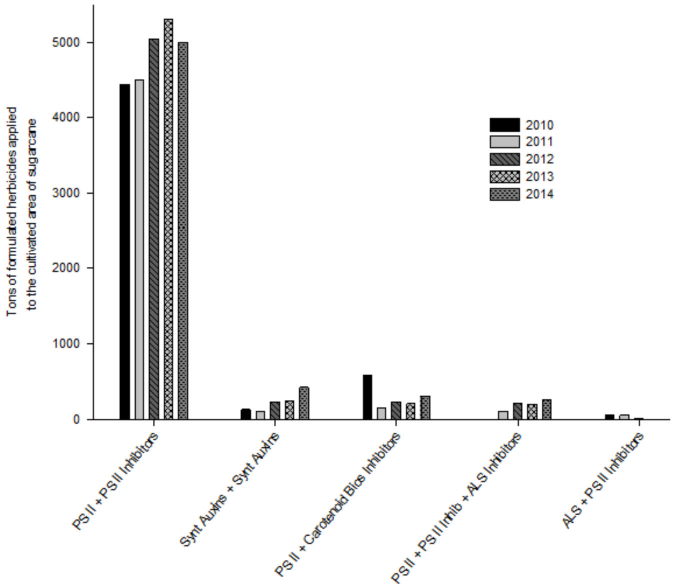
An increase in the total use of long chain fatty acid synthesis inhibitor herbicides was observed from 2010 to 2013, with a subsequent decrease in 2014 (44%). The same occurred with the amount applied per hectare, with a reduction of 47% from 2013 to 2014.

Photosystem II inhibitor herbicides were the most used both in total area and per hectare during the evaluated period (2010 to 2014) (Figures 1 and 2). Armas et al. (2005) evaluated the herbicide use in a sugarcane cultivated area in the region of the Corumbataí River basin (São Paulo State) and observed that in a four-year period (2000 to 2003), the most commonly used herbicides were glyphosate (EPSPS inhibitor) (19.88%), followed by atrazine (photosystem II inhibitor), ametryn (photosystem II inhibitor), 2,4-D (auxin mimic herbicides), metribuzin (photosystem II inhibitor), acetochlor (long chain fatty acid synthesis inhibitors), and diuron (photosystem II inhibitor), with participation values of 14.53, 14.39, 10.63, 9.43, 7.87, and 7.82%, respectively. However, the sum of the percentages of the photosystem II inhibitor herbicides applied was 46.17%. Franconere (2010) verified that the photosystem II inhibitor herbicide was the most used in Brazil from 2004 to 2009.

An increase in the use of formulated mixtures of herbicides (15%) was observed from 2010 to 2014 (Figure 3). This increase may be due to the advantages of using this type of product. The use of herbicides mixtures increases weed control spectrum, reducing the number of applications required, which may represent a reduction in control costs.

The use of the formulated mixture ALS + photosystem II inhibitor herbicides decreased in 2011 and 2012 when compared to 2010. In 2013 and 2014, its use was not mentioned. The formulated mixture of photosystem II inhibitor herbicides was the most used throughout the evaluated period, but a decrease was observed in 2014 in relation to the previous year (5%). The use of auxin mimic herbicides applied as a mixture increased during the evaluated period, while the use of the other formulated mixtures varied during the period.

Weed species cited by the interviewed producers as target of control with the highest area treated were those of monocotyledonous class (Table 5). This was expected because grasses (Poaceae), an important family within this class, are cited in the literature as the main weeds with widespread occurrence in sugarcane areas (Kuva and Salgado, 2014). In general, the treated area of the three groups of weeds (monocotyledonous, dicotyledonous and cyperaceae) mentioned




*PS II* Photosystem II Inhibitors; *Synt Auxins* Synthetic Auxins; *Carotenoid Bios Inhibitors* Carotenoid Biosynthesis Inhibitors.

***Figure 3 -*** Amount of herbicides (t) as formulated mixture applied in sugarcane cultivation areas of the State of São Paulo, from 2010 to 2014 by mechanism of action. The absence of bars indicates that the mixture was not used in the evaluated year.

***Table 5*** **-** Treated area (1,000 ha) with herbicides to control weeds, grouped by the control target monocotyledonous (except Cyperaceae), dicotyledonous, Cyperaceae, and desiccation in areas cultivated with sugarcane in the São Paulo State

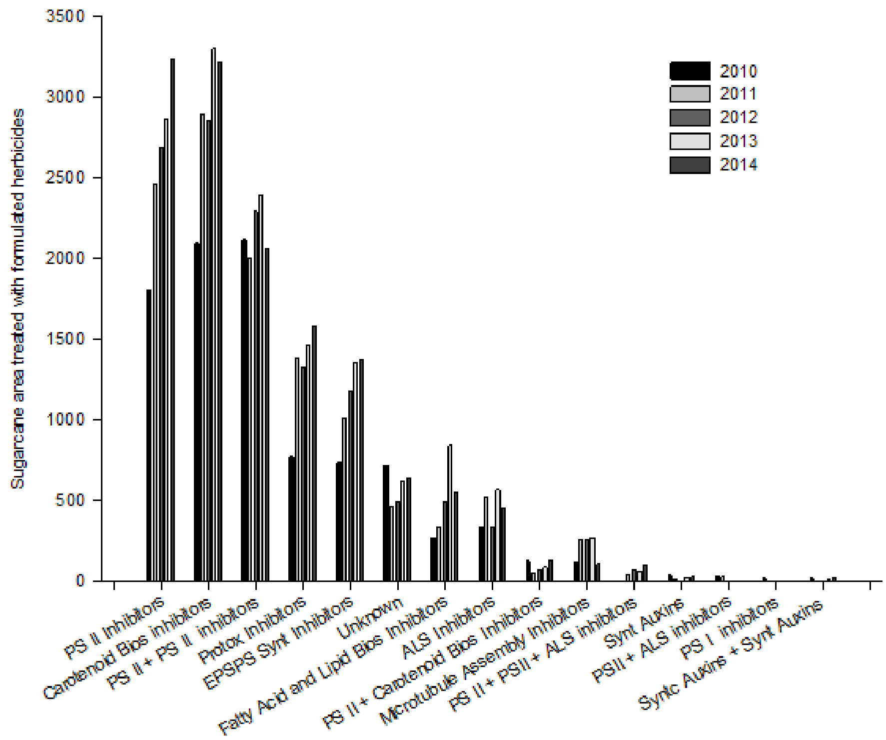
| Target of application | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| Monocotyledonous(1) | 8.614.91 | 10.358.01 | 11.049.88 | 12.859.54 | 12.279.28 |
| Dicotyledonous | 2.489.32 | 2.553.31 | 2.978.53 | 3.347.07 | 3.766.62 |
| Cyperaceae | 631.07 | 1.136.38 | 1.058.31 | 1.077.00 | 1.299.59 |
| Desiccation | – | 55.44 | 83.71 | 38.04 | 7.30 |
| Total | 11.735.3 | 14.103.14 | 15.170.43 | 17.321.65 | 17.352.79 |

(–) Means that in this period the use was not mentioned. (1) Except for Cyperaceae.

has increased during the five years evaluated due to an expansion of the area cultivated by the crop, which also explains the increased use of herbicides in the state.

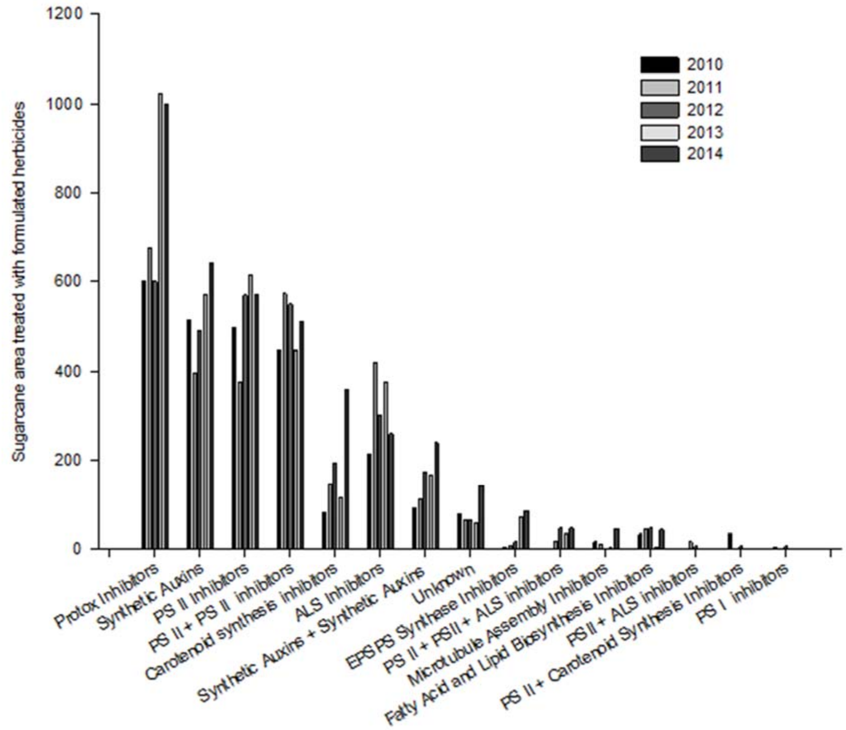
This increase in the area treated with herbicides was 42% for monocotyledonous and 51% for dicotyledonous (Table 4). Sugarcane harvest without previous burning and straw deposition on the soil altered the diversity of weed species in the cultivation area. The germination of some species such as *Richardia brasiliensis*, *Sida obtusifolia*, *Bidens subalternans*, and *Spermacoce latifolia* is not inhibited by the presence of straw (Mata et al., 2016). However, lower germination of small-seed species was observed in the areas, such as *Brachiaria plantaginea* (Silva Junior et al., 2016), which may be related to an increase in the area treated with herbicide aiming at the control of dicotyledonous species.

In order to analyze the area treated with herbicides of different mechanisms of action, according to the weed group, the data for the control of Cyperaceae and other weed species belonging to the monocotyledonous class are shown in Figure 4. In the Figures 4 and 5 it is possible to analyse the difference between the mechanism of action of herbicides used to control each weed group, which was expected since most of them are selective and, in general, control only certain groups of weeds.




*PS II* Photosystem II Inhibitors; *Synt Auxins* Synthetic Auxins; *Carotenoid Bios Inhibitors* Carotenoid Biosynthesis Inhibitors.

***Figure 4*** **-** Treated area (1,000 hectares) with herbicides of different mechanism of action for the control of monocotyledonous species (Poaceae, Cyperaceae, and Commelinaceae) in sugarcane cultivation areas of the São Paulo State.




*PS II* Photosystem II Inhibitors; *Synt Auxins* Synthetic Auxins; *Carotenoid Bios Inhibitors* Carotenoid Biosynthesis Inhibitors.

***Figure 5*** **-** Treated area (1,000 hectares) with herbicides of different mechanism of action for the control of dicotyledonous species in sugarcane cultivation areas of the State of São Paulo.

Carotenoid biosynthesis and photosystem II inhibitor herbicides were those that presented the highest treated area for the control of monocotyledonous species (Figure 4), followed by the formulated mixture of two photosystem II inhibitor herbicides. From 2010 to 2013, carotenoid biosynthesis inhibitor herbicides had a larger treated area, but the area treated with photosystem II inhibitor herbicides increased in relation to the other mechanism of action in 2014, reaching the same percentage of treated area of carotenoid biosynthesis inhibitor herbicides (23%).

For the control of dicotyledonous species, the area treated with PROTOX inhibitor herbicides was the largest throughout all years, followed by the area treated with auxin mimic and photosystem II inhibitor herbicides (Figure 5). Regarding the use of formulated mixtures, the area treated by the combination of two photosystem II inhibitor herbicides was the largest when compared to that of other mixtures. However, the area treated with this mixture has shown a decrease in recent years. In 2011, 20% of the entire treated area corresponded to this mixture, while in 2014 the treated area corresponded to only 12%. This may have occurred due to the availability of new formulated mixture products recommended for the control of species of this class.

In addition to data on the amount of herbicides used in the sugarcane areas, a more in-depth analysis of the herbicide market for sugarcane crop of the State of São Paulo would be required in order to evaluate the amount invested in recent years by farmers and as well as a projection of how much will be invested in the coming years. The joint analysis of these data would assist in the decision-making in relation to future investments in research and development of new molecules and products, marketing actions, and targeting of new product registrations. Although these data were not shown in this study, a clear expansion of the market of herbicides used to control weeds in the sugarcane crop was observed for the São Paulo State. The importance of sugarcane in the state is evidenced by other data, since a decrease was observed for the amount of commercial herbicide used in the same period in Brazil (SINDIVEG, 2017). In addition to the São Paulo State be the largest sugarcane producer, this is also due to the effectiveness of marketing actions and the availability of technologies to control weeds in this crop.

Despite the difficulties that the industry faced during the evaluated period, in this study the data presented indicated an increase in the use of herbicides per hectare, as well as in total amount. In addition, a greater concern of the producers for broadleaf species control was observed. These results will be useful for guiding future studies on weed control and herbicide residues in the soil and water in places close to sugarcane cultivation areas.

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