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Drift from herbicides application on cultivated and native plants: a review[1]

Deriva da aplicação de herbicidas sobre plantas cultivadas e nativas: uma revisão

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Abstract - Although the application of herbicides is essential for weed control and increased productivity of several crops, it is widely known that these products may affect *non-target* organisms. This impact may occur both in parallel to other cultivated crops, and in remaining vegetation next to farmland. Little is known about the effect that herbicides can present in these *non-target* species, and they are of considerable importance both in food production and in the conservation of natural landscapes. This study aims to address the different impacts that herbicides can cause in several cultivated species typically known and in native species that are important in environmental conservation.
Keywords: phytotoxicity; monitoring; conservation; food production

Resumo - Embora a aplicação de herbicidas seja essencial para o controle de plantas daninhas e no aumento da produtividade de diversas culturas, é de conhecimento que esses produtos possam afetar organismos não alvos. Este impacto pode ocorrer tanto em culturas cultivadas paralelas a outras, quanto em vegetações remanescentes próximas às áreas agricultáveis. Pouco se sabe sobre o efeito que os herbicidas podem apresentar nessas espécies não alvos, e os mesmos tem uma importância considerável tanto na produção de alimentos quanto na conservação de paisagens naturais. Este estudo buscou abordar os diferentes impactos que os herbicidas podem ocasionar em várias espécies cultivadas tipicamente conhecidas e em espécies nativas de importância na conservação ambiental.
Palavras-chaves: fitotoxicidade; monitoramento; conservação; produção de alimentos

Introduction

Agrochemicals, especially herbicides, compose an important part in the Brazilian agricultural production system, and they have contributed to increasing productivity of temporary and perennial crops and the quality of the raw material produced, if performed consistently in the context of integrated management weed. Although play a key role in agricultural production, the inappropriate use of chemicals resulting from excessive application or from the drift, has generated increasing concern, both in civil society and in the regulatory agencies as a result of environmental contamination potential (Luchini, 2004; Reichenberger et al., 2007; Fried et al., 2009).

The drift is a major cause of herbicides losses and an important problem of modern agriculture (Cunha, 2008). According to Carlsen

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et al. (2006ab) the drift is characterized when agrochemicals are applied to crops of interest and part of the sprayed syrup move beyond the target area - when unintentionally reaches areas not planned, either as droplets or as vapor. Like drops, the wind is a major weather event that affect the application by acting directly on them changing their displacement toward the target (Christofoletti, 1999). As steam, loss may occur during or after application, being primarily dependent upon the vapor pressure and the product Formulation characteristics (Costa et al., 2007; Carlsen et al., 2006a).

Direct exposure to these compounds represent potential risks on human and animals (wild and domestic) health, on the quality of air and water as well as on sensitive crops (Pimentel, 2005). Certain areas are particularly sensitive to pesticides drift, including areas of organic farming, beekeeping (Hahn, 2010), fruit production (Oliveira Junior et al., 2007), vegetables (Fagliari et al., 2005), areas of preservation with endangered species (Kjaer et al., 2006; Boutin et al., 2014; Egan et al., 2014), adjacent forest fragments to cultivated areas (Snoo and Van der Poll, 1999) and residences nearby the spray sites (Coronado et al., 2011). As an example, the herbicide 2,4-D has caused toxic effects on various kinds of crops nearby the site where it was destined. The use of this herbicide in nearby sensitive crop areas and under unsuitable climatic conditions or unsuitable use technology has resulted in large numbers of damage records; thus, its use has been limited in various municipalities (Fagliari et al., 2004; Antuniassi, 2006).

Many factors affect the drift spraying: weather conditions (wind speed and direction, high temperature, relative humidity and atmospheric stability), application techniques (type of spray, tip type, pressure on the tip, time of application, equipment conduction speed and nozzles spacing) and formulations (adjuvants) (Carlsen et al., 2006a; Hilz and Vermeer, 2013). For Costa et al. (2007) wind speed and direction are weather factors that directly interfere in the syrup deposition. In addition, the high temperature and low relative humidity can contribute to the evaporation of the sprayed droplet, reducing its size and sedimentation rate making them more prone to drifting (Holterman, 2003). According to Nuyttens et al. (2006), the drift can be reduced significantly when the application of agrochemicals is held in low wind speed conditions, with low temperature and turbulence, and high relative humidity.

The risk associated with the drift is also related to the size of the sprayed droplet, with fine droplets remaining longer in suspension, becoming exposed to air currents and consequently to derived losses. Thus, a drift reduction alternative is the proper selection of spray nozzles aiming the formation of coarse droplets (Christofoleti, 1999). Costa et al. (2012) evaluating the effects of tips and spray pressure in glyphosate drift in combination with 2,4-D, noticed smaller syrup deposits for induction spraying tip (AI 11002) over conventional tips. Air induction tips reduce the drift approximately 75% compared to conventional tips for bar sprayers (Miller, 2004).

Also associated with the application technology, air assistance in bar sprayers improves the spray penetration on the plants canopy and reduces drift (Raetano, 2002). Compared to conventional equipment (airless) application with air assistance in the sprayer significantly reduces both the airborne drift and drifting by sedimentation (Bauer and Raetano, 2000).

The formulations may also have significant effect on the application by the exerted influence on the behavior of the sprayed droplet and on its continuance on the action site (Costa, 2006). Adjuvants in agricultural sprays are used for various purposes, including as a drift reducing. Among them, the surfactants that work in contact between the droplets and the foliar surface stand out, increasing absorption, reducing evaporation and increasing the scattering and the retention time of the molecule at the target (Checheto et al., 2013).

Herbicides Drift Impact on Cultivated Crops

Since World War II, the herbicides are chemicals commonly used in weed control and crucial in increasing crop productivity (Boutin, 2013). The intensification of agriculture has enabled an increase in these products use and consequent exposure of plants cultivated in areas parallel to those applications (Ergan et al., 2014). It is known that toxic chemicals, such as herbicides, can arise quickly after treatment (Mitra et al., 2011), while indirect effects on *non-target* plants usually occur after product exposure time (Ergan et al., 2014; Martins et al., 2015).

For regulatory purposes, studies using pots or monoculture isolated growing species are needed to assess the potential side effects of herbicides on *non-target* plants (Boutin et al., 2014). Several authors have demonstrated the damages caused by herbicides drift with subdoses (simulated drift) in cultured species (Tuffi Santos et al., 2006; Yamashita and Guimarães, 2006; Yamashita and Guimarães, 2006; França et al., 2009; Vital, 2015). França et al. (2009) found that glyphosate drift promotes intoxication symptoms in coffee plants (*Coffea arabica*), characterized by leaf blade chlorosis and narrowing. Yellowing symptoms, followed by chlorosis and necrosis, were also observed in cotton plants (*Gossypium hirsutum*) (Yamashita and Guimarães, 2006), wherein the poisoning occurred faster in young plants and at the highest dose of the herbicide, which in some cases resulted in the death of the plant.

Tuffi-Santos et al. (2006) in glyphosate drift simulation test found that the herbicide doses of 172.8 and 345.6 g ha^{-1} on the lower third of eucalyptus (*Eucalyptus* spp.) caused the plants apexes death, especially in species, *E. grandis*, *E. urophylla*, *E. saligna* and *E. pellita* at 15 days after application (DAA). More severe symptoms of intoxication, such as necrosis, leaf wilting, over budding death of apical meristems and plant death, have been reported in other studies with Eucalyptus (Tuffi Santos et al., 2006), peach (Tuffi Santos et al., 2009) and pod (Yamashita et al., 2006) submitted to glyphosate drift.

In addition to the effects of this herbicide on morphological features of plants, other studies report that glyphosate also damages photosystem II (PSII) (Olesen and Adergreen, 2010; Yaniccari et al., 2012; Zhang et al., 2015). Cedergreen et al. (2010), for instance, reported that barley plants (*Hordeum vulgare*) treated with glyphosate, the reduction in stomatal conductance was a result of cessation of CO_2 fixation based on a decrease in the Rubisco regeneration process, rather than a direct effect on the stomatal conductance. This fact was also observed by Vital (2015) in which sunflower plants (*Helianthus annuus*) treated with reduced rates of glyphosate obtained CO_2 accumulation in substomatal camera from one (DAA) of the herbicide, indicating damage to those plants photosynthetic metabolism.

Studies with PSII inhibitors herbicides also show that this class products drift can also cause morphological and physiological changes in *non-target* plants. Galon et al. (2010), for example, observed reduction in the ratio between the internal and external concentration of CO_2 (C_i/C_a) and at the photosynthetic rate in sugarcane (*Saccharum* spp), after exposure to subdoses of ametryne. Studies carried out with vine plants (*Vitis* spp.) submitted to atrazine doses also showed decreased photosynthesis, decreased chlorophyll content *a* and *b* and increased carotenoid content. Additionally, deformations were observed on the leaves, such as the presence of dark chlorosis, followed by necrosis (Tan et al., 2012).

Those studies are in agreement with Mateos-Naranjo et al. (2009) and Dayan and Zaccaro (2012) who concluded that different herbicides classes may cause damage to the inhibitory photosynthesis. Damage caused by herbicides and 2,4-D nicosulfuron have been reported as a problem in many crops such as cotton and tobacco (*Nicotiana tabacum*) (Constantin et al., 2007), tomato (*Solanum* *lycopersicum*) (Fagliari et al., 2004), lettuce (*Lactuca sativa*) and cucumber (*Cucumis sativus*) (Nascimento and Yasmashita, 2008), grapes (Oliveira et al., 2007), eucalyptus (Tiburcio et al., 2010), beet (*Beta vulgaris*) (Eberlein and Guttieri, 1994).

Despite the 2,4-D being frequently used in weed control in applications targeting the coffee culture, Ronchi et al. (2005) demonstrated phytotoxicity symptoms in this species and abortion of young fruits. This effect is more detrimental in young plants and at higher doses of the product. The authors also report that more volatile formulations, even in normal application conditions, induce major symptoms in plants. Moreover, they recommend less volatile herbicide formulations to prevent further damages and potential losses in the final production.

The results confirm that even herbicides in low doses can promote changes in the morphological and physiological characteristics in various plants of agronomic interest. Assuming that under natural conditions damages might happen to cultivated species, limiting plant productivity. In this scenario, these studies are of particular importance in order to obtain information about the extent and the risks of crops being exposed to herbicides drifting. According to MAPA (Ministry of Agriculture, Livestock and Food Supply), herbicides drift on other species is caused mainly by the applicator lack of preparation and usage at inappropriate times, requiring monitoring in the application areas (ANVISA, 2008). Studies that are covering effects of other pesticides and particularly field studies are still incipient, thus increasing the importance of more results that encompass losses in the final productivity, for the guidance of farmers, improving sustainable use of chemicals.

Herbicides Drift Impacts on Native Plants

One of the main causes of biodiversity loss in terrestrial ecosystems is occasioned by the expansion of land use for human interests (Giam et al., 2010; Domingos et al., 2015). Although this biodiversity loss occurs due to human interference, appropriate methodological protocols are important in order to assess the potential effects of xenobiotics on the remnants native vegetation (Domingos et al., 2015). These protocols are determined by biomonitoring methods, which are based on measurement of selected responses (biomarkers) in bioindicators (Fräinzle, 2003; Domingos et al., 2015), which allows a better interpretation of the ecological relationships involved. Therefore, species of wide regional distribution and differential sensitivity to the pollutant employed are essential both for active and passive biomonitoring (Oliva and Figueiredo, 2005). The responses to disturbances resulting from the use of pollutants are characterized by biomarker, offering comprehensive and biologically relevant information on the impact of toxic contaminants on organisms (Pernía et al., 2008).

Among the native vegetation that most suffer biodiversity losses is the Brazilian Cerrado. This region is one of the world richest in terms of biodiversity and is considered one of the most important centers of biodiversity on the planet (Meyrs et al., 2000). The increased use of pesticides and fertilizers, particularly in soybean crops (*Glycine max*) and cotton, has occurred due to the growing expansion of the agricultural area in the Cerrado (Spadotto, 2002; Soares and Porto, 2007), causing damage to *non-target* organisms through the drifting process (Power et al., 2013; Boutin et al., 2014). The herbicides act by inhibiting enzymatic systems or specific plant proteins (Cole et al., 2000) and its deleterious effects are generally preceded by metabolic changes.

Biomarkers protocols with Cerrado species in the face of herbicide action are already being effected. In studies conducted by Silva (2015) it was evidenced that the 2,4-D and nicosulfuron herbicides promoted effects on plant of *Dipteryx alata*, popularly known as baru, such as changes in plant physiology, as well as increased activity of the antioxidant defense system enzymes, hydrogen peroxide and malondialdehyde concentration increase. Some nicosulfuron action biomarkers have been set for this species as visual symptoms, reduction in the acetolactate synthase enzyme activity (Silva, 2015).

For glyphosate, the main herbicide used in agriculture, it was demonstrated that for the species *Pouteria torta* (guapeva), the shikimic acid with stomatal conductance are good glyphosate action biomarkers (Batista, 2014). In plants of *Alibertia edulis* (quince) the accumulation of shikimic acid, was also a good biomarker of plants exposed to glyphosate (Crispim-Filho et al., 2015). It is known that the chlorophyll a fluorescence is a good biomarker in identifying certain herbicidal modes of action (Dayan e Zaccaro, 2012). In recent studies on the species *Bauhinia forficata*, native from the Cerrado, diuron caused major changes in the photosynthetic efficiency of plants, evidenced by chlorophyll a fluorescence, making a robust biomarker for the action of this herbicide in those plants (Lima et al., 2015).

The pequi tree (*Caryocar brasiliense*), native from Brazil and considered Cerrado symbol, presented simulated sensitivity to glyphosate herbicides on drift studies (Silva, 2014). Visual and anatomic changes of the leaves characterized by withered, misshapen summits, developed necrosis on leaf edges and sharp leaf senescence from 14 (DAA) were observed. Anatomical assessments of plant leaves evidenced, from the dose of 50g e.a. ha^{-1} of glyphosate, increase in the thickness of the spongy parenchyma, featuring a hormetic effect. Changes in gas exchange, chlorophyll a fluorescence and the levels of chlorophyll a, b and carotenoids were also noticed in pequi plants treated with glyphosate (Silva, 2014).

The decline of the diversity and abundance of plants has been widely reported in agro-ecosystems of North America and Europe (Boutin et al., 2014). It is known that the plantations margins are often the only remaining habitat for species of native plants, and due to the proximity of these areas to agricultural plantations, vegetation margins can be affected by herbicides applied to the crop. Between 5% and 25% of the herbicides dose applied should reach the vegetation in plantations margins (Weisser et al., 2002).

Field study conducted in Germany in the years 2010-2012, showed changes in the composition of plant communities, by applying the herbicide metsulfuron (ALS inhibitor). The application of this product occurred once a year (in April 2010, 2011 and 2012) and the authors noted lower biodiversity of species than in the control plots (Schmitz et al., 2014). In Australia, alarming effects on the use of herbicide fluazifop (ACCase inhibitor) applied at post-emergence were observed in the composition of native species. These changes may be evidence from residual effects, such as changes in soil seed bank, even plants growth in natural ecosystems (Rokich et al., 2009).

In Canada and Denmark, studies in woods adjacent to arable fields showed effects of herbicide spraying at different phenological stages of native plants. Delays in flowering and seed production reductions were noticed in a large number of *non-target* plants, particularly in reproductive stages (Boutin et al., 2014). Gove et al. (2007), in studies conducted in the United Kingdom, found that many forest species were affected by the glyphosate drift and showed differential sensitivity. The abundance of susceptible species was higher on the forest banks adjacent to fields with low exposure to the herbicide and lower alongside areas with high product spraying input. Such differences were observed at least 4 cm from the forest edge (Gove et al., 2007).

Studies conducted in those researches were able to demonstrate that negative impacts of herbicide drift can affect a variety of *non-target* plants in the vegetation margins bordering agricultural areas. The inability to evaluate properly and regularly the effects of the herbicides may have important ecological considerations to the plant survival (Gove et al., 2007). Thus, in order to preserve biodiversity near those agricultural areas, it is recommended to protect the margins vegetation from agrochemicals, being verified through biomonitoring action of these herbicides (Boutin et al., 2014; Schmitz et al., 2014).

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