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Opinion

Chemical Weed Control and Crop Injuries Due to Spray Drift: The Case of Dicamba

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Abstract: Herbicide volatility and drift are serious problems for chemical weed control. The extended use of dicamba, especially due to the commercial release of dicamba-resistant crops, revealed many off-target dicamba injury issues for sensitive crops. The objective of the present study is to give information on the chemical properties and volatility of dicamba and highlight some key issues, while a systematic review of the recently reported cases is attempted. Unfortunately, the problem is increasing, with a huge majority of the injuries reported in the USA, but it is also present in many other countries. Several arable, horticultural, and perennial crops suffer from such damage. Specific measures and approaches are suggested in order to quantify, reduce, and prevent such problems, while the training of farmers and stakeholders and further research are certainly required for the optimization of the several alternative options.

Keywords: dicamba; volatility; crop injury; drift; soybean

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1. Introduction

Dicamba (3,6-dichloro-2-methoxy benzoic acid) [1] is a systemic herbicide that belongs to the group of synthetic auxins [2]. Dicamba is a selective herbicide that is mainly efficient against woody plants and a wide range of annual and perennial broadleaf weeds [3]. It acts by increasing the plant growth rate; it is relatively low-cost and has a relatively good environmental profile. In the USA, it was used in 1967 for the first time [1], but its moderate volatility has caused huge issues [3]. Indeed, dicamba can harm neighboring plants that are exposed to the herbicide because of the vapor drift [3].

For many years, glyphosate-based herbicides were used, without any serious threat to the crops [4]. However, the overuse, misuse, and excessive reliance on glyphosate has led to the emergence of glyphosate-resistant weeds and rendered the use of herbicides, like dicamba, necessary [5,6]. In addition, dicamba-resistant crops, such as soybean and cotton [5,7,8], were introduced; ergo, the use of dicamba became wide again, and the herbicide is now one of the most widely used ones, and the interest in using and evaluating auxin herbicides is significantly increasing [7,9]. Dicamba applied alone or in mixtures can effectively control several weed species, including several glyphosate-resistant weeds like *Amaranthus palmeri*, *Conyza canadensis*, and *Ambrosia artemisifolia* [3,5]. Unfortunately, there is a plethora of cases where dicamba has injured very sensitive non-target plants [5], causing off-target problems in millions of hectares [7] due to particles and droplets or due to vapor drift from volatilization [2]. Indeed, the European Food Safety Authority (EFSA) raised a serious concern about the long-range transport of dicamba through the atmosphere. The outcome of off-targeted injured vegetation is cupping deformation, leaf epinasty, and chlorosis [2,7,10,11].

This opinion paper aims to present basic info on the herbicide dicamba with a special focus on its volatility and the drift injuries to several crops, highlight the increasing interest in such issues and presenting some of the spray drift prevention and reduction tools and practices.

2. Chemical Properties, Structure, and Volatility

2.1. Chemical Properties and Structure

Dicamba is a white crystalline solid and a strong acid with pKa = 1.87 [2,12]. As a herbicide, it is used in salts, and its structure is shown in Figure 1. Its most common salts are dimethylamine salt (DMA), sodium salt, diglycoamine salt (DGA), and isopropylamine salts (IPAs) [1,2]. Salts have different forms and solubility in water [1] than pure dicamba. Some of the chemical properties of dicamba are presented in Table 1.

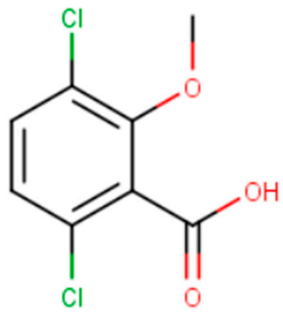

Figure 1. Structure of dicamba.

Table 1. Main chemical properties of dicamba [12].

Chemical Formula	$C_8H_8Cl_2O_3$
Molecular weight	221.03 g/mol
Melting point	200 °C
Boiling point	114–116 °C
Solubility in water (25 °C)	4500 mg/L

2.2. Volatility and Spray Drift

Dicamba is considered to have moderate volatility, which is dependent on a plethora of factors. The two ways that dicamba can harm non-target plants are by physical drift and vapor drift [2,3,13,14]. Physical drift consists of the droplets and particles of dicamba. During the time of the application of the herbicide, they transfer through the air to neighboring plants [2,7]. The application technique, the spraying equipment, and the climatic conditions are factors that affect the physical drift [2]. On the other hand, vapor drift is a result of the herbicide's volatility, and it takes place after dicamba application. Volatility generally describes how easily a substance becomes a gas from a liquid state. Dicamba volatility is most significantly influenced by temperature [2,5]. Egan et al. [3] have meticulously studied the amount of vapor drift in relation to temperature in greenhouse-grown soybeans. They found that the higher the air temperature, the greater the vapor drift, and this can harm plants even from a larger distance. Another interesting finding of this research is the fact that the humidity of the air contributes to an increase in volatility. The acidic nature of dicamba, and the fact that it forms numerous salts, makes its volatility susceptible to pH changes. The pH value determines the amount of protonated and deprotonated molecules [5]. Thus, when the pH is increased, the volatility drops [2,5,13]. Mueller et al. [5] experimented with pH in plants in humidomes. By adding glyphosate to the solution, they lowered the pH. They found that the volatility, and thus the injury in neighboring plants, increased. Furthermore, the presence of dicamba in the air was increased up to nine times after the addition of glyphosate and at temperatures lower than 15 °C [5]. As mentioned before, dicamba is also available in the form of salts, such as dimethylamine salt (DMA) and diglycoamine salt (DGA). It is proven that every salt has different volatility.

DGA is less volatile than DMA [2,5] and generally, the acidic form is more volatile than salts [14]. In other words, there has been much progress on new formulations (like DGA salt and BAPMA) with reduced volatility than older ones. Consequently, it could be said that except for meteorological conditions, the commercial formulation and several application parameters, like nozzle type, adjuvants, and spray volume, also affect the volatility of dicamba [15,16]. Indeed, drift reduction adjuvants may decrease dicamba volatility and drift but in parallel, an evaluation of the overall efficacy against the weeds is also necessary [5].

3. Crop Damage Due to Dicamba Drift

Our systematic literature review in the Scopus database revealed some very interesting findings. The following search was considered for a time range of 10 years (from 2014): (TITLE-ABS-KEY ("dicamba") AND TITLE-ABS-KEY ("drift"). As a result, 139 articles were discovered with increasing frequency. Table 2 shows the main crops in which injury due to dicamba drift was found published during the last two years (2022 and 2023).

Table 2. Crops damaged by dicamba spray drift published in 2022 and 2023 (indexed in Scopus database).

Crop	Reference
Soybean (*Glycine max* (L.) Merr.)	[7,17,18]
Rice (*Oryza sativa* L.)	[19]
Cotton (*Gossypium hirsutum* L.)	[20]
Peanut (*Arachis hypogaea* L.)	[21]
Tomato (*Solanum lycopersicum* L.)	[18,22,23]
Lettuce (*Lactuca sativa* L.)	[18]
Pumpkin (*Cucurbita maxima* Duch)	[18]
Oilseed rape (*Brassica napus* L.)	[18]
Pepper (*Capsicum annuum* L.)	[18]
Sunflower (*Helianthus annuus* L.)	[18]
Cucumber (*Cucumis sativus* L.)	[7]
Eggplant (*Solanum melongena* L.)	[7]
Snap bean (*Phaseolus vulgaris* L.)	[7]
Potato (*Solanum tuberosum* L.)	[24]
Sweetpotato (*Ipomoea batatas* (L.) Lam.)	[25]
Mandarin (*Citrus reticulata*)	[26]
Grapevine (*Vitis vinifera* L.)	[27]
Brazilian peppertree (*Schimus terebinthifolius* Raddi.)	[28]

Consequently, it is noted that the problem is obvious and ongoing not only in arable but also in horticultural and perennial crops. In addition, it has to be taken into account that despite the fact that the vast majority of the reported cases are in the USA, crop damage has been reported in a wide range of continents and countries (Figure 2).

Furthermore, an increasing concern about off-target injuries is obvious. The case of soybeans is indicative. From 2004 to 2013, only 11 papers indexed in Scopus were published on that topic, while from 2014 to 2023, the corresponding number is 67 (more than six times higher).

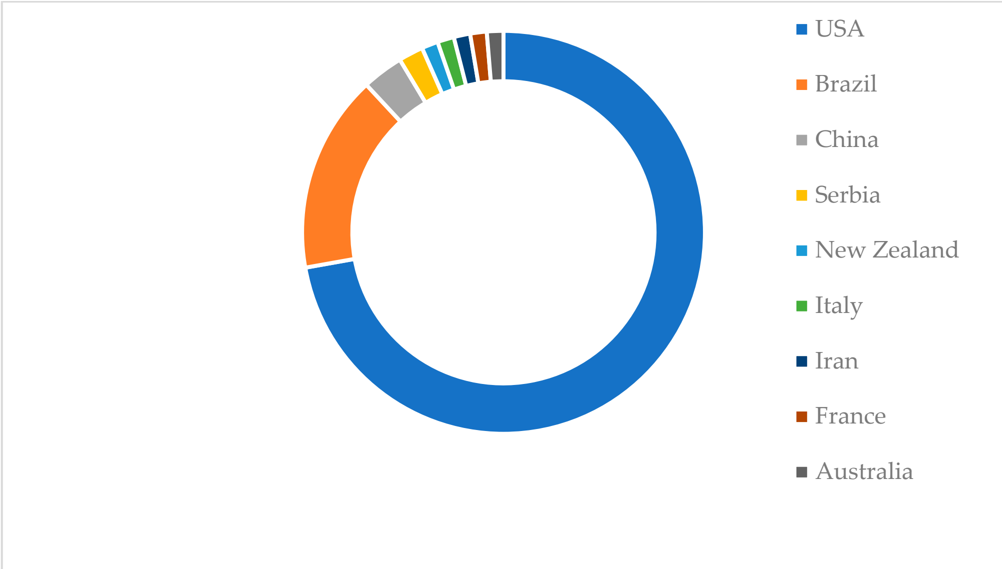

Figure 2. Cases of crop injury due to the spray drift of dicamba per country based on a literature review in Scopus database from 2014 to 2023.

So, is there hope? The answer is clearly positive but has some requirements. First of all, a quantification of the damage is necessary. Ferreira et al. [29] proposed a new methodology for the evaluation of the volatilization of dicamba and dicamba tank mixtures. Several researchers have quantified such damages, including parameters like distance from the treated field and application rate, and suggested practices to minimize drift [14,29–32]. It is noteworthy that Jones et al. (2019) proved that dicamba can move up to 152 m from the application area, and this is something to seriously consider [31]. Tian et al. (2023) proved that unmanned aerial vehicle (UAV) imagery and deep learning have great potential to accurately quantify soybean damage due to off-target dicamba and thus give the tools for a wide screening and selection of many soybean biotypes [33]. Marques et al. [34] quantified dicamba injury on soybeans by means of a spectral vegetation index, the Triangular Greenness Index (TGI). The evaluation of drift-related injuries is not very easy, especially in stressed crops caused by biotic or abiotic factors, and thus farmers should regularly monitor their crops and keep an eye on the neighboring fields. So, after quantifying and accurately evaluating the injuries, prevention measures should follow. Indeed, several precautions should be taken into account in order to limit or even minimize spraying drift and off-target damage. Products should be always used in full accordance with their label (registration). For instance, the Environmental Protection Agency (EPA) in the USA requires that an approved pH buffering agent (also called a volatility reduction agent) should be tank-mixed with over-the-top dicamba products prior to all applications. The fact that it is obligatory for applicators to document that they have purchased and used a sufficient quantity of the pH buffering agent proves raised awareness of the serious spraying drift issue.

Furthermore, the use of labeled nozzles (and not nozzles that produce very small droplets) and the maintenance of the spray boom low during the application could significantly reduce the drift. Low-drift nozzle selection is very important in order to minimize spraying drift. Lately, several compact anti-drift air-induction nozzles have been studied and used since they can result in significant spray drift reduction while keeping high efficacy against weeds [35–37]. Ferreira et al. [29] proved that the MUG11003 nozzle produced fewer driftable droplets and greater droplet size compared to other air induction nozzles. Grella et al. [38] revealed that using air induction nozzles, semi-shielded boom, and other spray drift reduction techniques significantly reduced spray drift up to 78%, while the maintenance of cropped buffer zones resulted in a reduction in the total spray drift up to 97%. The proximity with sensitive crops should be also taken into consideration, while a buffer zone in the field edges is also required. In particular, a downwind buffer is required in areas with endangered species concerns, and such distances are increasing in the new labels in order to minimize drift, reduce pesticide exposure, and avoid damaging neighboring crops and non-crop vegetation. Air temperature fluctuations and inversions promote drifting and, therefore, farmers and applicators should avoid sowing their crops in the low parts of their fields and stop spraying early in the morning [8,17]. As Soltani et al. [8] suggested, further research is necessary in order to determine the secondary movement of dicamba under various environmental conditions. The avoidance of spraying on days and places with strong winds and high temperatures is also crucial, as well as the application of low-volatile dicamba formulations and other herbicides or non-chemical alternatives [13,39]. However, using other herbicides is not always easy, especially in cases of weed biotypes resistant to glyphosate, ALS inhibitors, and PPO inhibitors. In all cases, it has to be noted that dicamba tank mixtures with substances, like lecithin + methyl soybean ester + ethoxylated alcohol and potassium glyphosate + saflufenacil, could substantially reduce injuries to sensitive crops [29]. Positive results are also valid for the combination of dicamba with several adjuvants due to the reduced pH values and the increased droplet size and uniformity they obtain [5]. Therefore, it is an important decision to be taken since the addition of the proper adjuvant is crucial not only for the minimization of spray drift damages but also for the higher efficacy of herbicides they achieve [40].

4. Conclusions

In conclusion, the present opinion paper presents the case of dicamba and its high volatility. Moreover, it highlights the serious and costly issue of crop damage caused by specific herbicides. Unfortunately, the problem is increasing; the majority of the cases are in the USA regarding soybeans; however, cases are also present in other continents and crops. Several measures are suggested in order to quantify, reduce, and avoid such damages, while there is an indisputable need to provide adequate training to the farmers to correctly apply this herbicide and consequently minimize its potential negative effects on the environment and crops adjacent to the treated fields. Further research is certainly required for the optimization of the several alternatives and the development of some new and innovative ones.

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