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Critical analysis of the extensive aerial application of pesticides and its implications for human health

Monica Lopes-Ferreira[1], Geonildo Rodrigo Disner[1], Sonia Corina Hess[2], Rubens Onofre Nodari[3], and Carla Lima[1]

Abstract

Agriculture is one of the most important commercial activities worldwide since it contributes to a great amount of the nation's gross domestic product, labor opportunities, and food production. However, on the other hand, current industrial agriculture is extremely dependent on chemicals, both pesticides and fertilizers that are a serious threat to the health of people and the environment. Despite the advent of new technologies like unmanned aerial spraying systems (UASS), regulations surrounding the aerial spraying of pesticides to accommodate the benefits and limitations necessary to ensure the protection of humans and ecosystems are still scarce. High concentrations of chemical substances released by drones in a spray solution at improper altitudes, inappropriate ambient temperatures, or with incorrect droplet sizes increase the risk of phytotoxicity effects and spreading to non-target areas, potentially contaminating non-resistant neighboring crops, agricultural workers, and surrounding communities. Following the increase in the number of aircraft, the contamination events due to the drift events of pesticides increased parallelly. Research points out that "technical drift" may reach up to 19% of the sprayed volume, which does not reach the target, but goes to the soil, water, air, nearby plantations, and communities. Exposure to pesticides in smaller and regular doses can lead to chronic health conditions, which is much more difficult to study and prove. In some cases, illnesses develop years or decades after exposure but still are of great concern since the use of pesticides, notably in highly agricultural countries, has increased greatly to reach food and commodities demand.

Keywords: Pesticides spraying; drift; agricultural aviation; pulverization; human and environmental health.

Introduction

Agricultural pesticides comprise different groups of manufactured chemicals synthesized to control insects, illnesses, weeds, and other pests. Besides, they are supposed to help increase productivity and crop yields and may expand the number of times per year a crop can be grown on the same land, which is particularly important in countries that face food shortages contributing to global food security. On the other hand, the presence of pesticide residues in the ecosystems is of great concern once they can pose serious risks to human and environmental health.

Potentially toxic pesticides to humans can have both acute and chronic health effects, depending on the quantity and ways in which one is exposed. People who face the greatest risks are those who are directly exposed, which includes agricultural workers who apply pesticides and anyone else

Affiliation:

[1]Immunoregulation Unit of the Laboratory of Applied Toxinology (CeTICs/FAPESP), Butantan Institute, Brazil

[2]Universidade Federal de Santa Catarina (UFSC) – Campus Curitibanos, Curitibanos, SC, Brasil.

[3]Department of Plant Science and Pos-Graduate Program in Plant Genetic Resources, Universidade Federal de Santa Catarina (UFSC), Florianópolis, SC, Brasil.

Corresponding author:
Dr Monica Lopes-Ferreira. Immunoregulation Unit of the Laboratory of Applied Toxinology (CeTICs/FAPESP), Butantan Institute, Brazil.

E-mail: monica.lopesferreira@butantan.gov.br.

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in the immediate area during, and shortly after, pesticides are spread. Still, the general population is vulnerable to significantly lower levels of pesticide residues through food and water (WHO, 2022).

From 2000 to 2013, the international trade of pesticides increased by around 220%, when China became the world's largest exporter. Meanwhile, Brazil had the highest growth rate of pesticide imports, becoming, since 2012, the world's largest importer and the second largest consumer market [22]. In 2021, 719,507.4 tons of active ingredients of pesticides were sold in Brazil, an amount 50.6% higher than in 2012 (IBAMA, 2022). Among the active ingredients sold in Brazil in 2021 (quantities >3,500 tons), there were 15 substances unauthorized in the European Union (EU): chlorothalonil, atrazine, acephate, chlorpyrifos, imidacloprid, carbendazim, diquat dibromide, methomyl, diuron, glufosinate - ammonium salt, tebuthiuron, bifenthrin, carbosulfan, thiamethoxam, and ametryn (IBAMA, 2022).

According to Bombardi (2017), 79% of the pesticides used in Brazil are applied to four crops intended for the production of agricultural commodities: 52% in soybean, 10% in corn, 10% in sugarcane, and 7% in cotton plantations. The area cultivated with soybean in Brazil increased from 25,090,559 hectares in 2012 to 39,185,745 hectares in 2021, an area 56.2% larger;

The advancement of areas occupied by crops demanded the implementation of new technologies, thus favoring the establishment of aerial spraying of pesticides, including fixed-wing aircraft, helicopters, airblast, boom and knapsack sprayers, and Unmanned Aerial Spraying Systems (UASS).

The Brazilian Federal legislation regulating pesticides does not prohibit such activity. An ordinance of the Brazilian Ministry of Agriculture prohibits the aerial spraying of pesticides near villages, cities, towns, neighborhoods, isolated dwellings, groups of animals and springs that collect water to supply the population. In contrast, in many countries, the ban on aerial spraying is already a reality, such as Slovenia (Pesticide Action Network, 2023).

China is a symbolic case to illustrate the rise in unmanned aerial devices. In 2014, China owned less than 1,000 plant protection drones, with an annual operating area of less than 0.28 million ha. By the end of 2020, the number reached 106,000, with a total yearly working area of 64 million ha [31]. In Europe, due to restrictions on the application of plant protection products with aerial technology - UASS (128/CE/2009) it has not been used at a large scale yet [25]. In comparison, Brazil has the second largest fleet of agricultural aircraft, second only to the USA. In Brazil, the United States, and Canada, more and more experimental research on UASS has been carried out, although agricultural aviation is widely used mainly with manned fixed-wing aircraft.

The beginning of Agricultural Aviation in Brazil is attributed by the National Union of Agricultural Aviation Companies - SINDAG to the year 1947 when the first agricultural flight was carried out in the country, to spray the BHC insecticide, based on hexachlorobenzene, aiming to control the attack of locusts in the region of Pelotas, Rio Grande do Sul (SINDAG; https://sindag.org.br/historia/). Still, according to this same source, aerial spraying was also carried out in an attempt to control diseases and pests in different states, with the creation of agricultural aviation companies. However, due to the lack of adequate technologies for the application of pesticides, agricultural aviation evolved little in Brazil until the end of the 20th century.

In Brazil, agricultural aviation is mainly used for the application of pesticides, but also fertilizers, seeds, populating lakes and rivers with fish, reforestation, and fighting fires in fields and forests. The National Civil Aviation Agency – ANAC is in charge of registering agricultural aircraft. The Instituto Brasileiro da Aviação Agrícola – IBRAVAG was created in 2018, to work among different sectors; one of its activities is the compilation of data on aircraft registered for agricultural aviation in the country. Table 1, based on data from the National Civil Aviation Agency – ANAC, shows the number of aircraft used in agriculture. It demonstrates the large increase in the number of aircraft in the country, as it jumped from 724 in 2000 to 2,342 in 2021 (Araújo, 2022), a growth of 223%. Naturally, during the same period, contamination events increased due to the drift of pesticides applied via aerial spraying.

Compared to a traditional fixed-wing aircraft, an UASS can fly lower, is significantly smaller and can hover above tall crops, and operate in complex terrain for extended periods. It is worth mentioning that the increase in precision and speed of higher concentrations of pesticide application with the use of UASS does not diminish the concern about safety for human and environmental health [13].

Pesticide aerial application is the most frequent source of drift events, causing exposure of workers involved in the practices and those inhabitants living in neighboring communities to pesticide-sprayed fields, water sources, animals, and non-target plantations [18]. Studies have shown that "technical drift", that is, the one occurring despite calibration and adequate environmental conditions, may reach 19% of the sprayed volume (Chaim, 2004). Still, research from the 1990s points out contamination resulting from the drift of aerial spraying up to 32 km from the target area.

According to Chaim (2004) the spraying equipment of the time, even calibrated, under ideal temperatures and wind, ensured that only about 32% of the sprayed pesticides were retained on the target plants and 49% goes to the soil and, after some time, part evaporates, part is leached into the water

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Table 1: Number of aircraft used in agriculture aviation per Brazilian state Source: Araújo (2022) based on data from the National Civil Aviation Agency

State	Aircraft number	Percentage
Mato Grosso	600	24.67
Rio Grande do Sul	419	17.23
São Paulo	322	13.24
Goiás	295	12.13
Paraná	143	5.88
Mato Grosso do Sul	134	5.51
Bahia	117	4.81
Minas Gerais	100	4.11
Pará	60	2.47
Tocantins	57	2.34
Maranhão	42	1.73
Rondonia	27	1.11
Piauí	23	0.95
Alagoas	18	0.74
Distrito Federal	17	0.7
Rio de Janeiro	14	0.58
Santa Catarina	14	0.58
Roraima	10	0.41
Pernambuco	9	0.37
Amazonas	5	0.21
Acre	3	0.12
Amapá	1	0.04
Espírito Santo	1	0.04
Sergipe	1	0.04
Total	**2,432**	**100**

table and another part degrades. That is to say, there is no use of pesticides without contaminating the environment surrounding the "treated" area, and consequently, without affecting the people who work or live nearby.

In the literature dedicated to the hazardous effects of pesticides, this topic has already been addressed since the end of the last century. Some noteworthy episodes provided the opportunity to evaluate the putative damages of the aerial spraying of pesticides on a large scale. For example, the endeavor to eradicate the Mediterranean fruit fly in southern California between August 1989 and July 1990, which included repeated aerial applications of malathion bait to urban areas where approximately 1.6 million people resided. Regarding that, Grether et al. (1987) published research describing the occurrence of congenital anomalies associated with exposure to low-dose malathion, after its aerial application. However, at the time no biologically plausible pattern of association was found. Similarly, Thomas et al. (1992) investigated the reproductive outcomes in relation to malathion spraying in the same location. Similarly, no important association was found between malathion exposure and spontaneous abortion, intrauterine growth retardation, stillbirth, or most categories of congenital anomalies.

Moreover, Guerrant et al. (1970) measured the amount of malathion deposited after the application of ultra-low-volume spray from aircraft against *Culex tarsalis* in Texas back in 1967 to reduce arbovirus transmission by mosquitoes. The contamination was determined by measuring the amount found on exposed filter papers. The average concentration was 65% of the dosage applied, and the remainder was presumed to have disappeared as a non-condensing vapor. Woods et al. (2001) presented results from field studies carried out during 1993-1998 to monitor off-target droplet movement of endosulfan insecticide applied to a commercial cotton crop, highlighting off-target deposition downwind of the field boundary.

Also, in the early 2000s, Rice et al. (2005) reported the association of unplanned releases and injuries associated with the aerial application of chemicals between the years 1995 to 2002. Out of the total events in the Hazardous Substances Emergency Events Surveillance (HSEES) system for the period, 0.17% were identified as aerial-application events at the time. The most commonly released substance was malathion. According to the records, there were 56 victims. A higher percentage of HSEES aerial-applicator events involved injury and death than did other HSEES transportation events.

Why does it continue to be such an emerging topic for risk assessors and toxicologists? Mainly because of the increase in the use of pesticides in large-scale applications, the raise in the cultivated areas and production demand (food/commodities) aligned to the expansion in the use of novel technology that facilitates the spraying of pesticides in crops, such as UASS or simply Unmanned Aerial Vehicles (UAVs). UASS consists of drones operated by a control system carrying a spraying device that is widely used to improve the efficiency of pesticide applications, to reduce human health risks by providing safer application rates of pesticides in crop fields, and to comply with regulatory standards [8].

Nevertheless, when comparing manned and unmanned systems, the drift rate (as normalized by the application volume) is therefore not significantly reduced. Current UASS drift research focuses on sediment and airborne drift, while the impact on non-target organisms is still limited. In-depth studies of UAV flight control technology for plant protection and pesticide drift control will become necessary to evaluate the environmental risks and potential to unequivocally affect human populations.

Concerning the risk of pesticides to humans, current research points out that acute intoxication, despite being the most easily identifiable part of the problem, is not the main effect caused by direct and constant contact with pesticides.

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Exposure to pesticides in smaller and regular doses can lead to chronic health conditions, which is much more difficult to study and prove. In some cases, illnesses develop years or decades after exposure [10] [19]. The issue gains new proportions as the use of these substances increases continuously and rural workers and other groups are exposed to multiple pesticides – and not just one active ingredient, as shown in the tests.

Brazilian data show that the number of poisoning cases by pesticides applied by air has been increasing [24]. Permanent Campaign against Pesticides and for Life, 2022). According to data collected by Agência Pública and Repórter Brasil, with data from 2019 to March 2022 from the Ministry of Health's DataSUS notification system, there were more than 14,000 cases of intoxication due to agricultural pesticides, resulting in 439 deaths. That means on average one person dies due to pesticides every three days even considering that the intoxication records are undernotified, so it is estimated that for each reported case 50 more occur. Nine of the 10 cities with the most cases of poisoning (to the total population) are in the Southern region of Brazil.

In the cases of occupational intoxication, there are more records related to soybean, tobacco, and corn crops, which might be due to the size of the plantations, where pesticides are sprayed on a large scale. In the State of São Paulo, Southeast Brazil, an unprecedented study reveals that 30% of pesticides applied by plane on sugarcane plantations are associated with the development of cancer. The planted area with sugarcane supplies the national and international sugar and ethanol markets. Seven potentially carcinogenic substances were found in 12 products sprayed in sugarcane fields. In most cases, cancer only appears after years of exposure to poisons, making it difficult to make a direct correlation between application and intoxication. However, in the city of Barretos, cancer increased by 63% in men and 28% in women. Furthermore, while 120 men per 100,000 inhabitants died from cancer in Brazil in 2019, the number of deaths jumped to 214 in this micro-region.

The risks arising from pesticides are even threatening the lives of those who are more vulnerable. In Brazil, there are records of contamination of breast milk by pesticides. In this sense, a survey was carried out with 62 nursing mothers from the city of Lucas do Rio Verde, in Mato Grosso, and it was found that in all samples there was at least one type of pesticide (Palma, 2011). Worldwide, studies aim to assess the pesticides' negative effects; for example, through the micronucleus assay in oral mucosa epithelial cells of workers occupationally exposed to chemicals during their aerial application to agricultural fields of Mexico. Martínez-Valenzuela et al. (2017) found significant differences in the micronucleus and nuclear abnormalities frequency suggestive of genotoxic damage even in younger pilots with two years of short working period. DNA damage induced by pesticides has been pointed out as a possible mechanism of toxicity and carcinogenesis.

In another example, Mancozeb and its main metabolite ethylene thiourea (ETU) may alter thyroid function in humans, which is essential for fetal brain development. In Costa Rica, mancozeb is aerially sprayed at large-scale banana plantations on a weekly basis. Joode et al. (2014) evaluated urinary ETU concentrations in pregnant women living near large-scale banana plantations and compared their estimated daily intake (EDI) with established reference doses (RfDs). Pregnant women's median urinary ETU concentrations were more than five times higher than those reported for other general populations. Seventy-two percent of the women had EDIs above the RfD. Women who lived closest to banana plantations on average had a 45% higher urinary ETU compared with women who lived farthest away.

Hicks et al. (2017) examined autism spectrum disorder (ASD) and developmental delay (DD) diagnosis rates in an area that employs yearly aerial pyrethroid pesticide applications to combat mosquito-borne encephalitis. The study identified higher rates of ASD/DD diagnoses in the area concluding that zip codes with aerial pyrethroid exposure were 37% more likely to have higher rates of ASD/DD. Moreover, other studies evidenced cell damage and cell death [27], poorer sperm morphology and lower luteinizing hormone levels [9], mucosal irritation, tachycardia, depressive signs, and cholinesterase changes [4], spirometry impairments [5] due to pesticide aerial exposure.

Despite the various scientific studies related to adverse effects on human health, companies producing agrochemicals tend to refute criticism of the harmful effects of their inputs, seeking to show that environmental problems and human contamination are "resulting from inappropriate use or non-compliance with of the technical norms for the application of pesticides", and not resulting from the chemical composition of the products itself. The problem involving aerial spraying is the reason not only for judicial conflicts and discussions about the need for changes in Brazilian legislation but also for conflicts between different countries, once the ecosystems do not respect geopolitical frontiers.

We have seen, especially in the last decade, a high number of cases of intoxication, including children, due to the spraying of pesticides by agricultural aviation. While other countries are advancing in more restrictive measures, in Brazil which holds the second largest number of airplanes to be used in agriculture, the rules are being relaxed to allow the use of more and more agrochemicals. There are not enough studies on the impact of this new method of spraying on the potentiation of the toxic effects of pesticides on the human population and the environment. Furthermore, the legislation is inadequate for human and environmental protection. Several

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researchers claim that most of the pesticides applied via aerial spraying do not reach the target, but go to soil, water, air, and nearby plantations, and communities. Therefore, there are no conditions under which aerial spraying can be considered completely safe.

Author Contributions

All authors have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

Lopes-Ferreira M; 0000-0003-0244-7482; monica.lopesferreira@butantan.gov.br

Disner GR; 0000-0002-4561-1361; disner.rodrigo@gmail.com

Hess, SC; 0000-0001-6137-5445; soniahess@gmail.com

Nodari, RO; 0000-0002-8884-2426; rubens.nodari@ufsc.br

Lima C; 0000-0002-8161-966X; carla.lima@butantan.gov.br

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Conflicts of Interest

The authors have no conflicts of interest to declare. Authors hold sole responsibility for the views expressed in the text, which may not necessarily reflect the opinion or policy of the institutions they are affiliated with.

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