PERSPECTIVE

Strategies for reducing airborne pesticides under tropical conditions

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Abstract Brazil is currently one of the largest pesticide consumers worldwide. However, a lack of scientific information regarding airborne pollution is still an issue, with tragic consequences to human health and the environment. To reduce pollution of the lower air layers, where pesticide spraying occurs, green barriers that filter the air could be an effective mitigation procedure. Modifying pulverization habits, by pulverizing in the late afternoon instead of in the morning could also reduce pesticide volatilization, while other recommendations with the purpose of lowering the pesticide amounts currently applied are likewise pursued. Data obtained about volatilization have demonstrated that, in order to reduce air pollution risks, one of the most effective preventive strategies is to ban products with high vapor pressure. Global/local stakeholders need to assume the responsibility to find the best way to reduce airborne pesticide pollution, which has increasingly shown disastrous effects as major poisons to human health and the environment.

Keywords Drift reduction · Human poisonings · Pesticide air pollution · Pesticide pulverization · Volatilization

INTRODUCTION

Pesticide control through registration procedures with banning of the most toxic products is slowly progressing, but food and environmental contamination still remain. The control of these products in food is somewhat effective when maximum permissible concentration limits are established by law, or when strict regulations are followed, while controlling pesticide bioavailability in the atmosphere is more complicated. Apart from the efforts to

reduce food, soil, and water exposure to these agents, the focus of the present study is to present strategies to reduce pesticide pollution in the air, which then spreads to the soil, water, and, finally, the entire biosphere. Particularly in Brazil, one of the largest pesticide consumers worldwide (Prada 2015), a large portion of these compounds does not reach their main target, crop plagues, whereas most of the applied amount are quite often lost in the air and acts on the non-targeted biosphere. This is even more worrisome due to special difficulties in obtaining consistent scientific information on pesticide air residues, as well as their effects on health, mainly in humans. Non-constant and quite variable pesticide amounts in the air, due to temperature, rain, wind intensity and direction, allow to aim for integrated model methodologies to assess whether pesticides pose a risk to the health of people living in close contact with agricultural activities (Pivato et al. 2015). The presence and movement of these products has been registered as far as uninhabitable regions, in places where they have never been applied, such as in Antarctica (Tatton and Ruzicka 1967), isolated pacific islands and mountains.

Despite the continental size of Brazil, the country is located between 5°16'20" north of the equator and at the south of Tropical of Capricorn with the latitude of 33°45'03", characterizing it as a tropical country, with temperature ranging from a minimum of 0 °C to about 40 °C. Agriculture typology is quite ephemeral, and it is remarkable that, in many parts of the country rich in water resources, three earnings per year can be obtained, leading to more intensive consumption of agrochemicals. Crops and fruits are important export products, while legumes are produced mainly for the local population. The kind of food produced is dependent on the soil and geomorphic and local climate conditions. Pesticide use and pulverization technology can be quite distinct, in which large soy and

maize farms are mainly treated with modern tractors in which operators are protected in a cabin and the spray sparger is directed against the ground, leading to reduced drift pollution (Langenbach et al. 2017), while orchards present much higher variation in this regard, with modern tractors and knapsack pulverization, where, generally, the sparger is directed in a horizontal position, with much higher drift production. Legumes are produced mainly by middle and small producers, generally using pesticides knapsacks, in which the operator walks into the pesticide cloud constantly without PPE (Fig. 1), with frequent hazardous effects on their health. No data are available concerning the relation between the numbers of operators with poisoning symptoms. Many farmers live in the countryside and, in this case, can become contaminated, as they live

near the spray sites, with consequently higher levels of pesticides in their body compared to other population (Coronado et al. 2011).

Economic losses in the US due to pesticide use total over US\$ 10 billion a year, including direct losses from crops, livestock, wildlife and human health, as well monitoring and registration costs (Pimentel 2005). Of all the pesticide poisonings in humans, about 3 million cases result in hospitalization, ranging from 220 000 to 355 000 fatalities (World Bank 2008) and about 750 000 chronic illness cases each year (Hart and Pimentel 2002). Modeling risk exposure under European guidelines show that the operator is much less exposed compared with land workers and bystanders, similar to modern tractor drivers in large Brazilian plantations. These conditions lead to a large

Fig. 1 Human risk exposure with different pulverization methods

spectrum of effects, some of them non-reversible, and enhance cancer incidence, as well as hormone disruption. As part of occupational exposures, hazardous effects on health are more often due to ingestion, where concentrations are higher as compared to inhalation but, nevertheless lung absorption and, therefore, toxic efficacy is much higher due to facilitated contact with blood (Andrade Filho and Souza 2013). Luo and Zhang (2009) in a study with a computer framework of human health risk due to organophosphate pesticides in the most productive valley of San Joaquim showed that intake amount by ingestion is higher than inhalation but considering the relative potency of inhalation, results in a higher margin exposure. Dermal exposure is quite significant, mainly when people are not protected by PPE (Andrade Filho and Souza 2013). Since the beginning of this century, the Agency for Toxic Substances and Diseases in their Division of Toxicology and Environmental Medicine is making a huge effort to establish a relationship between all sources of exposure, with quite interesting case studies. However, few publications are available to date outside the USA. Brazil only has local reports on this subject. The Cancer National Institute published a report in 2016 indicating that pesticides would contribute to Cancer cases in Brazil. More information can be obtained in www1.inca.gov.br (internet access on 31/08/2017). These issues are extremely important in human health and merit further discussion.

Considering the low number of registered fatalities with the enormous under-notification characterizing the lack of scientific reliable data in Brazil, Faria et al. (2007) summarize many data from published research with worker groups, and most (40–60%) of them show toxicological symptoms, an extremely high percentage (Fig. 2). The best strategy is to define environmental policies to prevent and mitigate pollution by finding a way to filter these residues near human activities from the air and in the process, also obtaining additional agricultural and other benefits.

Fig. 2 Brazilian and world pesticides consume: simulation of fatalities considering the average of the international risk

HEALTH EFFECTS OF PESTICIDES IN THE AIR

Pesticide toxicity in humans shows differences when occurring through air and food contamination routes. The main scientific information and control efforts are obtained and performed regarding pesticide residue limits in food established by registration procedures. In general, pesticide effects are displayed as chronic disease, in particular regarding endocrine disruptors, in which pesticides are gradually bioaccumulated up to high residue concentrations through daily intake. In these cases, mainly hormonal, skin, gut, and lung diseases occur, mainly.

However, pesticide air pollution is the main source of contamination, resulting in acute toxicity in people that work directly with pesticide pulverization. The highest risk is towards small farmers that use knapsacks and move in the pesticide cloud, protected or not by individual protection equipment (PPE). Pesticide air pollution health outcomes in human exposure also include hypersensitivity diseases such as asthma, rhinitis, and bronchitis (acute or chronic), as well as topic and gut allergies which have been described more often in farmers than in the general population, for decades. In addition, changes in behavior patterns, suicides, neuropathies, and Parkinson's disease are of significant concern amongst the rural community agricultural workers, but studies are quite limited in developing countries. Additional pesticide air pollution symptoms include chest pain, breathlessness, fatigue, headaches, dizziness, eyes and/or skin itching, cutaneous rashes, nausea and vomiting, nose bleeding, scratchy noses or throats and nail lesions, amongst others. Both chronic and acute toxicity are reported in Brazil, although cancer and/or hormonal effects are not usually the focus of these investigations. Nevertheless, the Brazilian Cancer Institute (2016) has quite recently pointed out that the incidence of skin, lung, and central nervous system cancers is rather high in rural areas of the country, mainly in the south, with higher prevalence in men. Acute toxicity is caused mainly due to exposure to air contamination during pesticide pulverization. The low education level of most farmers in underdeveloped and developing countries reflects in the lack of awareness in dealing with pesticides, leading to higher contamination risks. The opposite trend occurs in the case of well-educated farmers.

The levels and spectra of commercial-grade pesticide toxicity may vary enormously, particularly in tropical countries like Brazil, where the absorption rate of such compounds through the skin, gut, and lungs can be highly influenced by solubility, volatility, and also by the solvent carriers or adjuvant mixed with the pesticides. Likewise, the physicochemical properties of pesticides and their formulations are especially determinant of short- and long-term effects. Regarding long-term overall body intake in

agricultural workers, it is important to distinguish the amount absorbed by cutaneous and inhalation due to contaminated air exposure, mainly in farmers, from ingestion via food contamination affecting the entire population. In the US, for each 3.5 million dollars spent on pesticides one cancer victim is reported, and for less protected farmers in developing countries this rate is certainly higher.

Health effects due to air contamination are quite difficult to be studied, first because the exposure is very variable and relatively unknown, and second, due to limitations of data obtained in studies conducted with guinea pigs that have rather different physiologies than humans. In addition, it is not easy to distinguish pesticide effects from the synergistic influence with other products (e.g., tobacco smoking). Some interesting approaches have been performed with statistical representative data of exposed communities. Environmental markers of pesticide exposure that suffer influences of temperature, humidity, solubility, and volatility obtained from food, air, soil, water, or otherwise using human biomarkers are also difficult parameters to measure on a daily basis for long periods of time. Because of this, Brazilian Health authorities have focused on the control of pesticide residues only in food. However, pesticide concentrations in food are much higher, about 10- to 100-fold, than those found in air (Luo and Zhang 2009).

When long-term human pesticide inhalation is considered, depending on the air concentration per day, the pesticide amount absorbed (breathing 20 m³) can be significant, and when the pesticide particle size is smaller than 2.5 µm, therefore easy to reach blood not filtered by the lungs, a significant amount of pesticides is absorbed, which can lead to chronic diseases. Many pesticide-related diseases are non-reversible, with high medical costs.

Recently, Nascimento et al. (2017) developed an analytical method to measure particles above 2.5 µm, the most hazardous regarding health, in order to improve studies about airborne pesticides in Brazil. Despite few data in Brazil regarding pesticide intoxication, the challenge presented herein is to prevent and mitigate pesticide pollution.

PESTICIDES IN THE ENVIRONMENT

The main pesticide air pollution sources are spraying procedures and volatilization (Gil and Sinfort 2005). The spray strongly dilutes pesticides in the water contained in the pesticide knapsack or in the tractor tanks. This solution is spread to the targets by pulverization, many times at an upward angle, as performed in orchards. Immediately after pulverization, the pesticide droplets descend due to gravity, and during this drop movement, they can be moved in other

directions by the wind, thus drifting from their original target. The spray directed against orchard trees also changes speed when reaching the leaves, producing a vortex-like turbulence immediately over the canopy. This process exposes more drops containing pesticide residues to the wind, enhancing droplet drift (Salcedo et al. 2015).

The process in which pesticides change from solid/liquid to gas and move upward to higher atmosphere layers is named volatilization (Focus 2008). In the literature, a gray zone between volatilization from pesticide pulverization drops and volatilization from soil or leaves is observed (Schampheleire et al. 2008; Pivato et al. 2015). Data from Langenbach et al. (2017) indicate that pesticides in drop form are heavy and move down to the ground only a few minutes after pulverization and are submitted to drift by wind for only short time and move near the spray area. The exposure risk in this case is mainly for operators, land-workers, and people living near the field. Volatilization, in which pesticides change from solid/liquid to gas, moves upward to higher atmosphere layers can drift to different distances and also can move up to higher altitudes, thousands of kilometers away (Focus 2008). Volatilized residues diffuse in the first 0.5 cm of air and are exposed to increasing wind speeds when reaching higher layers, in a turbulence process that enhances the pesticide mixture in the air and exposes the pesticide residues to drifting (Focus 2008; Salcedo et al. 2015). This process depends on the physicochemical characteristics of the pesticide, mainly vapor pressure (Fig. 3), Henry's law constant (H) as well as solvent composition, soil adsorption capacity, environmental temperature, humidity, wind, and rain (Focus 2008). Volatilization can also occur from soil, leaves, and water. Pesticide molecules with low H remain longer in higher air layers and can travel long distances, arriving to other continents, like Antarctica. These molecules significantly contaminate mountains (Vila et al. 2006) and cold regions, in which precipitation is much more frequent than volatilization, but with intense snowmelt runoff (Daly et al. 2007). In contrast, in warmer regions no snowmelt runoff occurs, but endosulfan and hexachlorobenzene in the air were recently found Itatiaia National Park (2000-m-high mountains), by a drift that was led by wind from the eastern part of the country. Meteorological wind data exist in Brazil, but few research dealing mainly with pesticides application technologies is available (Gandolfo et al. 2013) and, therefore, impact models of pesticide drift are not feasible.

Despite the ten most consumed pesticides in Brazil displaying vapor pressure below 10⁻⁵ Pa, ground deposition studies that collected rain water from the highlands in the Northeastern Pantanal Basin in Brazil were shown to be polluted with substantial amounts of endosulfan, alachlor,

Volatilisation after soil application related to the vapour pressure

Fig. 3 Upward movement of volatilized pesticides and the influence of vapor pressure in this process

metolachlor, trifluralin, monocrotophos, and profenofos, at concentrations ranging from 0.3 to 2.3 g L⁻¹ (Laabs et al. 2002). Lowland rainwater samples taken 75 km from the

nearest application area contained 5- to 10-fold lower mean pesticide concentrations than the highlands. Cumulative deposition rates of the pesticide sums within the study

period ranged from 423 g m⁻² in the highlands to 14 g m⁻² in the lowlands. The atmospheric input of pesticides to ecosystems seems, thus, to be of higher relevance in the tropical study area than temperate regions. Rain is an important air cleaner, since it deposits residues onto the ground. Experiments with simulation of strong tropical rains have demonstrated that runoff of atrazine is much higher in 2 days compared to 15 days after pesticide application, while longer times increase adsorption and reduced residue mobility (Correia et al. 2007). In the same soil samples, residue analysis up to 50-cm deep after 90 days showed that atrazine, deisopropylatrazine, and desethylatrazine are almost null. Leaching after 60 days in an experiment with universal ¹⁴C-atrazine labeled carbon demonstrated that more than 50% of radioactivity is retained in the first upper centimeter layer, 10% in the second centimeter and the residual amount is subsequently distributed in the deeper layers. After longer periods of time, radioactive material is mainly strongly bound, probably to humine, and is not extractable.

Many molecules bioaccumulate environmentally and reach concentrations that are toxic to different species in the biosphere. Herbicides act on flora, while insecticides and fungicides affect fauna. The large list of species in extinction has certainly suffered important contributions from chemical poisonings (Pimentel et al. 1993), enhanced by endocrine disruption (Mnif et al. 2011). Pesticide pulverization can, thus, contaminate plants, soil, air, and, surface water.

STRATEGIES TO MINIMIZE DRIFT POLLUTION

In order for agriculture to reduce pesticide losses by pulverization, it is important to lower input costs alongside pollution decreases, but the priority is to protect the nearby population that does not use personal protective equipment, such as farm workers or people located nearby. This cannot be accomplished by using drift barriers. Reimer and Prokopy (2012) found a significant gap in pesticide perception and knowledge levels in both farmers and the general public.

Manifold pulverization devices offer options to reduce drifting by using reduction drift nozzle (Garcerá et al. 2017 and Torrent et al. 2017), by the addition of adjuvants (Gandolfo et al. 2013), careful equipment maintenance, and other pulverization practices (Santos and Maciel 2006; Reimer and Prokopy 2012). This approach can reduce losses by enhancing application efficiency, although it is limited to controlling drift pollution during pulverization and is not efficient in controlling the highest amount of airborne pollution due to volatilization. Currently, agriculture productivity is generally high and it makes no sense

to force higher production and profits when sustainability is in question. Therefore, the priority would be to protect non-target forms of life, including human health.

Pesticide drop movement is powered upwards and in sequence, downwards due to gravity. Thus, the spraying process is not a source of a vertical pollution but, in the meantime, floor drift can occur, observations made in our research (Fig. 4). The loss by droplet drifting during pesticide applications reaches up to 10% of the total applied amount in a single swatch treatment with tractors (Free-mark and Boutin 1995) and is about 3% in treated glebe areas (Ucar 2001). For highly volatile pesticides, air losses could account for over 90% of the total pesticide amounts (Hassink et al. 2003; Bedos et al. 2002), indicating that volatilization is the main source of air pollution. Despite the huge range of physicochemical properties that can influence volatilization, environmental diversity may also determine the intensity of this process. Products with high volatilization capacity move upward, constituting vertical pollution sources that can pollute higher altitudes, while also suffer drifting, which may allow for the partial overcoming of green barriers (Ucar and Hall 2001). This process can be quite significant, so air pollution control requires complementary measurements. New devices are helpful in this context to reduce pesticide applications by discrimination of leaf density with automatic regulation of the sparger (Giles et al. 2011). Other methods include the use of drones able to identify certain areas affected by weeds or other plagues that require pulverization, avoiding pesticide applications throughout the entire crop area, focusing only on a particular spot, for example. The most feasible method, however, is a preventive approach, restricting the use of highly volatile products in the registration process, which is still not considered by Brazilian registration authorities.

Green barriers can trap drifting droplets and, in some cases, also include volatilized air residues (Lazzaro et al. 2008; Kasiotis et al. 2014) (Fig. 4). These barriers can comprise forest strips or hedgerows, and can be planted in the vicinity of farms, margin of roads and mainly urban areas (Jong et al. 2008). The protection of surface water is established by law by riparian forest protection or reforestation (Bicalho et al. 2010; Marinho et al. 2011; Bicalho and Langenbach 2013). We could not find Brazilian references regarding plant barriers concerning the reduction of pesticide drift, and, therefore, no recommendation to farmers could be made. In fact, plant barriers exist in some farms with a different use, as a limit between neighbors, or for other purposes. Research in this field is an important challenge. The plant species in this regard must be resistant in order to survive applications of different herbicides and cannot be used as food due to high pesticide accumulation, due to exposure to manifold pulverization. These barriers

Fig. 4 Orchard pulverization with downward movement of pesticide drops: exposure of drift and green barrier filters

Fig. 5 Changing pulverization from morning to late afternoon would protect rural population in this habitations

are more efficient when they are as wide as possible. For large farms, it is best to use forest strips at least 10-m wide, but in smaller farms this approach demands the occupation of significant areas, so it is therefore advisable to use 1- or 2-m wide hedgerows, with twice the height of the cultivated plants, or at least 1 m higher (Van de Zande et al. 2000). An important parameter is the optical density of the barrier. By maintaining high optical density, hedgerows deviate the airflow and do not absorb the residue due to efficient filtering. Hedgerow pesticide uptake efficiency ranges between 50 and 90% (Van de Zande et al. 2000). Low optical density reduces residual uptake capacity from the air, and the best results have been obtained with medium optical densities.

Special considerations are necessary to protect the people residing in small farms in the middle of the crop fields, who are more exposed to pesticide health effects. It is a Brazilian habit to pulverize in the morning. During the warm period of the day, about twofold increases in

volatilization rates per 10 °C rises in temperature occur (FOCUS 2008), and as windows in residences are maintained open, thus significantly exposing the interior to pulverization drifts plus pesticide volatilization. At night, windows will be closed and pollution residues maintained indoors. A Brazilian study demonstrated that the exposure amount is proportional to the number of windows of the houses. An EPA study (Streicher 1997) also demonstrated that indoor pesticide pollution is higher than exterior contamination. Preliminary studies in our laboratory performed during 24 h indicate that volatilization is 15–30% higher when pulverization occurs in the morning compared to applications at the end of the afternoon (Costa et al. 2016). This is probably due to the dryness of surface soil, which shows higher pesticide adsorption capacity (K_d) (Rüdel 1997; Vanclooster et al. 2003), with decreases in movement and volatilization. Humid fallow soils due to dew show lower adsorption, and the result is enhanced volatilization (Glottfelty et al. 1984). Pulverizations during

Fig. 6 Green barrier protecting farm house and not school

late afternoon could be followed up by closing nearby windows, avoiding pulverization drifts, and reducing between 15 and 30% volatilization residues the next day (Fig. 5). This, however, involves habit changes. Pulverization in other countries is generally performed in the late afternoon, such as in Italy (Pivato et al. 2015), and by night low volatilization is observed (Lichiheb et al. 2014).

OTHER BENEFITS OF GREEN BARRIERS

Erosion control due to wind and water can be achieved by placing contour lines and planting certain types of grasses, such as Vetiver, which can also be helpful in reducing pesticide drift and runoff (Granato, personal communication). The trapping capacity of airborne pesticides is more efficient when wind barriers are distributed in 10- to 20-m intervals in the crop fields. Near forest strips, that have a much higher canopy to avoid photosynthetic loss due to shadow, wind barrier distances must be greater between the strips. These barriers have remarkable importance when positioned transversally, since they may reduce soil erosion by retaining water, as well as fertilizers and organic matter, thus preserving soil fertility.

Green barriers can also maintain and benefit arthropods important for biological control. Directive 91/414 of the European Commission for placing new plant protection products on the market includes the need for specific risk assessments in order to not target arthropods.

Hedgerows also maintain higher air humidity with less water vapor air saturation deficit (Leuchner 2002). In addition, both hedgerows and contour lines are wind barriers, resulting in higher air humidity in crops and field, leading to enhanced productivity. Higher yields are also obtained by positioning hedgerows in a north–south direction instead of an east–west direction, but this is not universal (Trentacoste et al. 2015). External benefits from shelterbelts for private and public can be identified, such as economic value (Kulshreshtha and Kort 2009), reduction of greenhouse gas emissions, protection or enhancement of biodiversity, applications in energy conservation, air quality (non-odors), water quality, wildlife consumption (hunting), bird-watching, odor reduction, health impacts, and aesthetics.

CONCLUDING REMARKS

It is essential for regional and federal authorities, alongside farmers and scientists, to discuss the best form of pesticide air pollution control. Medical treatment has limited efficiency, especially when pesticide exposure occurs via contaminated air. Therefore, the main approach is to perform prevention and mitigation procedures regarding pesticide air pollution. However, technical solutions are only efficient when accepted by populations and authorities. An important prevention approach is to perform pesticide applications under the concept of “treat-only-when-

necessary,” avoiding regular pulverizations. Regarding mitigation, the challenge is how to introduce green barriers along road margins, houses, and urban areas. The strategies must stimulate the population through convincing arguments, citing advantage concerning farmer’s health, as well as that of the surrounding residents, and protection and preservation of the surrounding environment, which can also aid regarding decreasing plague rates. Knowledge is required for land workers but does not usually lead to behavioral changes regarding environmentally adequate practices (Grob 1995). Thus, enforcement by law should be a condition for agricultural financial support, which has been shown to be a highly efficient tool in Brazil. In this context, green barriers could perhaps be introduced in the current “sustainable farm award” with interruption of monoculture in the big plantations of the central Brazil (Fig. 6). The final consideration is to highlight the importance of volatilization parameters in the registration process, since Brazil has a highly humid climate with high temperatures in the summer season, when pesticide applications are most frequent. This demonstrates the challenge of preventing airborne pesticide residues, which, when present, are unfortunately uncontrollable, since human inhalation occurs by necessity, contrary to ingestion of contaminated foodstuffs, in which there is still a choice.

Sweden was a pioneer in the nineteenth decade of the last century, introducing a pesticide reduction program, where the final result was about 60–70% less pesticide applications (Larsson et al. 2017). Many cultural controls, known as Integrated pest Management (IPM), were applied, such as crop rotation, soil, and water management, planting time, crop-plant density, trap crops, polycultures, parasite predators, plague intensity identification for pulverization and biobeds to avoid soil pollution by proper handling. This is a successful example, but not easy to perform in a much bigger country with diversified ecosystems in which environment is not a priority, ranking behind social, economic, and political issues. Regarding small farmers in Brazil, an important constraint is the low level of education-information and, in general, the priority of profit is hegemonic, with low environment awareness. Therefore, the recommendation is to put into practice the different feasible and inexpensive proposals presented herein, which can strongly reduce pesticide air pollution, thus preserving both human and environmental health.

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REFERENCES

- Andrade Filho, A., and S.D. Souza. 2013. Anticolinesterásicos. In *Toxicologia na Prática Clínica Folium*, 89–98, 2nd edn.
- Bedos, C., P. Cellier, R. Calvet, E. Barriuso, and G. Gabrielle. 2002. Mass transfer of pesticides into the atmosphere by volatilization from soils and plants: Overview. *Agronomie* 22: 21–33.
- Bicalho, S.T.T., and T. Langenbach. 2013. The fate of tebuthiuron in microcosm with riparian forest seedlings. *Geoderma* 207–208: 66–70.
- Bicalho, S., T. Langenbach, R. Rodrigues, F. Correia, A. Hagler, M. Matallo, and L. Luchini. 2010. Herbicide distribution in soils of a riparian forest and neighboring sugar cane field. *Geoderma* 198: 392–397.
- Coronado, G.D., S. Holte, E. Vigoren, W.C. Griffith, D. Barr, E. Faustman, and B. Thompson. 2011. Organophosphate pesticide exposure and residential proximity to nearby fields: Evidence for the drift pathway. *Journal of Occupational and Environmental Medicine* 53: 884–891.
- Correa, F.V., A. Macrae, L.R.G. Guilherme, and T. Langenbach. 2007. Atrazine sorption and fate in an Ultisol from humid tropical Brazil. *Chemosphere* 67: 847–854.
- Costa, D., T. Campos, T. Langenbach, and A. Haddad-Nudi. 2016. Aplicação e volatilização do 2,4-D na superfície de solos em diferentes horários. In *Conference: XVIII Congresso Brasileiro de Mecânica dos Solos e Engenharia Geotécnica*. Minas Gerais: ABMS.
- Daly, G.L., D. Ying, Y.D. Lei, C. Teixeira, D. Muir, L. Castillo, and F. Wania. 2007. Accumulation of current-use pesticides in neotropical mountain forests. *Environmental Science Technology* 41: 1118–1123.
- Faria, N.M.X., A.G. Fassa, and L.A. Facchini. 2007. Pesticides poisoning in Brazil: The official notification system and challenges to conducting epidemiological studies. *Ciência & Saúde Coletiva* 12: 25–38.
- FOCUS. 2008. Pesticides in air: Considerations for exposure assessment. Report prepared by the Working Group on Pesticides in Air (FOCUS Air Group).
- Freemark, K., and C. Boutin. 1995. Impacts of agriculture herbicide use on terrestrial wildlife in temperate landscapes: A reviews with special reference to North América Agriculture Ecosystem. *Environment*. 52: 57–91.
- Gandolfo, M.A., R.G. Chechetto, F.K. Carvalho, U.D. Gandolfo, and E.D. Moraes. 2013. Influence on spray drift of nozzles and adjuvants with a glyphosate spray solution. *Revista Ciência Agronômica* 44: 474–480.
- Garcera, C., C. Román, E. Moltó, R. Abad, J.A. Insa, X. Torrent, S. Planas, and P. Chueca. 2017. Comparison between standard and drift reducing nozzles for pesticide application in citrus: Part II. Effects on canopy spray distribution, control efficacy of *Aonidiella aurantii* (Maskell), beneficial parasitoids and pesticide residues on fruit. *Crop Protection* 94: 83–96.
- Gil, Y., and C. Sinfort. 2005. Emission of pesticides to the air during sprayer application. A bibliographic review. *Atmospheric Environment*. 39: 5183–5193.
- Giles, D., P. Klassen, F. Niederholzer, and D. Downey. 2011. Smart sprayer technology provides environmental economic benefits in California Orchards. Report, Division of Agriculture and Natural Resources of the University of California.

- Glottfelty, D.E., A.W. Taylor, B.C. Turner, and W.H. Zoller. 1984. Volatilization of surface-applied pesticides from fallow soil. *Journal of Agricultural and Food Chemistry* 32: 638–643.
- Glottfelty, E., J. Shomburg, M. McChesney, C. Sajebil, and N. Seiber. 1990. Studies of the distribution, drift, and volatilization of diazinon resulting from spray application to a dormant peach orchard. *Chemosphere* 21: 1303–1314.
- Grob, A. 1995. A structural model of environmental attitudes and behavior. *Journal of Environmental Psychology* 15: 209–220.
- Hart, K., and D. Pimentel. 2002. Public health and cost of pesticides. In *Encyclopedia of Pest Management*, ed. D. Pimentel, 677–679. New York: Marcel Dekker.
- Hassink, J., J.A. Guth, F.J. Reischmann, R. Allen, D. Arnold, C.R. Leake, M. Skidmore, and G.L. Reeves. 2003. Vapour pressure and volatile losses of plant protection products from plants and soil. In *Proceedings of the XII Symposium Pesticide Chemistry*, eds. Del Rey A., A.M. Capri, E. Padovani, L., and M. Trevisan, 359–366, Piacenza, Italy.
- Jong, F., G. Snoo, and J. Zande. 2008. Estimated nationwide effects of pesticide spray drift on terrestrial habitats in the Netherlands. *Journal of Environmental Management* 86: 721–730.
- Kasiotis, K., C. Glassw, A. Tsakirakis, and K. Machera. 2014. Spray drift reduction under Southern European conditions: A pilot study in the Ecopest project in Greece. *Science of Total Environment* 479–480: 132–137.
- Kulshreshtha, S., and J. Kort. 2009. External economic benefits and social goods from prairie shelterbelts. *Agroforestry Systems* 75: 39–47.
- Laabs, V., W. Amelung, A.A. Pinto, M. Wantzen, C.J. Silva, and W. Zech. 2002. Pesticides in surface water, sediment, and rainfall of northeastern Pantanal Basin in Brazil. *Journal of Environmental Quality* 31: 1636–1648.
- Langenbach, T., D. Mano, M.M. Campos, A.L.M. Cunha, and M.P. De Campos. 2017. Pesticide dispersion by spraying under tropical conditions. *Journal of Environmental Science and Health Part B* 52: 843–849.
- Larsson, M., K. Boye, T. Nanos, M. Kreuger, and J. Boye. 2017. <https://www.slu.se/globalassets/ew/org/centrb/ckb/publikationer/postar/poster-york—swedish-environmental-monitoring-program.pdf>19).
- Lazzaro, L., S. Otto, and G. Zanin. 2008. Role of hegedrows in intercepting spray drift: evaluation and modelling of the effects. *Agriculture, Ecosystem, Environment* 123: 317–327.
- Leuchner, C. 2002. Air humidity as an ecological factor for woodland herb: leaf water, nutrient uptake, leaf anatomy, and productivity of eight species grown at low or high vdp levels. *Flora* 197: 262–274.
- Lichiheb, N., E. Personne, C. Bedos, and E. Barriuso. 2014. Adaptation of a resistive model to pesticide volatilization from plants at the field scale: Comparison with a dataset. *Atmosphere Environment* 83: 260–268.
- Luo, Y., and M. Zhang. 2009. Multimedia transport and risk assessment of organophosphate pesticides and a case study in the northern San Joaquin Valley of California. *Chemosphere* 75: 969–978.
- Marinho, D.A., S.T. Bicalho, E.M. Ferreira, and T. Langenbach. 2011. Distribution and Mineralization of ¹⁴C-Hexazinone in Soil Microcosm with the Riparian Forest Specie *Cecropia hololeuca*. *Journal of Bioremediation & Biodegradation*. <https://doi.org/10.4172/2155-6199.S1-002>.
- Meire, R.O., M. Khairy, A.C. Targino, P.M.A. Galvão, J.P.M. Torres, O. Malm, and R. Lohmann. 2016. Use of passive samplers to detect organochlorine pesticides in air and water at wetland mountain region sites (S-SE Brazil). *Chemosphere* 144: 2175–2182.
- Mnif, W., A. Hassine, A. Bouaziz, A. Bartegi, O. Thomas, and R. Roig. 2011. Effect of endocrine disruptor pesticides: A review. *International Journal Environmental Research Public Health* 8: 2265–2303.
- Nascimento, M.M., G.O. Rocha, and J.B. Andrade. 2017. Pesticides in fine airborne particles: From a green analysis method to atmospheric characterization and risk assessment. *Scientific Reports* 7: 2267. <https://doi.org/10.1038/s41598-017-02518-1>.
- Ochieng, A.A., M.A. Dalvie, F. Little, and H. Kromhout. 2013. Relationship between environmental exposure to pesticides and anthropometric outcomes of boys in the rural Western Cape, South Africa. *South African Medical Journal* 103: 942.
- Pimentel, D. 2005. Environmental and economic cost of the application of pesticides primary in the United States. *Environmental Development Sustainability* 7: 229–252.
- Pimentel, D., H. Acquay, M. Biltonen, P. Rice, M. Silva, J. Nelson, V. Lipner, S. Giordana, et al. 1993. Assessment of environment and economic impacts of pesticide use. In *The pesticide question: Environment, economics and ethics*, ed. D. Pimentel, and H. Lehman, 47–84. New York: Chapman and Hall.
- Pivato, A., A. Barausse, F. Zechinato, L. Palmeri, R. Raga, M. Lavagnolo, and R. Cossu. 2015. An integrated model-based approach to the risk assessment of pesticide drift from vineyards. *Atmospheric Environment* 111: 136–150.
- Prada, P. 2015. Fateful harvest, why Brazil has a big appetite for risky pesticides. <http://www.reuters.com/investigates/special-report/brazil-pesticides/>. Accessed 20 January 2017.
- Reimer, A.P., and L.S. Prokopy. 2012. Environmental attitudes and drift reduction behavior among commercial pesticide applicators in a U.S. agricultural landscape. *Journal of Environmental Economics and Management* 113: 361–369.
- Rosas A.C.S. 2003. Avaliação da dispersão de agrotóxicos no ar – estudo de caso em Nova Friburgo. Master Thesis, CESTEH/ENSP/FIOCRUZ. Avaliação da contaminação no ar por organofosforados em São Lourenço, Rio de Janeiro.
- Rüdel, H. 1997. Volatilisation of pesticides from soil and plant surfaces. *Chemosphere* 35: 143–152.
- Salcedo, R., C. Garcera, R. Granell, E. Molto, and P. Chueca. 2015. Description of the airflow produced by an air assisted sprayer during pesticide applications to citrus. *Spanish Journal Agriculture Research* 13: 1–15.
- Santos, S., and A. Maciel. 2006. Proposta metodológica utilizando ferramentas de qualidade na navegação do processo de pulverização. *Engenharia Agrícola* 26: 1–10.
- Sanusi, A., M. Millet, P. Mirabel, and H. Worthman. 2013. Comparison of atmospheric pesticide concentrations measured at three sampling sites: Local, regional and long-range transport. *Science of Total Environment* 18: 263–277.
- Schamphelreire, M., K. Baetans, D. Nuytens, and P. Spanoghe. 2008. Spray drift measurements to evaluate the Belgian drift mitigation measures in field crops. *Crop Protection* 27: 577–589.
- Streicher, J. 1997. Air concentrations and inhalation exposure to pesticides in the agricultural health pilot study. EPA/600/Sr-97/059.
- Tatton, J.O.G., and J.H.A. Ruzicka. 1967. Organochlorine pesticides in antarctica. *Nature* 215: 346–348.
- Thompson, J. 2011. Organophosphate pesticide exposure and residential proximity to nearby fields. *Journal Occupational Environmental Medicine* 53: 884.
- Torrent, X., C. Garcerá, E. Moltó, P. Chueca, R. Abad, C. Grafulla, C. Román, and S. Planas. 2017. Comparison between standard and drift reducing nozzles for pesticide application in citrus: Part

- I. Effects on wind tunnel and field spray drift. *Crop Protection* 96: 130–143.
- Trentacoste, E., D. Connor, and M. Gomez-del-Campo. 2015. Review: Row orientation: Applications to productivity and design of hedgerows in horticultural and olive orchards. *Scientia Horticulturae* 187: 15–29.
- Ucar, T., and F. Hall. 2001. Windbreaks as a pesticide drift mitigation strategy: A review. *Pesticide Management Science*. 57: 663–675.
- Vanclooster, M., J.D. Piñeros-Garcet, J.J.T.I. Boesten, F. Van den Berg, M. Leistra, J. Smelt, N. Jarvis, S. Roulier, et al. 2003. *APECOP*: Effective approaches for adjustment of the pesticide risk index used in environmental policy in Flanders.
- Van de Zande, C., J. Michielsens, H. Stallinga, and A. De Jong. 2000. The effect of windbreak height and air assistance on exposure of surface water via spray drift. In: *Proceedings of the British Crop Protection Conference-Pest and Diseases* 2000, 91–96. Brighton: UK.
- Villa, S., C. Negrelli, V. Maggi, A. Finizio, and M. Vighi. 2006. Analysis of a firn core for assessing POP seasonal accumulation on an Alpine glacier. *Ecotoxicology and Environmental Safety* 63: 17–24.
- World Bank. 2008. *World development report: Agriculture for development*. Washington, DC: TheWorld Bank.

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