Agrociencia Uruguay 2023 | Volume 27 | Article 1156
DOI: 10.31285/AGRO.27.1156
ISSN 2730-5066

Pesticide dependence and associated risks in Uruguayan agriculture: limitations in its approach

Dependencia y riesgos del uso de fitosanitarios en la agricultura uruguaya: limitaciones para su análisis

Dependência e riscos do uso de produtos fitossanitários na agricultura uruguaia: limitações à sua análise

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Received *3 Jan 2023*
Accepted *12 May 2023*
Published *23 May 2023*

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Abstract

Pesticides have become an essential input for agriculture in the last decades. However, the growing concern about the potential impact produced by such dependency on human health and the environmental level has led to strong questionings about the use of pesticides worldwide. This paper aims to analyze the use of pesticides in Uruguay's agriculture and their potential risks with an emphasis on ecotoxicological risks. For such purposes, data on imports and use of pesticides in Uruguay and some other agricultural regions corresponding to the last two decades (2000-2020) were collected. In addition, information on the risks associated with the use of different pesticides compiled in the Pesticide Properties Database of the University of Hertfordshire was reviewed, as well as information generated by related national and international research. The information collected indicates high intensity usage of pesticides in Uruguayan agriculture and uncertainties in relation to environmental risks that may arise from the current forms of use.

Keywords: ecotoxicology, toxicology, environmental fate

Resumen

Los fitosanitarios se han convertido en un insumo indispensable para la agricultura en las últimas décadas. Sin embargo, la creciente preocupación sobre los impactos que pueda generar esta dependencia a nivel de la salud humana y/o la sostenibilidad ambiental ha determinado fuertes cuestionamientos al uso de pesticidas a nivel mundial. El presente trabajo pretende analizar el uso de fitosanitarios en la agricultura de Uruguay y sus riesgos potenciales con énfasis en los ecotoxicológicos. Con tal objetivo, se procedió a la recopilación de información de datos de importación y uso de fitosanitarios a nivel nacional e internacional de otras regiones agrícolas, correspondientes a las dos últimas décadas (2000-2020). Complementariamente, se revisó la información de los riesgos asociados al uso de distintos pesticidas compilada en la base de datos de la Pesticide Properties Database de la Universidad de Hertfordshire, así como la generada en investigaciones nacionales e internacionales relacionadas con la temática. La información relevada señala alta intensidad del uso de fitosanitarios en la agricultura del país e incertidumbres en relación con los riesgos ambientales y humanos que puedan derivarse de las formas de uso actual.

Palabras clave: ecotoxicología, toxicología, destino ambiental

Palladino C, García I, Fernández G. Pesticide dependence and associated risks in Uruguayan agriculture: limitations in its approach. Agrociencia Uruguay [Internet]. 2023 [cited dd mmm yyyy];27:e1156. Doi: 10.31285/AGRO.27.1156

Resumo

Nas últimas décadas, os pesticidas tornaram-se um insumo indispensável para a agricultura. No entanto, a crescente preocupação com os impactos desta dependência na saúde humana e/ou na sustentabilidade ambiental levou a fortes questões sobre a utilização de pesticidas em todo o mundo. Este documento visa analisar a utilização de pesticidas na agricultura uruguaia e os seus riscos potenciais. Para tais fins, foram compiladas informações sobre a importação e utilização de produtos fitossanitários a nível nacional e internacional de outras regiões agrícolas durante as últimas duas décadas (2000-2020). Além disso, foram revistas informações sobre os riscos associados à utilização de diferentes pesticidas compiladas na Base de Dados de Propriedades dos Pesticidas da Universidade de Hertfordshire, bem como informações geradas na investigação nacional e internacional relacionada com o assunto. A informação coletada indica uma elevada intensidade de utilização de pesticidas na agricultura do país e incertezas em relação aos riscos ambientais e humanos que podem surgir das atuais formas de utilização.

Palavras-chave: ecotoxicologia, toxicologia, destino ambiental

1. Introduction

Pesticides are one of the most important inputs in agricultural production. They effectively reduce losses caused by insects, diseases and weeds, improving crop yields and their quality[1-3]. However, it has been widely demonstrated that, by reaching soil, water and air compartments, they also represent a major threat to environmental sustainability. Non-target organisms such as birds, fish, beneficial insects, plants and others are systematically exposed to pesticides and therefore affected by their toxicity[4]. Pesticides also pose serious risks to human health. Human exposure can occur directly due to occupational, agricultural, and household use, or indirectly, mainly through contaminated food and water consumption[5-6].

Despite the cumulative evidence generated in the past years and the growing awareness of negative impacts from pesticides; various attempts proposed to mitigate the overuse of pesticides have been practically ineffective. One of the most cited examples is the adoption of integrated pest management (IPM). Moss[7] pointed out that IPM implementation has been poor, with little evidence of concomitant reductions in pesticide use.

Moreover, the quantity of pesticide production and consumption has kept increasing annually at the global level. According to the latest data from the Food and Agricultural Organization[8], the total pesticide consumption worldwide has risen from 2,047,087 tons in 2000 to 2,611,124 tons in 2020.

Pesticide dependency is a fundamental part of modern agricultural regime and a very complex phenomenon. Even when pesticide resistance has been widely considered as one of the major causes[9-10]. Hu[11] argues that pesticide dependency is not only a technological issue as pesticide resistance thesis indicates, but rather a man-made issue, with socioeconomic and political reasons for both the country and the farmers, involving multi-dimensions, multi-actors and multi-scales factors.

Consequently, multiple and complex actions at different levels are required when addressing pesticide dependency mitigation[12]. The actions to be developed in each region or country, as well as their prioritization and urgency, require previous and basic analysis of the intensity of pesticide use, the expected behavior in environmental fate and the associated risks[13].

The objective of this work was to analyze pesticide use in Uruguay, combined with the information available on its potential risks with an emphasis on ecological risks.

2. Materials and methods

The information made available by the General Directorate for Agricultural Services (DGSA) from the Ministry of Livestock, Agriculture and Fisheries of Uruguay (MGAP)[14], and the Food and Agriculture Organization of the United Nations (FAO)[8] corresponding to the last two decades (2000-2022) was used for the diagnosis of pesticide use in Uruguay and other agricultures regions.

For the estimation of the most used active ingredients in the country, a sample was taken using information collected from the DGSA's system of pesticide application registrations from 2019 to 2022[15]. For the potential risks associated with its use, the information reviewed considered the Pesticide Properties Database[16], national and international research related to the subject.

3. Results and discussion

3.1 Use of pesticides in Uruguayan agriculture

The use of these products has had a sustained increase since the year 2000, showing very similar trends to those observed worldwide. The total amount of active substances imported varied from 3.9 to 10.6 tons between 2000 and 2021[14] (Figure 1).

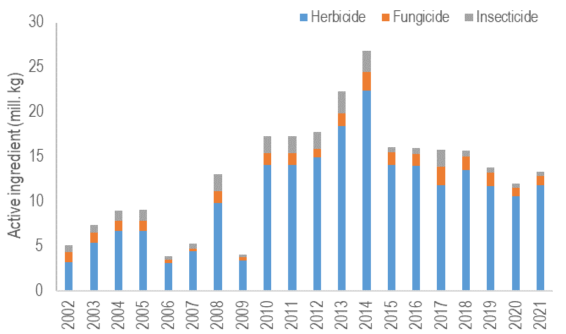

Figure 1. Pesticide imports from 2000 to 2021 in Uruguay[14] Values include raw material

Herbicides were the group that registered the greatest change, representing 89% of the total volume increase in kg or l of the formulates in 2021[14]. While comparing the worldwide use of pesticides in 2020, 53% is the share of herbicides, 18% is the share of insecticides, 23% is that of fungicides, and others account for 7% only[8].

It should be clarified that pesticide products imports are not necessarily a synonymous of the use of such product. There is no information on how much of the imported pesticides are truly used in the country, nor if the use is exclusively for agricultural purposes. Despite this, it is an indicator commonly used for global and comparative analyses in this subject[17].

The greater use of pesticide products in the country has a strong association with the agricultural area's growth in this period. Favourable agricultural prices and a rapid generalization of the practice of zero tillage were determinants of agriculture expansion towards non-traditional areas and mainly agriculture intensification process, as a result of massive adoption of double cropping[18].

In this way, the increase in pesticide products imports reflects an increase in the intensity of their use, and therefore refers to greater quantities of pesticide products per hectare cultivated and per year. The information collected shows that higher amounts of pesticides per hectare in the periods between 2000 and 2020 varied from 2.58 to 7.97 kg/ha in Uruguay, just as it can be observed in Figure 2[8]. There are also marked differences between regions. While in Europe there is a tendency to decrease the intensity of pesticide use, the Southern Cone of South America shows an increasing trend, which is noticeable in the case of Uruguay.

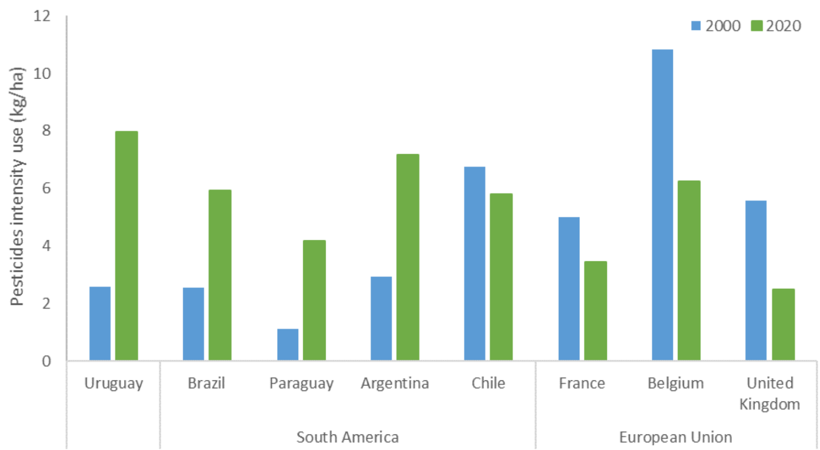

Figure 2. Pesticides intensity use in Uruguay *vs*. South American and European countries[8]

When we analyze the active ingredients comprising the groups of pesticide products imported in 2021[14] in detail, a clear predominance of a few active ingredients was revealed (Table 1). The most notorious case is that of herbicides, where 88% corresponds to only 5, while 68 active ingredients correspond to the remaining 12%. In the case of imported fungicides and insecticides, this is not so evident, although a few active ingredients still predominate.

Table 1. The most imported active ingredients in Uruguay in 2021[14]

	Active ingredients	%
Herbicides	Glyphosate	67
	2,4-D	9
	S-metolachlor	6
	Clethodim	2
	Paraquat	3
	Others (68)	12
Insecticides	Chlorpyrifos	47
	Paraffin oil	12
	Triflumuron	6
	Aluminium phosphide	5
	Chlorantraniliprole	3
	Others (33)	27
Fungicides	Sodium metabisulphite	18
	Mancozeb*	18
	Copper oxide	14
	Ziram	8
	Captan	8
	Others (44)	35

*Mancozeb is also imported in mixtures with metalaxyl. These quantities were not considered because they are not separately reported.

Nevertheless, considering that pesticides are used at very different doses per hectare, kilograms of active substances do not reflect directly the use.

In this context of increasing pesticides imports, but mainly of higher intensity of use, it seems likely that associated risks would also increase, depending on their toxicological and ecotoxicological hazards.

3.2 Toxicology and ecotoxicology characterization of major used pesticides

In an attempt to make a rough estimate of the potential risks of the most commonly used active ingredients in Uruguay, a hazard profile was compiled (Table 2) using information from the DGSA's Register of Application of Pesticide[15]. It is important to clarify that this hazard profile only considered information on the parameters currently required to register pesticide products in Uruguay[19].

Table 2. Toxicological profile according to Pesticide Properties Database[16] of the main used pesticides (2019-2022)[15]

		Human health	Terrestrial ecotoxicology			Aquatic ecotoxicology	
		Mammals	Earthworms	Honeybees	Birds	Fish	Aquatic invertebrates
Insecticides	Chlorantraniliprole	green	green	yellow	green	yellow	red
	Triflumuron	green	yellow	green	yellow	red	red
	Chlopyrifos	red	yellow	red	red	red	red
	Lambda-cyhalothrin	red	yellow	red	green	red	red
	Bifenthrin	red	red	red	yellow	red	red
Herbicides	Glyphosate	green	green	green	green	green	green
	2,4 D	yellow	yellow	green	yellow	yellow	green
	Clethodim	yellow	yellow	yellow	yellow	yellow	green
	Clopyralid	green	green	yellow	yellow	yellow	yellow
	S-metolachlor	green	yellow	green	green	yellow	yellow
Fungicides	Azoxystrobin	green	yellow	green	green	yellow	yellow
	Prothioconazole	green	green	green	green	yellow	yellow
	Pyraclostrobin	green	yellow	green	green	red	red
	Epoxiconazole	green	yellow	green	green	yellow	yellow
	Tebuconazole	yellow	green	green	yellow	yellow	yellow

Toxicity scale (Ts): mammals (rat) acute oral LD_{50} (mg/kg) < 5-50= very hazardous (red); 50-2000= moderately hazardous (yellow); > 2000 = unlikely to present an acute hazard (green). Ts in earthworms (*Eisenia foetida*) acute 14-day LC_{50} (mg/kg), > 1000 = Low 10 - 1000 = Moderate < 10 – High. Ts in birds (*Oncorhynchus mykiss/ Colinus virginianus*) Acute LD_{50} (mg/kg) > 2000 = low (green); 100 - 2000 = Moderate (orange); < 100 = High (red). Ts in honeybees (*Apis mellifera*) acute LD_{50} (μg/bee) > 100 = Low (green); 1 - 100 = Moderate (orange); < 1 = High (red). Ts in fish (*Colinus virginianus*) acute 96 h LD_{50} (mg/l) > 100 = Low (green); 0,1 - 100 = Moderate (orange); < 0,1 = High (red); Aquatic invertebrates *(Daphnia magna)* acute 48 hour EC_{50} (mg/l) > 100 = Low; 0.1 - 100 = Moderate and < 0.1 = High.

The danger for humans from pesticide products is classified into toxicological categories. These categories are defined according to the acute risk in mammals, resulting from a single or repeated exposure over a relatively short period of time with the pesticide product. Based on this classification, we notice that in the case of herbicides and fungicides predominant substances do not represent a major threat to human health (Table 2). However, in the case of insecticides, those which predominate are highly dangerous to humans.

National epidemiology studies in human toxicology have identified a wide range of conditions and diseases associated with environmental exposure to pesticides. Evidence has been found in the working environment, in rural and urban populations associated with agriculture[20-22]; and in the general unexposed population[23].

The human health risk assessment is complex due to its strong dependence on periods and levels of exposure, type of pesticides used, and characteristics of the environment and the human communities of the areas where pesticides are applied. Long-term, standardized and validated studies are needed to confirm the link between pesticides and their negative effects on human health. In addition, the risk to human health should be assessed not only for specific active substances and different formulations, but also for the possible cumulative and interactive effects of exposure to multiple pesticides over time[24-25]. It is firmly suggested that risk assessment of pesticide-exposed populations use occupational exposure matrices that consider the tasks performed, the crops and active ingredients, and more complete occupational histories, which could reduce errors due to exposure[26].

Regarding the ecotoxicological characteristics of the profile (Table 2), the main insecticides used present more toxicity in terrestrial and aerial organisms in relation to the other groups. However, in the case of aquatic organisms, all three groups of pesticide products present toxicity problems.

Ecotoxicological studies are also complex. They are performed with standard organisms generally selected according to the simplicity of their laboratory study. These organisms are not necessarily the organisms of interest in all the environments in which the pesticide product would be applied[27].

In addition, much of the information currently included in the pesticide registry is based on toxicity studies under laboratory conditions, focusing on groups of individual organisms and evaluating each active ingredient separately. Although these types of tests allow methodological homogenization and easily comparable results, they may be questionable in their ability to effectively protect ecosystems, given the differences between the assessment conditions and the conditions of real use[28-29].

Currently, and especially in extensive agriculture, pesticides are used in mixtures, and may generate synergistic toxicological effects, greater than those tested individually. In addition, these systems already have pesticide products in the process of degradation, generating cocktails of numerous compound that lead to stressful conditions for non-targeted organisms. In addition, risk assessments assess the effects on individual organisms, but not on population or community level[30].

Also, information regarding the potential effects of the resulting secondary metabolites from degradation is very limited. They have their own toxicological and ecotoxicological characteristics and can be even more toxic than the parent compounds[31].

Moreover, the risk generated by a compound is not only linked to the dose and metabolites it generates, but is also dependant on its environmental behaviour. A clear example is the persistence or active bioavailability of pesticide residues over time in different environmental compartments, which is strongly dependent on the physio-chemical characteristics of the compound and the variable characteristics of the destination compartment[16][32-33]. In this sense, glyphosate is considered of low risk in soil, among other aspects based on its categorization as non-persistent. At present, it is known that it may persist according to its form of use, to the point that its reclassification as pseudo-persistent is recommended[34].

Pesticide residues cause direct and indirect negative effects on non-targeted organisms[23], microorganisms, flora, physicochemical, and biological properties of agricultural soil[35-36].

In Uruguay, the presence of pesticide residues has been reported in watercourses and drinking water[37-38], in soil[39-40], in the air[41], in beehives and in component parts of beehives[42-45], and in agrifoods[46-48]. Furthermore, there are several studies on the effect of the use of pesticide products at the biota level in environmental compartments[49-57].

Based on the toxicological-ecotoxicological parameters and environmental fate of an active ingredient, pesticide products are registered, suspended, restricted or prohibited for their use.

There are currently 2601 pesticide products registered by MGAP in Uruguay. Eighty one of the registered active ingredients (which comprise 330 products containing these active ingredients) are classified as highly hazardous pesticides (HHPs)[58]. HHPs are defined by the World Health Organisation, the Globally Harmonised System of Classification and Labelling of Chemicals, Pesticide Action Network International and FAO[59-60] as pesticides that pose particularly high acute or chronic risks to human health or the environment. The European Union and many other countries have banned 41 of the 81 active ingredients that are classified as HHPs and that are registered and commercially available in Uruguay[58].

Uruguay has only 22 banned active ingredients according to PAN[61], similar to Argentina, Chile and Paraguay (18, 27 and 11 active ingredients, respectively), while Brazil has 133 banned active ingredients. Countries from the European Union are more restrictive with the use and registration of pesticide products[61]. When we relate this information with that corresponding to the effectively used amounts, we notice that the countries with the greatest use of pesticide products are those with the least restrictions.

It is worth mentioning that in countries with more restrictions the environmental risk assessment required for the registration of new pesticide products must be carried out in different cultivation scenarios, soil and climate representative of the region in which they will be used[(24)]. Despite the associated costs of these types of studies, they are essential to better estimate the impact of pesticide use on a particular ecosystem.

4. Final considerations

The available information indicates a high intensity of pesticide use in Uruguayan agriculture. It also evidences the presence of pesticide residues in different environmental compartments, and several negative effects have been reported on local non-target organisms.

Improvements on the registration and renewal system of pesticides, as adopted by countries with more restricted regulations, could be an effective strategy to mitigate deleterious effects of pesticides use.

Transparency of data

Available data: The entire data set that supports the results of this study was published in the article itself.

Author contribution statement

All authors contributed equally to the content.

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