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The links between the research on pesticides and agroindustrial multinationals: the case of glyphosate

Los vínculos entre la investigación sobre agrotóxicos y multinacionales agroindustriales: el caso del glifosato

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ABSTRACT

Nowadays, glyphosate is the most used herbicide in the southern cone. Its effects on human health, particularly the carcinogenic ones, are evaluated as far as from the 80s. In 2015, the International Agency for Research on Cancer belonging to the WHO classified it as "probably carcinogenic in humans". A year later this organism and the FAO concluded that it is improbable that it presents carcinogenic effects. The European Commission, after assuring that it was not detrimental, approved in renewing its license; although there was conclusive scientific evidence as being a probable carcinogenic substance. There are antagonistic ideological positions between the economic interests of the technological and farming development and social movements which question the consolidation of this productive model because of their consequences. These social movements question: what scientific knowledge is generated? who generates it? and how? This work contributes to the debate of those questions, characterizing the production of scientific knowledge in the mainstream of the Web of Science (WOS), linked to the 6 greatest world agroindustrial multinationals: Basf, Bayer, Dow Agroscience, Dupont, Monsanto and Syngenta. The results show delay or generalized absence of analysis of the environmental and human health impacts of glyphosate (1970-2011). Currently, in this frame of worldwide and intensive use of glyphosate a slight increase in the evaluation of its effects was detected but still remains low.

RESUMEN

Actualmente, el glifosato es el herbicida más utilizado en el cono sur. Sus efectos sobre la salud humana, en particular sus efectos cancerígenos, han sido evaluados desde la década del 80. En 2015, la Agencia Internacional para la Investigación del Cáncer perteneciente a la OMS lo clasificó como "probablemente cancerígeno en humanos". Un año después, este organismo y la FAO concluyen que es improbable que presente efectos cancerígenos. La Comisión Europea, después de asegurar que no era perjudicial, aprobó la renovación de la licencia; aunque hubo evidencia científica concluyente como una probable sustancia cancerígena. Existen posiciones ideológicas antagónicas entre los intereses económicos del desarrollo tecnológico y agrícola y los movimientos sociales que cuestionan la consolidación de este modelo productivo debido a sus consecuencias. Estos movimientos sociales cuestionan qué conocimiento científico se genera, quién lo genera, y cómo. Este trabajo contribuye al debate, caracterizando la producción de conocimiento científico en la corriente principal de la Web of Science (WOS), vinculada a las 6 mayores multinacionales agroindustriales del mundo: Basf, Bayer, Dow Agroscience, Dupont, Monsanto y Syngenta. Los resultados muestran demora o ausencia generalizada de análisis del impacto ambiental y a la salud humana (1970-2011), postulando una degradación "rápida y natural". Actualmente, en un contexto de uso extendido y masivo de glifosato, se visibiliza un leve incremento en el número de estudios que evalúan sus efectos.

Palabras clave: Glifosato, Impactos ambientales, Salud pública, Financiamiento de la investigación, Estudios métricos de la información, Análisis de redes sociales.

INTRODUCTION

Glyphosate-based herbicides[1] have been widely used in last years, promoted as an efficient product with minimal indirect effects for weed control. Nowadays, it is the most used herbicide worldwide (Wakelin *et al*., 2004). Its production was estimated in 630,000 T in 2013. In 2015, in the southern Cone, 50 million hectares of soybean were cultivated (Pengue, 2015), which implied a use of 350 million L of glyphosate. In recent years, alarms about possible direct and indirect effects of the massive use of glyphosate on the environment and the human health, have constituted an important research and debate issue. Simultaneously, some worrying scientific results in relation to their massive use have begun to spread. In addition the study of what it is known as "Monsanto papers" contravenes the official history maintained from the agrochemical companies for more than four decades. Recently, the European Commission and the agencies of Food Safety [EFSA] and Chemical Products (ECHA), after assuring that glyphosate was not detrimental to human health, approved to renew its license until 2022. However, there is important conclusive scientific evidence on the toxicity for humans and as a probable carcinogenic substance, (Bretveld *et al*., 2007; Garry *et al*., 2002; Gasnier *et al*., 2009; Koller *et al*., 2012; Mesnage *et al*., 2010; Mesnage *et al*., 2015; Richard *et al*., 2005; Samsel and Seneff, 2013; Thongprakaisang *et al*., 2013). Currently, the possible indirect effects on plant, animals and human health are recognized. Progressively, studies showing evidence of glyphosate affecting human health are increasing (Benachour and Seralini, 2009; Carrasco, 2011; Hardell *et al*., 2002; Samsel and Seneff, 2015). However, the environmental evaluation and effects on human health related to glyphosate use shows its weaknesses in a worldwide context of increased use of this herbicide. Hayes and Hansen (2017) based on their analysis on the current use of agrochemicals highlighted that glyphosate is a powerful endocrine disruptor, which alters the structure of ovaries and affects the sexual differentiation and regulation of sexual steroid production. These authors also reported that masculine fertility decreases since glyphosate causes necrosis and apoptosis in testicular cells. In addition, they identified that glyphosate stimulates cells of breast cancer, among other physiologic effects.

One of the main limiting factors for the development of scientific research is having access to funding sources. The origin of public or private funds can represent the demands of society or the pressures from the organisms that fund it (Núnez *et al*., 2009). Within this background it is more likely that research funded by the industry generates positive results on their activities (Aveyard *et* al., 2016). The historical debate related to the controversy in the relationship between the results from research financed by the tobacco industry constitutes an outstanding example in this sense, having thus proposed a set of criteria to evaluate the funding models (Cohen *et al*., 2009). The sources of funding referred to environmental issues today constitute an example in which tensions between groups of opposed interests become explicit.

The analysis of the role of funding in the results of scientific research highlights the questioning raised by Sarewitz (1996) who postulated that scientific information provides an objective basis to solve political disputes. This frame is based on the epistemologic concept of modernity according to which, *nature* is unique and cognoscible whereas politics is inscribed in relativism due to its feature as a social constructor, being both strongly linked because of its different *nature* (Arellano Hernández, 2011).

This link calls on the effects of agrochemicals in human health and the environment that are the basis for the model of agricultural intensification. The beginnings of this interpellation was formalized with the publication in 1962 of the book 'The Silent Spring' (Carson, 1962) that alerted society about the detrimental effects on animals, plants and human beings when agrochemicals are constantly used. The latter publication mobilized the civil society, the government of the USA and the scientific community in an intense debate. In fact, the president J.F. Kennedy expressed that the governmental investigation on DDT use was impelled "particularly after the publication of Carson book" (Friedman, 2008). After a lively debate in relation to the effects of these products in 1972, the Environmental Agency of Protection of the United States (EPA) prohibited almost the totality of the uses of DDT. Debates in relation to DDT have continued to this day since its importance in the control of diseases like malaria. Later, a process of similar characteristics appeared with transgenic crops; corporations appealed to important campaigns of biotechnology performing political management to convince public and authorities, disclosing deceptive information, that there was irrefutable data, on which this new food was safe, on the base of scientific works that, in several aspects, have not even maintained a veracity standard (Druker, 2015).

Nowadays, a similar debate has settled in relation to the use of glyphosate-based herbicides. In the 80s the EPA catalogued it as potentially carcinogenic in humans; but the same organism modified its declaration at the beginning of the 90s, concluding that it did not show any carcinogenic effect. In 2015 the International Agency for Research on Cancer, which belongs to the Worldwide Organization of Health, classified glyphosate among probable human carcinogenic substances. Just a year later the latter organism jointly with

[1] More details please refereed to "Trends in glyphosate herbicide use in the United States and globally" (Benbrook, 2016).

the FAO of the United Nations, reviewed the scientific information available and concluded that it is unlikely that glyphosate has carcinogenic effects in humans. A scene of conflict arose around glyphosate, which articulates on one hand, economic interests linked to the technological development and the farming production, and on the other, social movements that question the consolidation of an agricultural intensification model based on using this agrochemical. Within this context of antagonistic ideological positions, the scientific knowledge has acquired relevance, and some questions have become especially important: what scientific knowledge is being generated on this subject? and who generates it?

Our work contributes to the debate in the use of Glyphosate by the means of characterizing the academic production on the subject in the literature comprised in the Web of Science (WOS). In particular, the production of scientific knowledge linked to 6 agro-industrial multinationals was characterized: BASF, Bayer, Dow Agroscience, Dupont, Monsanto and Syngenta. These multinationals were selected as they are the main worldwide producers of Glyphosate; BASF (Germany), Bayer Crop Science (Germany), Monsanto Company (USA), Nufarm Ltd. (Australia), Syngenta AG (Switzerland), Dow AgroSciences LLC (USA), DuPont (USA), Sino Harvest (China), Zhejiang Xinan Industrial Chemical Group Company, Ltd. (China), Jiangsu Good Harvest-Weien Agrochemical Co. Ltd. (China) and Nantong Jiangshan Agrochemical & Chemicals Co. Ltd. (China) (Markets and Markets, 2015). In the current work, we intended to contribute at investigating the possible existence of external influences which frame the knowledge generation in the present context of glyphosate debate.

A first work in relation to the analysis of scientific publications of glyphosate in the WOS database was made in 2016 (Fontans *et al*., 2017), with the achievement of a descriptive scheme of the situation. The scientific literature linked to glyphosate has displayed a sustained growth since its initial commercialization in 1974 (Fontans *et al*., 2017). However, although the number of publications continues to grow, this growth gradually begins to slow down. The role of Latin America in the generation of knowledge on this issue is considered as far as from 2000, being Brazil and Argentina the countries with a greater number of publications. This fact agrees with the beginning and consolidation of the agribusiness model linked to the production of soybean in the region of South America (Pengue, 2015).

Fontans *et al*. (2017) also highlighted that between 1974 and 1999, publications related to glyphosate, mainly referred to plant sciences and agronomy, had research questions aimed at the importance of its application from a technical management of crops point of view; but in the 2000s, topics on toxicology and environmental impacts were also included. Nevertheless, these aspects, and other associated ones, are not among the main research subjects in spite of the current existing international debate on this issue and the relevance of its impacts on the population and environment within a context of an increasing use of this product (Fontans *et al*., 2017).

Nowadays, the use of glyphosate is part of the so-called agricultural intensification, which argues that the impacts of intensive development will be minimized with technological development and greater environmental control (Perfecto and Vandermeer, 2012). This logic is adjusted to the strategies of transference and technological adaptation from industrialized countries to non-industrialized countries (Tilman *et al*., 2011).

MATERIAL AND METHODS

The source used, the Web of Science (WOS), is one of the most important online databases of bibliographic, scientific and multidisciplinary information. Specifically, the Core Collection database was used, which gathers a collection of 18,000 journal headlines in eight databases: Science Citation Index Expanded (SCI-EXPANDED), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), Conference Proceedings Citation Index-Science (CPCI-S), Conference Proceedings Citation Index—Social Science & Humanities (CPCI-SSH), Emerging Sources Citation Index (ESCI), Current Chemical Reactions Expended (CCR-EXPANDED) and Index Chemicus (IC) (Mangan, 2017). The search strategy consisted in retrieving all entries with the word "glyphosate" included in a headline, summary or keywords. We obtained 8366 entries that were downloaded to an Excel file (Microsoft Office 2016). All files that were not scientific articles were deleted (e.g., letters, editorial notes...), ending up with a documentary corpus of 8174 total entries covering the period from 1974 to 2016.

In order to identify the most influential articles we divided the analyzed period 1974 to 2016 into four intermediate periods 1974-1990; 1991-2000; 2001-2010, 2011-2016. We identified the ten most cited articles in each period. These articles (40) were analyzed in order to identify its main research topic.

To characterize the production of scientific knowledge linked to agroindustrial multinationals the data from the authorship field (AU in WOS) was extracted and it was standardized using *Open Refine* (Verborgh and Wilde, 2013) with the aid of the data contained in the field of author's complete name (AF in WOS). The corpus had 17,896 authors and after normalization (for example, name variations, typing errors for the same author) 17,523 authors were identified. For the production indicator (quantity of articles by author) the whole count method was used, that is to say, an article was entered to each investigator who appeared signing a document.

For the analysis of the institutional connection, the data from the field of institutional affiliation (C1 in WOS) was extracted. The documentary corpus had 837 documents with this field empty (that were discarded for this analysis); 10,887 institutions without normalizing were identified. After normalization (for example, different acronyms or abbreviations, name variations, typing errors for the same organization) 2,830 institutions without variation in frequency were obtained. The high variation in the number of institutions is due to the fact that the level considered was the most generic for the institution, therefore, in universities the level of faculties or departments was not achieved. For the six multinational agrochemical companies (Basf, Bayer, Dow Agroscience, Dupont, Monsanto and Syngenta) which were of interest in this work, all the names were normalized in their local branches under its generic name. Sometimes, when it was possible to be identified, a company that belongs to one of the above mentioned firms was assigned under the name of "parent company".

A social network is a graphical representation (a graph) composed by at least two components: the nodes or actors and their relationships or links among them (edges) (Börner *et al*., 2007). Nodes can represent individuals or people, groups, countries, companies, events, keywords, etc., while edges represent links that exist among the nodes according to the researcher approach (Carrington *et al*., 2005; Molina, 2001; Wasserman and Faust, 1994). For this work, the link was established when two authors sign a joint work altogether, then, there is a link in terms of co-authorship or collaboration, therefore this type of network is known as collaboration network (Newman, 2001a, b, c).

To identify the production link with the multinationals we used egocentric networks (Figure 1). An egocentric network is a kind of social network that can be represented as a graph that starts from a node (the ego) and then its relations are established with a geodesic distance of one, that is, with its immediate neighbors. The set of nodes and established relationships between the ego and its immediate neighbors form the 1st Order Zone. If a geodesic distance of 2 is considered (the neighbor's neighbors of the ego), a 2nd Order Zone is established, and so on (Ovalle-Perandones *et al*., 2010) (Figure 1).

In this work, the egocentric network was developed using three steps:

1. Identifying articles in which at least one of the investigators had a connection with one of these multinational companies.
2. Identifying all authors who collaborated on that article.
3. Establishing the 1st Order Zone as the group of identified authors.

Considering the above, there is no distinction between the investigator directly linked to the multinational and the investigators who collaborate with him, as all belong to the 1st Order Zone. Once an author is identified in this zone, the count of all of his work is considered as linked with the multinational. Consequently, when interpreting the data presented in this work, an author who is identified in the 1st Order Zone must be interpreted as:

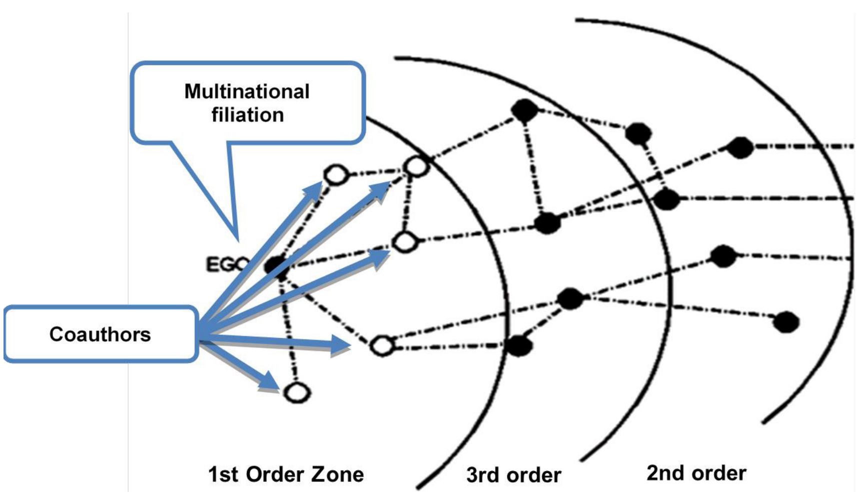

Figure 1. Egocentric networks, strategy to identify the production linked to multinationals. (Source WOS, own elaboration).

Figura 1. Redes egocéntricas, estrategia para identificar la producción vinculada a las multinacionales. (Fuente WOS, elaboración propia).

1. At least once this author wrote an article in connection with one of the multinationals included in this work or,
2. At least once the author wrote an article linked to a multinational at a proximity level equal to 1. In other words, the author signed a work together with somebody linked to a multinational.

On the other hand, if an author is not in the 1st Order Zone must be interpreted as:

1. Not having written an article linked to one of the multinationals included in this work or,
2. He was never co-author of an "ego". If he did it, it was done at two or more proximity levels.

In order to simplify the records, the 1st Order Zone is defined as Zone 1, and the rest of the zones as Zone 2.

The egocentric network was performed using the software Gephi (Bastian *et al*., 2009); the distribution algorithm of Fruchterman - Reingold (Fruchterman and Reingold, 1991) and Force Atlas 2 were used to its visualization (Jacomy *et al*., 2014). A network can be divided into communities, groups within which the network connections are dense, but between which they are sparser (Newman and Grivan, 2004). In this work we used the Gephi's algorithm to detect communities in the egocentric network (Blondel *et al*., 2008; Lambiotte *et al*., 2008).

A component is the maximum sub connected graph, that is, that for each pair of nodes that integrates it, there is a path that connects them (Herrero, 2000). The giant component in a network is the biggest component that integrates it. We identified the giant component as the one with the highest number of nodes. By doing this it is possible to detect how cohesive or fragmented the research community is or the studied fields are, and it also indicates the existence of an important nucleus in the research community (Kumar, 2015).

RESULTS AND DISCUSSION

The main results obtained by the analysis of the most influential articles show that in the first period, 1974-1990 articles emphasized some characteristics of glyphosate-based herbicides such as adsorption (Sprankle *et al*., 1975a; Sprankle *et al*., 1975b), mobility and its "fast and natural" degradation in the environment (Rueppel *et al*., 1977). Thus, there is an outstanding positive vision on the herbicide that suggests it is an environmentally safe product. Only one of these works warned about the effects on the population of young fishes in streams contaminated with glyphosate residues (Folmar *et al*., 1979). Between 1990 and 2000, the most important articles were oriented towards the promotion of glyphosate-based herbicides and their use was stimulated. The latter was emphasized for its good results for the control of spontaneous plant species in crops, and also for its good environmental behavior (Padgette *et al*., 1995; Herrmann and Weaver, 1999; Huston and Pignatello, 1999). Was within this period that early works arose which researched the effects of using glyphosate on the human health (Marrs, 1993) and the environment (Giesy *et al*., 2000). At the beginning of the 21st century, the central concern in scientific production was connected with the articulation between glyphosate and genetically modified organisms (Kuiper *et al*., 2001; VanGessel, 2001; Baerson, 2002). Thus, publications were mainly focused on the development via transgenic technology of resistant crops to glyphosate. In the fourth period, 2011-2016, the most important articles have concentrated on the problem of resistance sprouting because of herbicides in some spontaneous species, very oriented towards the handling and management of the herbicide (Mortensen *et al*., 2012; Duke, 2011; Délye *et al*., 2013). In this period problems were also identified and consequently recommendations for the need of sustainable management criteria of herbicides and their toxicological risks.

Out of the 17,523 authors in the documentary corpus, 1,536 (9%) integrate Zone 1, with a production of 2,302 articles (28%). These results point out that 28% of the published articles are linked to some of the 6 agroindustrial multinationals. In addition, the 10 most productive authors are also include in this zone (Table 1), so the most productive authors in this area are linked to these agroindustrial multinationals.

When the most productive authors are considered (authors with 10 or more articles) the resulting graph includes 285 investigators, with 123 in Zone 1 and 162 in Zone 2.

With these data, 47 communities were detected, the majority of which has 5 or less nodes, and 32 connected components (Figure 2). We will center our work in describing the giant component.

The giant component has 227 authors, which represent the 80% of the nodes in the graph. There is an internal parity of the components between the authors that belong to both zones (118 in Zone 1 and 109 in Zone 2). However, there is an important difference in respect to the graph: 96% of researchers in Zone 1 are in the giant component, against 67% in Zone 2 (Figure 3).

As far as the production is concerned, if authors are ordered by their number of articles, without considering the zone which they belong to, there are 46 authors in the giant component with a greater productivity. The author with the best performance outside this component would be in position 27 in the *ranking*.

The distribution of communities in the giant component again shows a preponderance of the authors in Zone 1 (Table 2). The author id (with a greater weighed degree) was assigned to the community (*weighed de-*

	Zones				Zones		
Number articles	1	2	Total	Number articles	1	2	Total
90	1		1	25	4	3	7
79	1		1	24	3	2	5
77	1		1	23	5	2	7
63	1		1	22	1	3	4
61	1		1	21	4	1	5
60	1		1	20	8	2	10
59	1		1	19	1	2	3
58	1		1	18	5	2	7
53	2		2	17	3	4	7
49		1	1	16	5	10	15
48	1		1	15	5	6	11
42	1		1	14	4	17	21
41		1	1	13	11	11	22
40	1		1	12	11	20	31
38	1		1	11	9	26	35
37	2		2	10	10	39	49
36		1	1	9	14	31	45
34	2		2	8	23	60	83
33	2	4	6	7	22	119	141
32		1	1	6	28	148	176
31	2	1	3	5	57	228	285
30	2		2	4	91	459	550
29	1	2	3	3	114	843	957
28	3		3	2	263	2397	2660
27	1	1	2	1	801	11540	12341
26	5		5	**Total**	**1536**	**15987**	**17523**

Table 1. Distribution of authors and productivity by zones. (Source WOS, own elaboration).

Tabla 1. Distribución de autores y productividad por zonas. (Fuente WOS, elaboración propia).

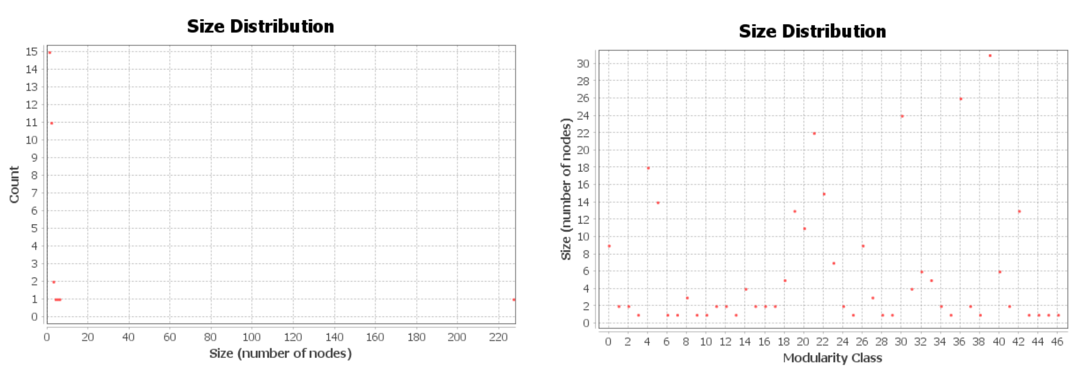

Figure 2. General characteristics of the graph. Left: size distribution of connected components. Right: size distribution of communities. (Source WOS, own elaboration).

Figura 2. Características generales del gráfico. Izquierda: distribución de tamaño de los componentes conectados. Derecha: distribución de tamaño de las comunidades. (Fuente WOS, elaboración propia).

gree), and they were ordered by this criteria. Of the 16 communities, only 6 are led by a Zone 2 author; and, as it is shown in Table 3, the 6 most important communities are in Zone 1.

Summing up, there are a relevant number of authors whose filiation belongs to multinationals companies.

Authors' filiation is generally related to financing source. Funding is likely to condition research issues and questions (Núnez *et al*., 2009) and thus it could bias scientific results (Michaels, 2008). In this frame it is important to point out that knowledge generation on glyphosate could be biased in the service of herbicide producing companies, presenting results on the effectiveness in weed control, as the benefits of the product were always independently of the environmental impacts and effects on human health.

Considering that glyphosate was used for the first time in 1974, the results obtained in this work allow

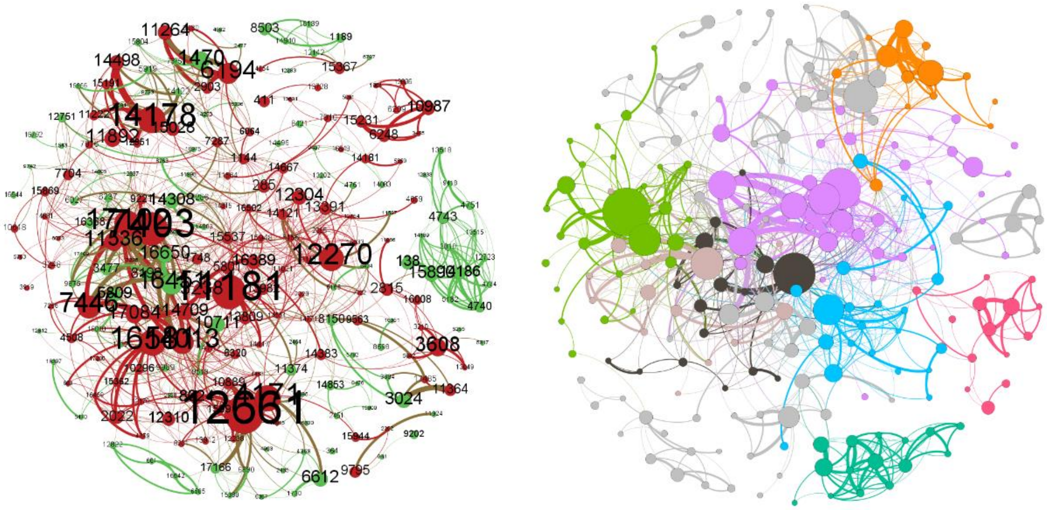

Figure 3. Giant component of the graph generated by the authors with more than 10 articles. The size of the nodes is proportional to the number of articles, the edges representing collaboration. Left: red for Zone 1, green for Zone 2; right: colors identify 16 communities. (Source WOS, own elaboration).

Figura 3. Componente gigante del gráfico generado por los autores con más de 10 artículos. El tamaño de los nodos es proporcional al número de artículos y los bordes representan la colaboración. Izquierda: rojo para la Zona 1, verde para la Zona 2; derecha: los colores identifican 16 comunidades. (Fuente WOS, elaboración propia).

Community	**weighted degree**	**Zone 1**		**Zone 2**		**Total**	
		#	**%**	**#**	**%**	**Nodes**	**%**
12661	147	11	42%	15	58%	26	11%
7403	144	17	55%	14	45%	31	14%
14178	142	6	55%	5	45%	11	5%
16581	142	17	71%	7	29%	24	11%
6194	107	6	46%	7	54%	13	6%
11181	104	9	50%	9	50%	18	8%
14186	88		0%	15	100%	15	7%
10987	63	14	100%		0%	14	6%
12770	63	17	77%	5	23%	22	10%
3024	53	2	40%	3	60%	5	2%
3608	49	7	78%	2	22%	9	4%
14121	36	4	31%	9	69%	13	6%
14308	30	3	43%	4	57%	7	3%
8503	28	2	22%	7	78%	9	4%
12822	24		0%	4	100%	4	2%
9795	15	3	50%	3	50%	6	3%
		118		**109**		**227**	

Table 2. Distribution of communities in the giant component. Red for Zone 1 authors, green for those in Zone 2. (Source WOS, own elaboration).

Tabla 2. Distribución de comunidades en el componente gigante. Rojo para los autores de la Zona 1, verde para los de la Zona 2. (Fuente WOS, elaboración propia).

to partially explain the low occurrence of studies on environmental and health impacts in the period 1970-2011 claiming its "fast and natural" degradation. It is also striking that between the 1980s and 1990s, but particularly between 2000 (expansion of its use associated to the soy-ization in the southern cone) and 2016, there is "a contradictory" scientific production in respect to the effects on the environment, but mainly in human health (cancer), while nowadays its use keep rising.

CONCLUSIONS

In this work, the production of scientific knowledge on glyphosate was characterized on the basis of published articles in the Web of Science (WOS) during the last four decades, pointing out the links to 6 agroindustrial multinational companies: Basf, Bayer, Dow Agroscience, Dupont, Monsanto and Syngenta.

The methodological strategy was suitable and allowed to identify those communities/groups of investigators and investigation leaders who produce bibliography on glyphosate and are linked to multinational companies that produce the herbicide. From the analysis of the collected data, five main conclusions can be stated.

1. In the period 1974-2016, 28% of published articles were linked to some of the 6 agroindustrial multinationals.
2. It was possible to determine that the most productive authors in this area are linked to these agroindustrial multinationals.
3. The 96% of the most productive authors that belongs to zone 1 are part of the research front (giant component).
4. It is to emphasize that communities identified in the giant component are led, in its majority (10 out of 16 communities), by authors linked to agroindustrial multinationals.
5. The obtained results would indicate a relevant involvement of agroindustrial multinationals in the processes of knowledge generation on glyphosate, which is published in a scientific article format.

The involvement between investigators and the multinational companies questions the contribution that this knowledge can make to society in the debate about the use of glyphosate, warning on a pretended neutrality, even relativizing it, that questions the scientific objectivity to solve political disputes promoting a potential biased role of science as a legitimator to its funding sources.

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