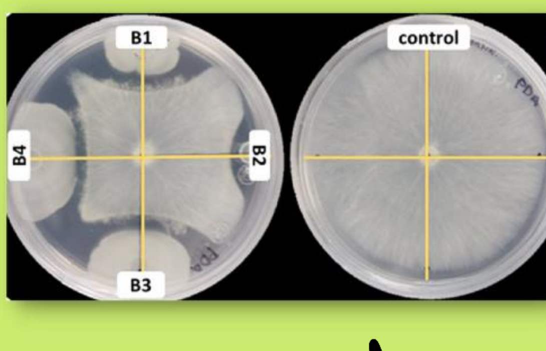
Investigaciones Biológicas, Agrícolas y Ambientales de México

Leandris Argentel Martínez
Ofelda Peñuelas Rubio
Organizadores



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Prólogo

Investigaciones Biológicas, Agrícolas y Ambientales de México es un libro electrónico científico, basado en estudios experimentales desarrollados por un colectivo de prestigiosos investigadores de México y de otros países que, en colaboración, aportan respuestas a problemáticas existentes en dichas ramas del saber. Estos trabajos aparecen divididos en capítulos donde se ofrece información actualizada sobre los avances más recientes en dichas áreas, con un estilo de artículo científico y con referencias bibliográficas de gran nivel de actualización científica.

El proceso de revisión de los capítulos fue desarrollado, bajo la modalidad a doble ciegas, por varios investigadores que participan en el comité editorial de PANTANAL EDITORA. Se agradece a los autores de los respectivos capítulos por la dedicación al atender las sugerencias y comentarios realizados por los revisores, optimizando el tiempo de los procesos de revisión y aceptación.

Los autores

Sumário

Capítulo 8

Use of nitrogen fertilizers in the Yaqui Valley: a compilation of three decades of knowledge

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ABSTRACT

The Yaqui Valley is known for its intense agricultural activity since the Green Revolution. In this region, several scientific studies regarding the use of agrochemicals have been performed, particularly regarding nitrogen fertilizers. In this study, we compiled published research papers about the use of nitrogen fertilizers in the Yaqui Valley. As a result of the search, 97 publications published in 36 databases were found; these were mainly scientific articles (80%). Most of the studies fall within the subject of conservation agriculture (32.4%), followed by conventional agriculture (27%), leaching (22.5%), and emissions of nitrogen compounds (18%). Approximately 50% of the studies focused on soil and 36% on urea, which is a nitrogen compound of widespread use. Most of the studies to date have focused on wheat (87.5%). The worldwide challenge of food security urges more research about the nitrogen cycle in general and how sustainable agricultural practices in particular may decrease the negative effects of nitrogen fertilizers on agroecosystems.

INTRODUCTION

In Mexico, agriculture is a primary activity with an important cultural legacy and great economic value. Annually, approximately 20 million hectares are cultivated, with a production of approximately 260 million tons.(SIAP, 2019). Despite the arid and semiarid climate in northwestern Mexico, in the state of Sonora, the past five years, an area of 622,475 hectares was cultivated, and in 2019, an agricultural productivity of 8,457,748 Mg was generated where the municipalities of Cajeme, Hermosillo, Etchojoa, Navojoa, and Huatabampo reported the higher productivity of wheat (1,449,714 t), watermelon (627,268 t), potato (417,850 tons), grapes (338,267 t), and asparagus (174,811 t), respectively.

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The present study focuses on the Yaqui Valley, since it represents one of the most productive areas in Sonora and particularly in the municipality of Cajeme, which has a crop area of 219,813 hectares, and its main production is cereals, vegetables, and oilseeds.(SIAP, 2019).

Analyzing the socioeconomic context and agricultural management in the Yaqui Valley relies on the fact that high yields depend on the application of synthetic nitrogen fertilizers, whose use intensified by 25% (263 kg ha^{-1}) from 1980 to 2000.(Matson, 2012). The use of agrochemicals and the semiarid climate of the Yaqui Valley have negatively affected the chemistry of the soil, which has a low content of organic matter (<1%) and an alkaline pH (pH 8.1).(Ibarra-Villarreal et al., 2020). Additionally, in the Yaqui Valley, the predominant soils are vertisol or aridisol, characterized by a reduced amount of organic matter and a soil texture composed mostly of mixed montmorillonite clays, silty clays and clay loams.(Ahrens et al., 2008; Matson, 2012).

Table 1. Impacts of nitrogen fertilizers reported by various authors on agroecosystems.(Grageda-Cabrera et al., 2000; Altieri, 2009; Armenta-Bojórquez et al., 2012; Parra-Cota et al., 2018; Ibarra-Villarreal et al., 2020).

Biocenosis	Soil	Atmosphere
Crop loss and loss of biodiversity and genetic resources	Soil erosion	N_2O emissions
	Fertility loss	Global warming
Plagues	Salinization and alkalinization	Ozone layer depletion
	Nutrient leaching	
Loss of natural control mechanisms	Microbiota changes and losses	
	Organic matter loss	

The impact of the use of nitrogenous fertilizers has been observed in the soil and air systems, which are essential components of agroecosystems (Table 1). Nitrogen is a basic element present in the molecules responsible for the growth and development of the plant; it is also a vital nutrient for photosynthesis, carbon fixation, and the accumulation of organic matter and promotes the increase in agricultural yield.(Ballesteros et al., 2015). The most commonly used technique to apply nitrogen is direct sowing, which requires extreme care when defining the appropriate dose of fertilizer for the plant to take advantage of this nutrient efficiently (Ballesteros et al., 2015; Hamilton & Casey, 2016) and to reduce chemical losses. Although there have been notable increases in agricultural productivity generated by the use of nitrogenous fertilizers, the applied fertilizer is not 100% used. Approximately 50% of these nitrogenous compounds end up in the harvested crops, while the rest accumulates in the soil or is lost in the agroecosystem.(Andraski et al., 2000; Smil, 1999).

Nitrogen is lost or transported in various ways through harvesting, leaching into soil horizons and underground aquifers, surface runoff, erosion, and gaseous emissions, and these losses have significant and undesirable consequences for the atmosphere, water systems, oceans, and human health (Table 1).(Carpenter et al., 1998; Matson et al., 1998; Townsend et al., 2003; Galloway et al., 2003; Beman et al., 2005).

The Green Revolution was inspired in the Yaqui Valley by the work of Norman E. Borlaug and his colleagues in the mid-20th century.(Matson, 2012). To secure food production, the main objective was to increase productivity per planted area, and some of the strategies included the use of improved crops, application of chemical products, and water management through irrigation.(Ahrens et al., 2008; Duchemin et al., 2015). The result of such measures was a planned region in the coastal plain of southern Sonora, between the sea and the mountains, with approximately 225,000 hectares and irrigation canals laid out in a grid (Figure 1).(Parra-Cota et al., 2018). After decades of research in this region, there is no study that compiles the information generated to date on the state of knowledge of the use of nitrogenous fertilizers in the different reservoirs of the Yaqui Valley agroecosystem.

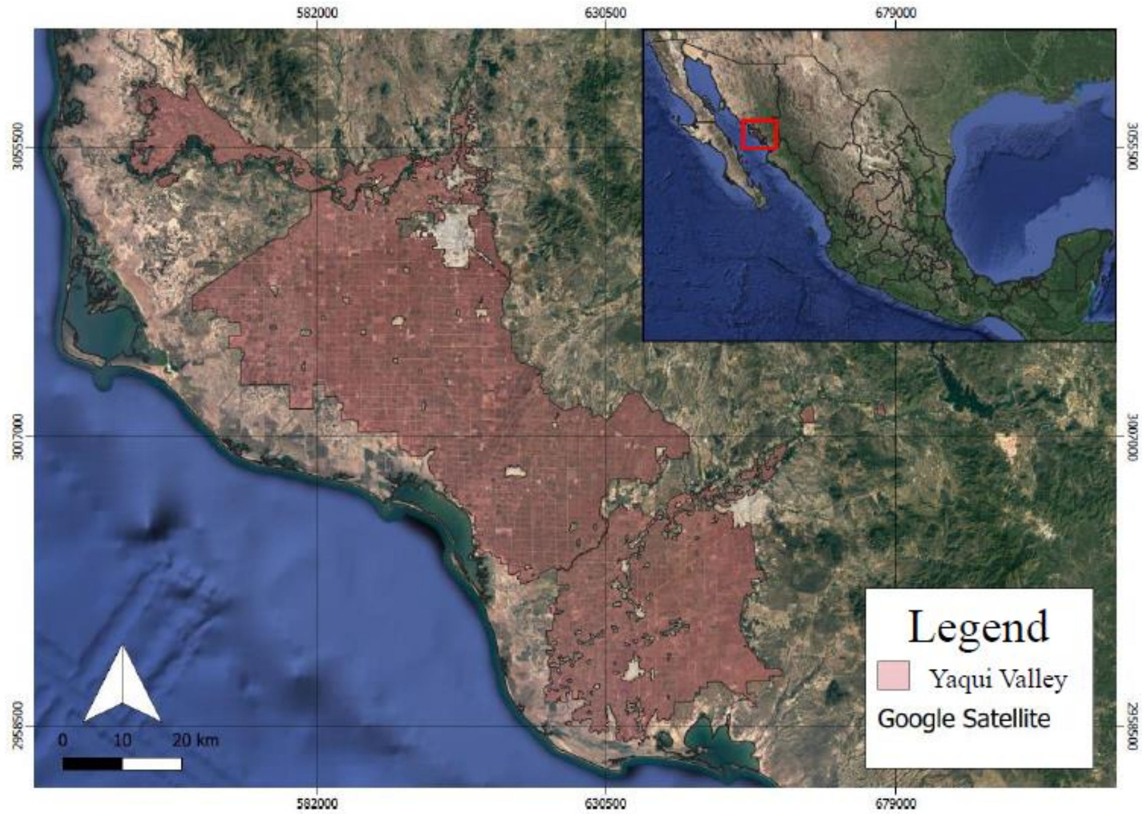

Figure 1. The Yaqui Valley is located in the State of Sonora in the semiarid zone of Northwest Mexico. Geographic coordinates UTM 12N WGS 84.

The general objective of this study was to compile information from the investigations carried out on the use of nitrogenous compounds in the Yaqui Valley in the last 30 years, which were organized in a database and analyzed considering criteria such as year of publication, type of fertilizer, biogeochemical reservoir of impact, and type of agriculture used.

MATERIAL AND METHODS

Compilation of scientific information

The literary research to develop this work consisted of a systematic search of different scientific materials published in databases and repositories of Springer (https://www.springer.com/la), Science Direct (https://www.sciencedirect. com/), SciElO (https://scielo.org/), Redalyc (https://www.redalyc.org/), Repository of the International Maize and Wheat Improvement Center (CIMMYT) (https://www. cimmyt.org/) and library of the Technological Institute of Sonora (ITSON) (http://sib2.itson.mx/cgi-bin/koha/opac-main.pl). The Google Scholar search engine was also used. The search for publications was carried out using the keywords Valle del Yaqui and nitrogen, alternating the words soil, water and atmosphere, and type of agriculture. The search yielded a total of 97 publications, where scientific articles, theses, reports, summaries, reports and book chapters in Spanish and English were found. The information of each publication was captured (Microsoft Excel ®), including the source database, document title, type of document, year of publication, subject, reservoir studied (e.g., soil, water, atmosphere), compound nitrogen studied, type of crop, and type of agriculture. The database is published in Zenodo https://zenodo.org/record/4474323#. YBya6uj0nIU

Categorization criteria

The categories defined below were used for the analysis, and they were stated in consensus based on previous literature.(Claus-Peter, 2010; FAO, 2017; Garzón & Cárdenas, 2013; Matson, 2012; Schlesinger & Bernhardt, 2013; Tarbuck & Lutgens, 2005; Vasquez & Vignolles, 2015).

Reservoir

- Atmosphere: The gaseous layer that surrounds the planet; in this work, it is the closest portion of the troposphere, that is, the planetary boundary layer, where the hydrological cycle and transport of gases such as N_2O take place.
- Water: In agriculture, part of the hydrosphere that is used in irrigation moves through evapotranspiration, runoff, leaching and infiltration.
- Plant: Autotrophic organisms that perform photosynthesis represent the biosphere reservoir.

- Soil: Matrix composed of organic and mineral matter, and in its pores water and air; Multiple biogeochemical processes are carried out in it, it is susceptible to weathering and wind and water erosion.

Nitrogenous compound

- Anhydrous ammonia: Fertilizer with a high nitrogen content (82%) and commonly used.
- Ammonium: Inorganic nitrogen compound.
- Poultry Manure: Poultry excreta used as fertilizer.
- Gas (NH_3): Ammonia is used in the manufacture of fertilizers, is composed of hydrogen and nitrogen and is very soluble in water.
- N_2O: Nitrous oxide is the third most important greenhouse gas (after carbon dioxide and methane). In agriculture, it is the result of microbiological activity in the soil.
- Nitrogen (N): N is an essential element for life; in combination with sugars, N promotes the vegetative growth of plants.
- NO: Mixture of nitrogen and oxygen. May evaporate from water or form nitric acid.
- NO_2: Nitrogen dioxide is a reddish-brown gas denser than air with a pungent odor. It is taken as a reference to measure the levels of contamination in the air.
- NO_3: Nitrate is easily transported in water, so it is mobile in agricultural fields.
- Organonitrogenated: They are amines, amides, nitriles, and nitro compounds.
- Ammonium sulfate: Ammonium sulfate is a readily available soluble source of nitrogen and sulfur (S). Ammonium sulfate is an acidifying fertilizer, so its use is recommended in alkaline soils.
- Urea: Urea is a plant metabolite; in agriculture, urea is intensively used as a nitrogenous fertilizer.

Context scheme

- Conventional agriculture: it is a production system dependent on external inputs such as fossil fuels and chemicals, the technology can vary, and the general idea is to maximize production.
- Conservation agriculture is a farming system that encourages the maintenance of permanent soil cover and the diversification of crops.
- Emission of nitrogenous compounds: Transport of nitrogenous compounds from the agrosystem to the atmosphere.
- Leaching: Transport of water and solutes to deep layers in the soil.

Analysis of data

Qualitative statistics were performed using Microsoft Excel® and R-Studio.

RESULTS AND DISCUSSION

Trends in nitrogen studies

Of the 97 investigations analyzed, 16% were found in the Springer database, 13% in Science Direct, 8% in the Wiley Online Library, and 6% in the Stanford University Repository database and ResearchGate (Figure 2). On the other hand, less than 5% were found in the Repository of the International Maize and Wheat Improvement Center (CIMMYT), SciELO, Agris FAO, American Geophysical Union (AGU), International Atomic Energy Agency (IAEA), Astrophisics Data System, Library of the Technological Institute of Sonora (ITSON), Multidisciplinary Digital Publishing Institute (MDPI), and Repository of the University of Sonora (UNISON) (Figure 2).

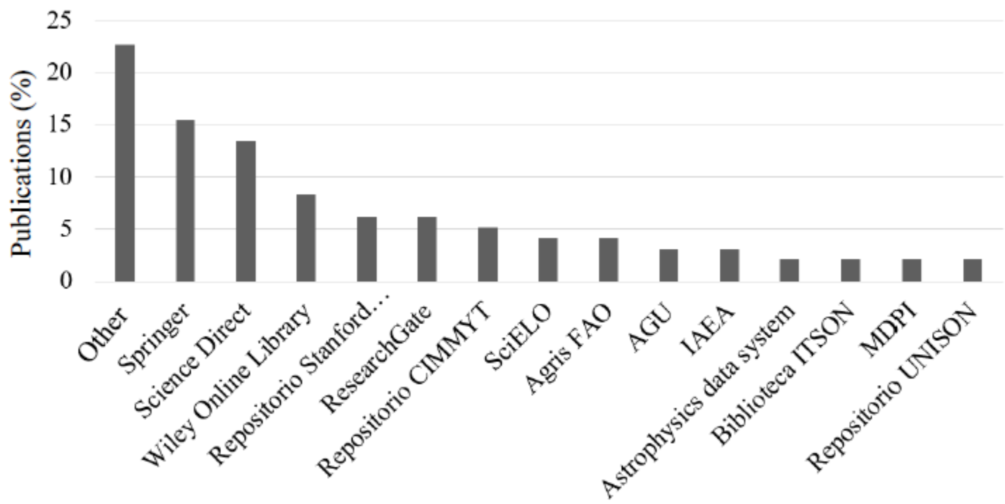

Figure 2. Percentage of publications found in each database on the use of nitrogen fertilizers. The category Others represents 22 databases.

In others (23%), we categorized databases with less than 5% and included AgEcon Search, Biblioteca Unikassel, CiteSeer, Digital University of Nebraska, Ecological Society of America (ESA), Elsevier, Instituto Mexicano de Tecnología del Agua (IMTA), India Environment Portal, JSTOR, National Center for Biotechnology Information (NCBI), PeerJ, Proceedings of the National Academy of Sciences (PNAS), Redalyc, CIBNOR Repository, CINVESTAV Repository, COLPOS Repository, Iowa State University Repository, Oxford University Repository, Weninger Repository University, Whitman College Repository, ScienceMag, Taylor & Francis Online (Figure 2).

Nearly ~30% of all publications were found in Springer and Science Direct, which are world-class databases. This makes sense since a significant number of researchers from the International Maize and

Wheat Improvement Center (CIMMYT) collaborate with various institutions around the world; it should be noted that it is one of the 15 scientific research centers in the agricultural sector. In addition, Figure 2 shows publications found in the database of the Stanford University Repository. This result is due to the scientific contribution of the researcher Pamela Matson and her interest in the Yaqui Valley.

The publications were divided according to the type of document and topic (Figure 3.a). Eighty percent of the publications related to the use of nitrogen in this agricultural area are scientific articles. The large number of articles can be explained by the institutions that motivate this work.(Burbules, 2020).

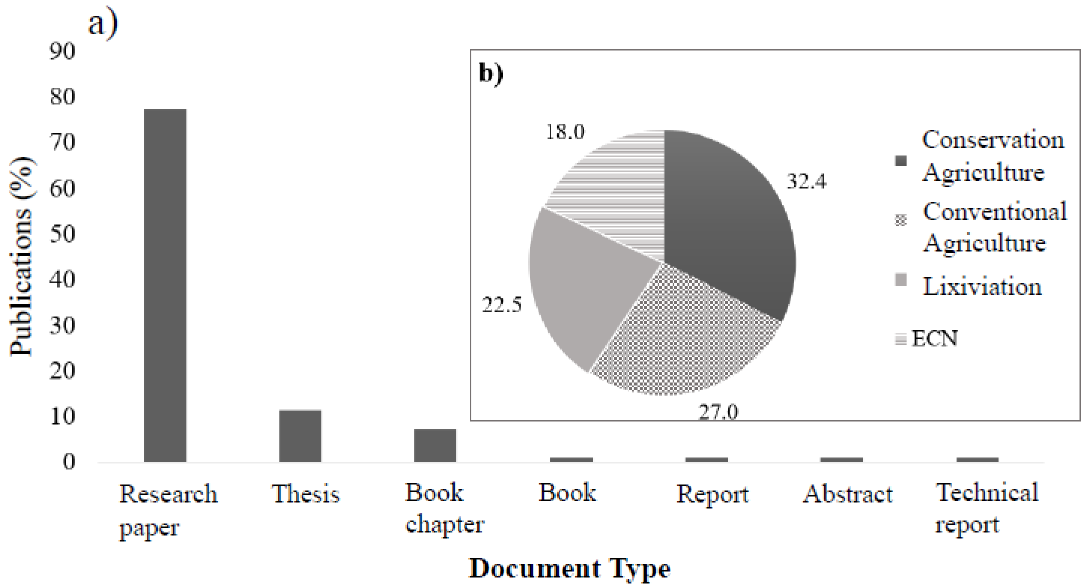

Figure 3. a) Percentage of the document type on the use of nitrogen fertilizers in the Yaqui Valley. b) Percentage of the topics of the publications found on the use of nitrogen fertilizers in the Yaqui Valley. ECN refers to emissions of nitrogen compounds.

Regarding the four topic categories (Figure 3.b), 32.4% of the publications focused on conservation agriculture, 27% on conventional agriculture, 22.5% studied the losses of nitrogenous fertilizers due to leaching toward agricultural drains and irrigation canals and 18% studied the losses of nitrogenous compounds due to emissions into the atmosphere (NCE), such as nitric oxide (NO) and nitrous oxide (N_2O).

The excess of nitrates acidifies the soil, and its leaching can reach the water table, (Jandl et al., 2004), a topic that has generated interest. On the other hand, the transformations and transfers of nitrogen from the continent to the sea in the agricultural region of the Yaqui Valley in northwestern Mexico highlight that approximately 50% of the applied N is lost.(Riley et al., 2001). For approximately 15 years, various scientists, including Pamela Matson and Toby D. Ahrens, have conducted research focused on the study of the use of nitrogenous fertilizers in the Yaqui Valley. These investigations aim to achieve the transition toward the sustainability of water and nutrient resources in the agricultural region of the Yaqui Valley.(Beman et al., 2005; McCullough & Matson, 2016).

In this investigation, the oldest document found was from 1990. The general trend from that period was an increase in publications, with a maximum of 16 publications per period (3 years). The oldest document found in this research addresses the topic of agronomic research and the growth of agricultural productivity after the Green Revolution.(Traxler, 1990). Between 1950 and 1990, there was an increase in the industrial fixation of N due to the demand for the use of nitrogenous fertilizers, which caused an alteration to the nitrogen cycle at a global level. In addition, in this same decade, awareness began to be raised about the effects of the losses of these fertilizers and their impacts on ecosystems.(McCullough & Matson, 2016). At the beginning of the 1990s, industrialized countries began to develop environmental strategies and policies to maintain the control of greenhouse gas emissions such as SO_2 and NOx.(Rodríguez & Sánchez, 2010). In turn, this gave way to ratifying the Protocol that is part of the aforementioned agreement; the Montreal Protocol aims to protect the ozone layer by reducing the generation and consumption of substances that react with ozone, and it is proven that they are responsible for its depletion.(DOF, 1987, 2018).

For the above reasons, the behavior of research on nitrogen deposition has continued to rise. There is a growing need to know the effects and movement of these compounds in the environment, which has led to research on crop yields with the efficient use of nitrogen, as well as the loss and transport from agricultural fields to other areas.

Agrosystem reservoir and compounds

This classification shows the reservoirs that were studied according to the bibliographic review of 97 documents. On some occasions, a product was studied in more than one reservoir; therefore, for the purposes of this study, the reservoir was considered an independent variable of the total number of publications found and was classified individually by the type of impacted reservoir.

The most studied reservoir in relation to nitrogen in the Yaqui Valley was the soil (50.8%). In this case, edaphic studies of different kinds were carried out to define the impacts of agricultural practices on nitrogen in the soil. In second place, water has been studied more frequently (18.8%), followed by the atmosphere (15.5%) and finally plants referring to crops (14.7%).

The soil, which is the most studied reservoir in this area, has been mostly studied since it is the support of the vegetation and the place where processes of transformation and nutrient cycling were developed. In the Yaqui Valley, extensive planting of monocultures is widely used, so farmers and researchers are interested in its long-term sustainability. This includes social and ecological well-being, capacities for adaptation and mitigation to climate change, food security, and ecosystem services such as biological diversity, nutrient cycling, and the hydrological cycle.(Nelson et al., 2013). On the other hand, in agriculture, mechanical tillage and the use of agrochemicals are the cause of soil degradation. Soil degradation results in the decline of physical, chemical and biological properties, (Karlen & Rice, 2015), leading to an increase in bulk density (porous spaces), less stability of aggregates, susceptibility to compaction, loss of fertility, nutrient leaching, decreased productivity and microbial activity, and increased greenhouse gas emissions such as CO_2 and N_2O.(Soane & van Ouwerkerk, 1995; Shah et al., 2017; De Los Santos et al., 2018). All this makes it of great importance to study this reservoir in the Yaqui Valley to seek its conservation and maintain food production.

In terms of water, this was the second most studied reservoir, in part because of the hydrological basin (Yaqui River) and because of the contribution of the dams to these nonrainfed fields. These water bodies can be seriously impacted by agricultural practices and the intensive use of fertilizers. It is important to mention that almost 66% of the N applied in fertilizers is lost from the Yaqui Valley, of which approximately 20–40% is lost to surface waters.(Harrison & Matson, 2003; Riley et al., 2001). Following each irrigation event, runoff flows through a network of artificial drainage channels to coastal waters. The drainage rate of the Yaqui Valley is influenced by management practices. Data such as electrical conductivity and temperature increase, and the increase in water salinity is associated with soil fertilization processes, (Beman et al., 2005), which suggests that being able to monitor water to know its quality is a fundamental piece to avoid its deterioration.

In the air, due to the agronomic management of this activity, gases such as nitrous oxide (N_2O) can be released, which comes from the volatilization of the applied fertilizer and acts as a powerful greenhouse gas (GHG) that contributes to atmospheric warming and stratospheric ozone depletion. Agriculture contributes approximately 60% of global anthropogenic N_2O emissions, mainly due to the application of nitrogenous (N) fertilizers to cropland. The second largest source of GHG emissions is N_2O from cultivated soils. Hence, it is important to study them in such an important agro-system for Mexico.(Millar et al., 2018). Additionally, in the atmosphere, due to connectivity and atmospheric circulation, these nitrogenous compounds are transported away from agricultural areas, impacting natural systems through acid deposition.(Granados Sánchez et al., 2010).

In Figure 4.a, the types of fertilizers, such as urea, anhydrous ammonia, N2O, ammonium sulfate, ammonium, NO3, NO, chicken manure, gas (NH3), NO2 and organonitrogenated fertilizers, were considered. In addition, the articles did not mention a specific type of nitrogenous fertilizer but units of "Nitrogen".

One of the main and most polluting activities in agricultural management is fertilization. The most applied fertilizer is nitrogen. It has been determined that in cereals, a lack of nitrogen (N) availability can produce a decrease in the efficiency of the leaf area index, which harms the dry weight of the spikes, therefore affecting the number of grains, which is the main component of crop yield. In such a way, the productivity of a crop is connected with the management and use of fertilizers.(Reussi & Echeverría, 2006).

On the other hand, the way in which the fertilizer is applied in the Yaqui Valley results in the use of 10 to 60%, which represents an economic expense and environmental problems since the rest of the fertilizer is transported down the basin.(Peña et al., 2002).

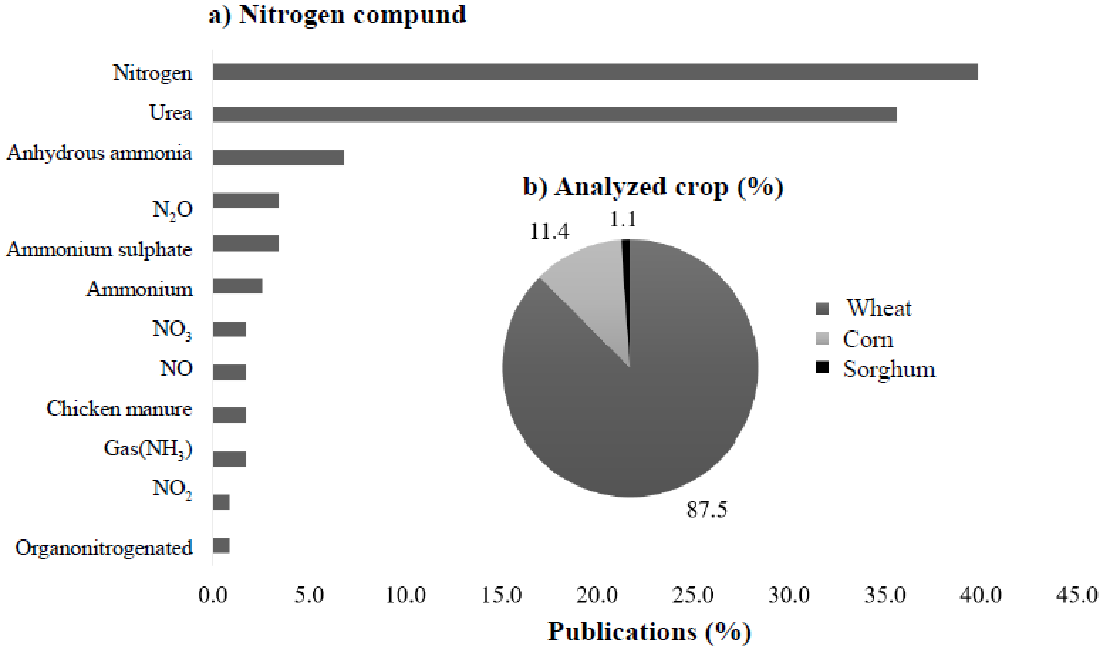

Figure 4. a) Percentage of nitrogen compounds studied in publications on the use of nitrogen fertilizers in the Yaqui Valley, Sonora. b) Percentage of the type of crop studied in the publications on the use of nitrogen fertilizers in the Yaqui Valley, Sonora.

In the studies carried out in the Yaqui Valley that mention some nitrogenous compound present in the site, 39.8% is presented as "Nitrogen" that can refer to any type of fertilizer, which is done to generalize the behavior of N inputs to the system. Regarding the type of fertilizer used, urea is the most common at 35.6%; it contains 46% of N in amine form and is the cheapest per unit of N; therefore, it is the most used in the region.

In the Yaqui Valley, the nitrogen that is not used by the crop represents a reduction in economic income and generates emissions into the atmosphere either as nitrous oxide or nitric oxide, leaching under the root zone and runoff toward surface waters of the river to the Gulf of California, resulting in the proliferation of algae.(Ortiz-Monasterio & Raun, 2007). In the studies evaluated, it was observed that they mentioned compounds such as nitrous oxide (3.4%) and nitrogen dioxide (0.8%) due to their enormous environmental impact.

Unfortunately, we are far from a pragmatic solution; world production is growing at a fast pace, increasing the demand for food.(Godfray et al., 2010). This means that agricultural production per hectare needs to be extended, resulting in pressure on the already depleted soils of the Yaqui Valley, which will increase the use of fertilizers.

Cereals play a very important role in diets worldwide due to their nutritional, caloric, and protein content; wheat is a great example. In the Yaqui Valley, research has focused on improving wheat crops to increase yield and productivity, resulting in success stories since the Green Revolution promoted by Dr. Norman E. Borlaug in the late sexties. Therefore, it is not surprising to find that 87.5% of the studies reviewed in the Yaqui Valley refer to wheat crops (Figure 4.b). Wheat has economic and historical importance in the area because varieties and practices have been generated here that favor the growth and yield of this crop.

Among the main crops produced in the Yaqui Valley are wheat (173,495 ha), soybeans (48,695 ha), corn (21,082 ha), safflower (17,923 ha) and sorghum (10,327 ha). As shown in Figure 4, within the studies found, publications were obtained that studied corn (11.4%) and sorghum (1.1%) due to the low planting density that each one represents. The rest of the crops are studied with a smaller proportion due to the smaller extension and low planting density that they present compared to that of wheat.

CONCLUSIONS

In this review, a compendium of scientific information was made, and 97 publications were found on the use of nitrogenous fertilizers in the Yaqui Valley over a period of 30 years. These articles address topics such as conservation agriculture, conventional agriculture, leaching, nitrogenous compound emissions and their impact on water bodies and greenhouse gas emissions into the atmosphere. In the publications found, the soil reservoir that is subjected to agricultural practices is studied because it is the support of the crop. To better understand the impact of nitrogenous compounds on the agroecosystem, it is necessary to increase studies directed at other components of the agroecosystem, such as the atmosphere and water, which are also impacted by the chemical products applied. Almost 80% of the studies found are about the cultivation of wheat. At the global level, we face the challenge of food security, which is why it is necessary to continue conducting research on the nitrogen cycle in the Yaqui Valley agroecosystem. In particular, it remains to be analyzed how sustainable agricultural practices could reduce the negative effects of nitrogen fertilizers on agroecosystems.

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