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NITROGEN MANAGEMENT TRENDS FOR AGRICULTURAL AND ENVIRONMENTAL SCIENCE

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ABSTRACT

Nitrogen is one of the most important nutrients for plants and is required by them in relatively large quantities. This paper presents an overview of scientific literature related to nitrogen management, with a specific highlight on permanent grasslands and has involved a bibliometric analysis of scientific literature regarding nitrogen management. The analysis was performed using the SCOPUS, which is an extensive database of literature all over the world, with wide coverage in keyword of analysis. For visualization and analysis, VOSviewer 1.6.18 was employed, which is an open access computer program, developed for creating bibliometric maps. The search results were downloaded as full record and citation data, with information related to document type, year of publication, title, author, keywords, abstract, references, funding agency, citations. A number of 3,948 articles were retrieved for analysis. The articles were sorted by relevance. The information was downloaded as .csv file and imported into VOSviewer 1.6.18 application software. Using the search query "nitrogen management", "meadows" and "pastures" indicated that 90% of the papers retrieved were research articles indexed in agricultural and biological sciences, followed by those in the environmental sciences, with themes of the ecosystem process, environmental management, land use, nitrogen fixation, organic nitrogen, soil structure, soil processing techniques.

Keywords: nitrogen efficiency, bibliometrics, nitrogen budget, grassland.

INTRODUCTION

It is estimated that about half of the world's population is now dependent on nitrogen fertilizers to provide them with food. In addition to growing crops, nitrogen fertilizers are needed to support activities such as animal husbandry, biofuel production, and timber production. A main objective in soil quality management is to maintain an optimal carbon-nitrogen ratio in soil by integrated technology practices that involves organic and chemical fertilizers (Mărin et al., 2021), different cover crops (Petcu et al., 2022) or sustainable pasture management.

Only part of the nitrogen fertilizer applied to the fields is removed with the harvested crops. The remaining nitrogen is involved in a number of complex biological, chemical and physical reactions that can be difficult to predict and control. This undiscovered nitrogen can cascade through soil, micro-organisms, plants, freshwater and ocean ecosystems while continuing its reactions. The goal of responsible management is to use nitrogen fertilizers as efficiently as possible and to minimize preventable losses from the soil system.

Nitrogen is one of the most important essential nutrients for plants and is required by them in relatively large quantities. Successful nitrogen management can

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optimize crop yields, improve profitability and minimize nitrogen losses. However, nitrogen management is a rather complex process. Nitrogen deficiency can lead to weak growth, chlorotic leaves and a significant reduction in yield. Excess nitrogen can lead to poor root development, weakened immunity (the plant becomes susceptible to disease), and poor crop quality.

The rising cost of nitrogen (N) fertiliser, and possible limited supply in spring 2022, are causing concern across the livestock industry. The international fertiliser market has seen significant volatility since autumn 2021.

In this context, this paper is presenting an overview of scientific literature related to nitrogen management, with a specific highlight on permanent grasslands.

MATERIAL AND METHODS

The present study involved a bibliometric analysis of scientific literature regarding nitrogen management with specific highlight on permanent grasslands. The analysis was performed using the SCOPUS database. This choice is justified by the fact that SCOPUS is an extensive database of literature all over the world, with wide coverage in keyword of analysis. Moreover, it has been commonly used by other author when conducting such analysis.

For reader friendly visualization and analysis, VOSviewer 1.6.18 was employed. VOSviewer is an open access computer program, is developed for creating bibliometric maps, being convenient for presenting large bibliometric data in an easy-to-interpret way (van Eck and Waltman, 2010).

The data between 1931 to 2023 was downloaded from SCOPUS for analysis using the search query “nitrogen management”, “grassland” or “pasture”, in December 2022. The search results were downloaded as full record and citation data, with information related to document type, year of publication, title, author, keywords, abstract, references, funding agency, citations. A number of 4,289 articles were retrieved for analysis.

For finding out the current hotspots of research, the exploration was further restricted to the period of the last five years, between 2017 to 2021 retrieving 3,948 articles. For creating co-occurrence maps based on keywords, the articles were sorted by relevance and first 2,000 documents were retrieved for further study. The information was downloaded as .csv file and imported into VOSviewer 1.6.18 application software (The Center for Science and Technology Studies, Netherlands; van Eck and Waltman 2010).

RESULTS AND DISCUSSION

The search according to the previously mentioned criteria returned a number of 3,948 articles published between the years 1931 and 2022. The year 2023 was excluded since it was ongoing year during the preparation of the manuscript.

Publication trend overview

The earliest paper retrieved belong to Greenhill and Page (1931) and is reporting on the mineral content of pastures farmed under the Intensive System of Grassland Management. The experimentation sample included three locations, and data were retrieved along two seasons in a three to five weeks period of growth. The results reveal that the phosphoric acid showed consistently a very highly significant positive correlation with the nitrogen content of the grass. The behavior of this correlation on the metabolism of the plant and on the phosphatic and nitrogenous manuring of pastures was also discussed (Greenhill and Page, 1931).

Until the late 80s, a few articles on the subject appeared in specialized literature. Considering the level of digitization and the registration of publications in the online system, this period does not represent a particular interest in the current analysis, having only an informative role.

A possible trigger for directing research works could be the regulatory framework. Analyzing policies concerning the nitrogen management, the following were identified:

Since 1979 the Convention on Long-range Transboundary Air Pollution (CLRTAP) has addressed some of the major environmental problems of the United Nations Economic Commission for Europe (UNECE) region through scientific collaboration and policy negotiation. Starting with 1984, CLRTAP developed a series of 8 protocols related to air pollutant emissions, including one on nitrogen oxides (1988 Sofia Protocol).

The EU Directive (91/676/EEC) was released in 1991 and is also known as the Nitrates Directive. It is aiming to reduce nutrient losses from agricultural activities in order to protect groundwater and surface waters from nitrate pollution. The main important aspects of this directive were: reduction of water polluting nitrates from agricultural sources; limits for N-containing fertilizers: 170 kg N/ha/year from livestock manure; promoting good farming practices; setting rules for nitrate-vulnerable zones (Figure 1).

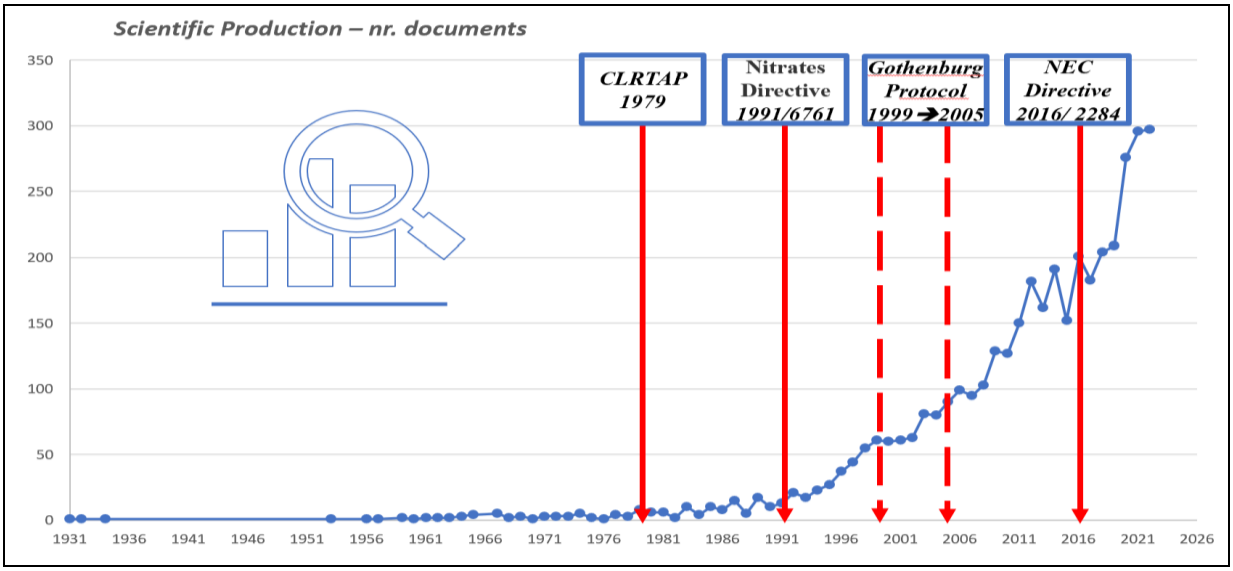

Figure 1. Annual publications in focus area of nitrogen management (1931-2022)

The Gothenburg Protocol was established in 1999, and became in force internationally in 2005. It is addressing pollutants that cause acidification and ground-level ozone, setting ceilings for the year of 2010 on several pollutants including sulphur dioxide, nitrogen oxide, ammonia and volatile organic compounds. An update for including particulate matter and black carbon was released in 2012 as well as new commitments for 2020.

Another relevant directive related to agriculture emissions is Directive (EU) 2016/2284 also known as National Emission Ceilings Directive on the reduction of national emissions of certain atmospheric pollutants. This included aspects related to: national emission reduction commitments; emission inventories; air pollution control measures. It was clearly stated that all Member States are obliged to establish a national advisory code of good agricultural practice to control ammonia emissions, taking into account the UNECE Framework Code for Good Agricultural Practice for Reducing Ammonia Emissions of 2014, covering among others, the nitrogen management, taking into account the whole nitrogen cycle.

Types of documents

There were retrieved 3,948 documents using the search query "nitrogen management" and "grassland" and "pasture". The majority of documents retrieved were research articles (3,540; 90%) followed by review articles (159; 4%), conference papers (155; 4%), book chapters (91; 2%), conference reviews (3) (Figure 2a).

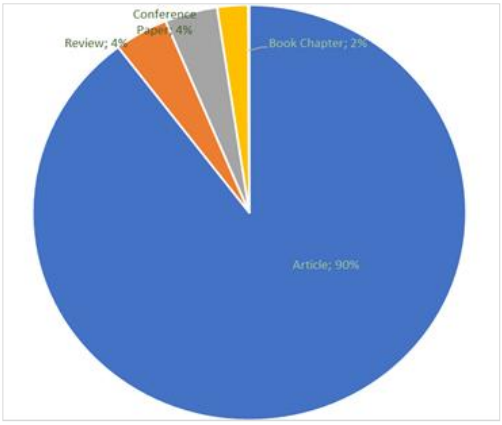

Figure 2a. Categories of documents retrieved

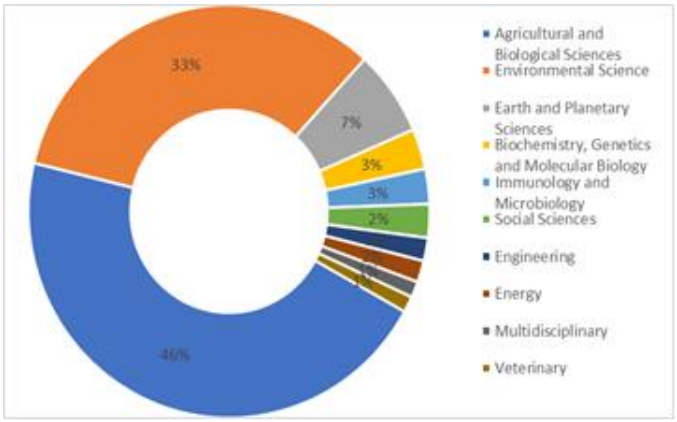

Figure 2b. The subject area of documents retrieved

Most of the articles were in English language (3,948), Portughese (18) Spanish (9), German (6), Chinese (5) and other languages.

Most of the documents were indexed under the subject area of agricultural and biological sciences (2,745) followed by environmental sciences (1,984) earth and planetary sciences (403) biochemistry, genetics, and molecular biology (190), immunology and microbiology (165) social sciences (158) engineering (108), energy (102), multidisciplinary (75) veterinary (75) (Figure 2b).

Citation analysis

It is understood that highly cited articles have a significant impact on the concerned subject worldwide. The citation analysis of retrieved documents showed 138,910 citations with an average of 35.18 citations per document. Table 1 shows the top ten highly cited articles. The retrieved documents had a h-index of 152 with a range of citations from 0 to 2,161.

Table 1. Top ten most cited articles in focus area of nitrogen management

Nr.	Year	Document title	Authors	Journal title	Total citations
1	1997	The influence of functional diversity and composition on ecosystem processes	Tilman, D., Knops, J., Wedin, D., Reich, P., Ritchie, M., Siemann, E.	Science	2,161
2	1998	Aggregation and soil organic matter accumulation in cultivated and native grassland soils	Six, J., Elliott, E.T., Paustian, K., Doran, J.W.	Soil Science Society of America Journal	1,279
3	2016	Greening of the Earth and its drivers	Zhu, Z., Piao, S., Myneni, R.B., Huang, M., Zeng, Z., Canadell, J.G., Ciais P., et.al.	Nature Climate Change	1,246
4	2016	Climate-smart soils	Paustian, K., Lehmann, J., Ogle, S., Reay, D., Robertson, G.P., Smith, P.	Nature	985
5	1999	Field management effects on soil enzyme activities	Bandick, A.K., Dick, R.P.	Soil Biology and Biochemistry	921
6	2009	Ecological impacts of early 21st century agricultural change in Europe - A review	Stoate, C., Baldi, A., Beja, P., Boatman, N.D., Herzon, I., van Doorn, A., de Snoo, G.R., Rakosy, L., Ramwell, C.	Journal of Environmental Management	895
7	1991	Methane and nitrous oxide fluxes in native, fertilized and cultivated grasslands	Mosier, A., Schimel, D., Valentine, D., Bronson, K., Parton, W.	Nature	803
8	2003	Hot-water extractable carbon in soils: A sensitive measurement for determining impacts of fertilisation, grazing and cultivation	Ghani, A., Dexter, M., Perrott, K.W.	Soil Biology and Biochemistry	786
9	2002	Nitrate leaching in temperate agroecosystems: Sources, factors and mitigating strategies	Di, H.J., Cameron, K.C.	Nutrient Cycling in Agroecosystems	780
10	2006	N_2O and NO emission from agricultural fields and soils under natural vegetation: Summarizing available measurement data and modeling of global annual emissions	Stehfest, E., Bouwman, L.	Nutrient Cycling in Agroecosystems	777

Nine of the most cited articles were research articles and only one was reviews. These articles discussed the aspects of ecosystem process, environmental management, land use, nitrogen fixation, organic nitrogen, soil structure, tillage techniques, enzyme activity. Common agricultural policy as a policy to enhance valorisation of ecosystem services, including for grassland was also analysed (Stoate et al., 2009).

The most cited (2,161 times) article was published in 1997 titled "The influence of functional diversity and composition on ecosystem processes" in Science 277. The review article promotes the idea that in a balanced ecosystem, the species are not equal and parameters that produce an alteration of the configuration of the ecosystem are likely to strongly affect ecosystem processes. Such parameters include as invasive species, nitrogen deposition, disturbance frequency, fragmentation, predator annihilation, species extinctions, and alternative management practices (Tilman et al., 1997).

Six et al. (1998) performed a specific technique known as the 'wet-sieving' technique to demonstrate that no-tillage and conventional tillage exert various effects on different particulate organic matter (Six et al., 1998). This method was further used by many researchers as standard technique, and thus given the high citation volume.

In another article, soil enzymes were evaluated relative to soil management and soil quality (Bandick and Dick, 1999). The results suggested that accumulation of organic C and N in surface soils under a reduced tillage system and a greater accumulation of inorganic nutrients under no-till affects enzyme activities. Moreover, the enzyme activity is decreasing with increasing application of ammonium-based N-fertilizer.

Another insightful contribution to the field is an overview of the ecological status of agricultural systems across the European Union in the context of policy changes in Eastern European countries of the beginning of the 2000's (Stoate et al., 2009). The authors draw attention that the decreasing quantity and quality in semi-natural grassland systems of linked to declines in biodiversity and related ecosystem services. Nutrient cycling, soil functioning and pollination and were discussed, along with other ecosystem services.

Active authors, institutions, and organizations

The analysis of the most active authors is relevant for the identification of some researchers who created working groups that intensively studied a certain field. They are potential mentors of those who research a certain phenomenon who evaluate the experimental results in order to substantiate some strategic decisions.

A total of 159 unique authors generated the documents retrieved for the defined search string. Sollenberger, L.E. authored a number of 25 articles that were cited 541 times, and latest affiliation is under University of Florida (Figure 4). The authors' work is concentrated on research areas such as: impact of grazing management on soil nitrogen, phosphorus, potassium, and sulphur distribution, effects of grazing intensity and nitrogen fertilization on soil organic carbon pools under perennial grass pastures; nutrient cycling in grazed pastures; soil carbon and nitrogen stocks in nitrogen-fertilized grass and legume-grass forage systems.

Han, Xingguo authored a number of 24 articles that were cited 2,658 times, and latest affiliation is under Institute of Botany, Chinese Academy of Sciences, and University of Chinese Academy of Sciences both located in Beijing, China. Most contributed topics are related to nitrogen, soil acidification, alpine meadows nutrient resorption (physiology), phosphorus, carbon nitrogen ratio.

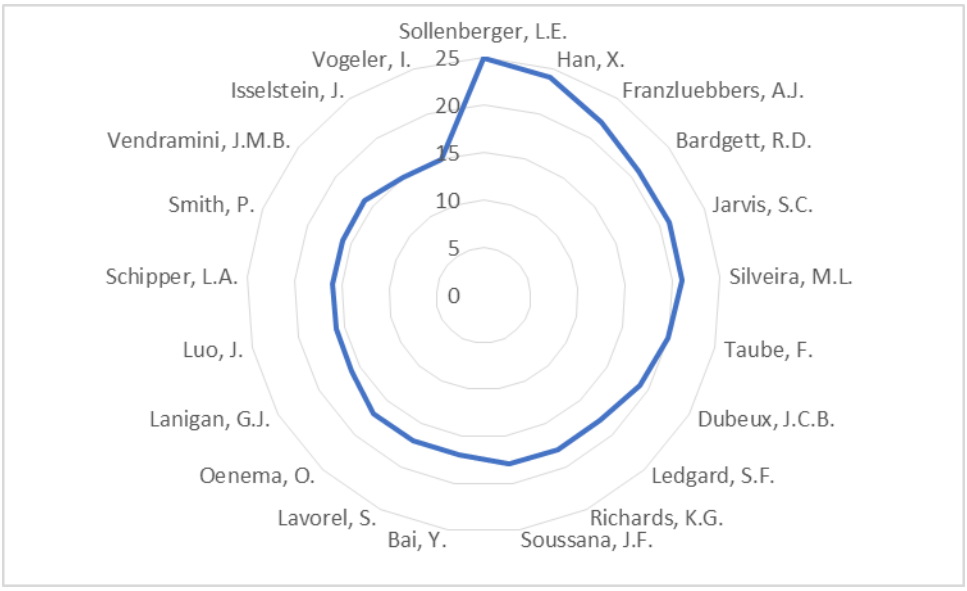

Figure 4. The most active authors that intensively studied a certain field

Only a number of 9 documents include authors affiliated to institutions from Romania. The most cited article of these 9, is dealing with an overview of ecological impacts of early 21st century agricultural change in Europe (Stoate et al., 2009). Although the authors state that agriculture accounts for about 70% of nitrate pollution in rivers for some regions, such as UK, the review shows that in Central and Eastern European countries there is a serious decline in the use of artificial fertilizers that contributed to a decrease of nitrate and phosphate in the freshwater. This contrasting situation should also be reflected in regional strategies towards agri-environmental practices.

For further in-depth analysis, the top 10 most active organization and affiliated countries are showed in Figure 5a and 5b.

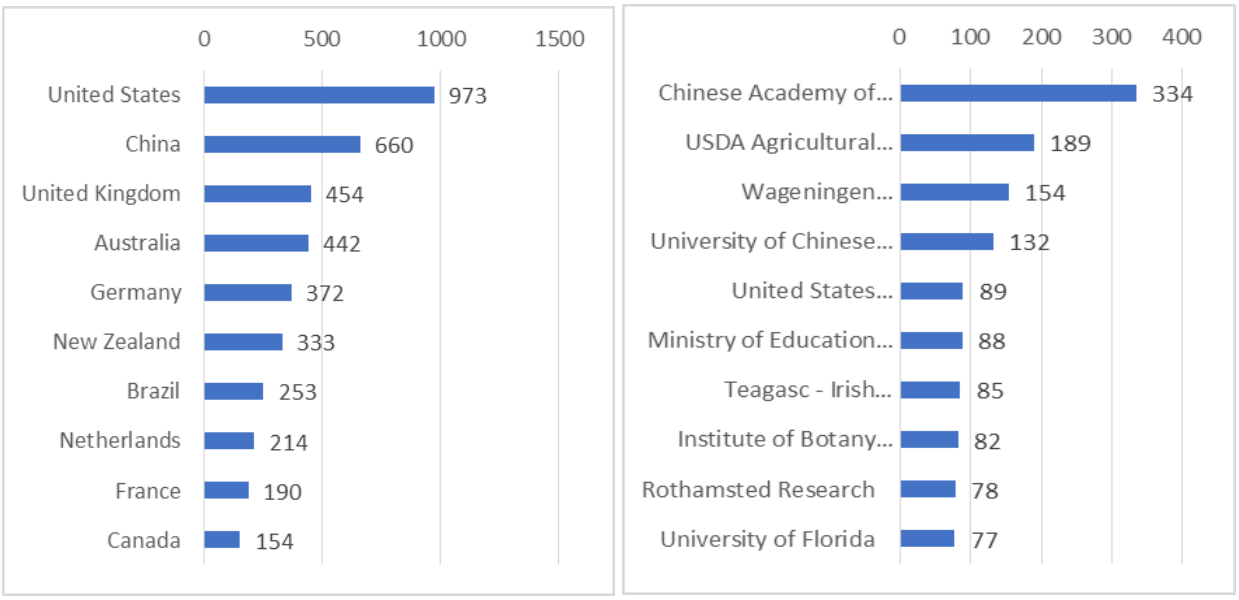

Figure 4. Top 10 most active organization and affiliated countries

Bibliometric analysis of keywords

The scope of keywords co-occurrence analysis is to evaluate the links between keywords and study their relationships in order to discover hotspots for research concerns.

For the analysis of the keywords, the retrieved documents were sorted by relevance

and first 2,000 registrations were exported as a csv. file for further study. The keywords were analyzed using VOSviewer. The total number of keywords that occurred in the title and abstract fields was 9,418, and 119 met the threshold set to 40 occurrences. The top 10 most used keyword and their link strength are shown in Table 2.

Table 2. Top 10 most used keywords and their link strength

No.	Keyword	Occurrences	Total link strength
1	nitrogen	827	9,341
2	grassland	788	8,785
3	pasture	475	4,913
4	grazing	282	3,240
6	soils	263	4,001
7	soil nitrogen	253	2,870
8	agriculture	242	3,549
9	phosphorus	239	2,948
10	fertilizer application	228	2,675

The results were further filtered to remove country names and bug-words (eg. article, journal, non-human). A density visualization map is showing the frequency of keyword occurrences (Figure 5).

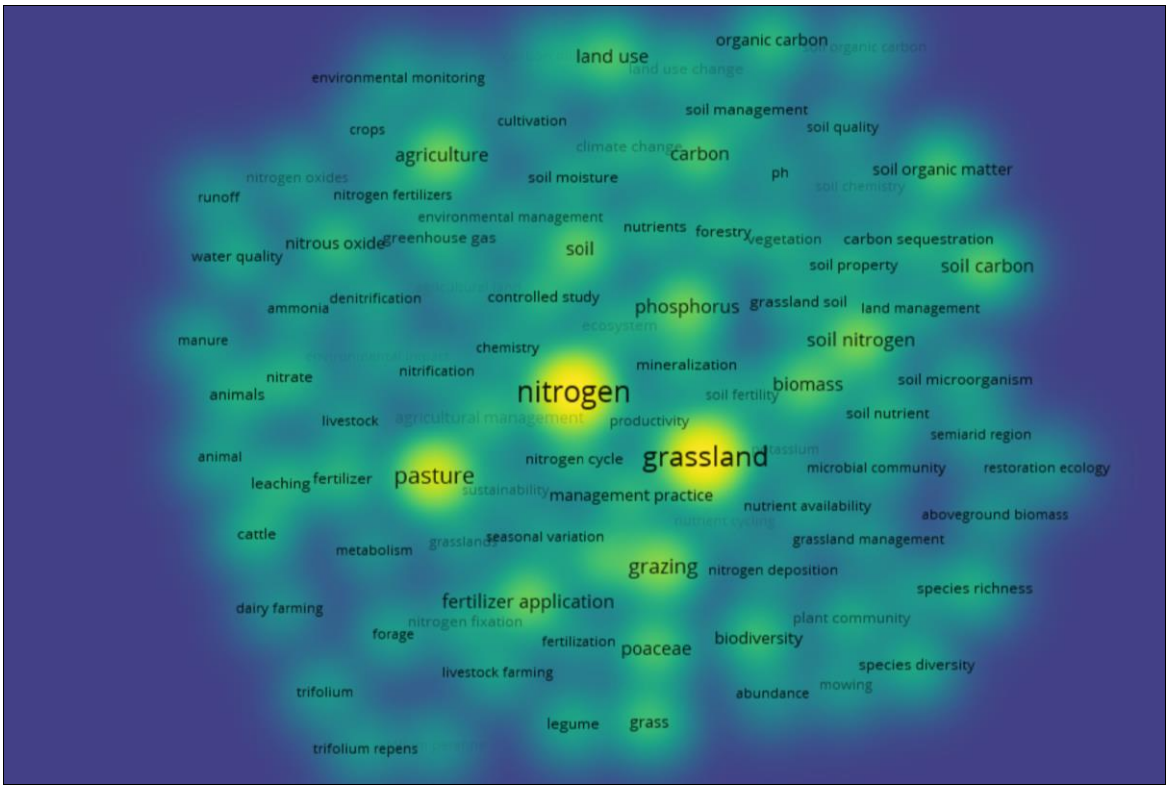

Figure 5. Frequency of keyword occurrences

The node size of each keyword represented the frequency of occurrence of the keyword in the retrieved documents. A larger node size is revealing an increased frequency of occurrence and a thick connection line showed a close relationship between two items. Frequent terms were mapped into 4 clusters (Figure 6), representing a particular theme. The different colors of the nodes represent different clusters.

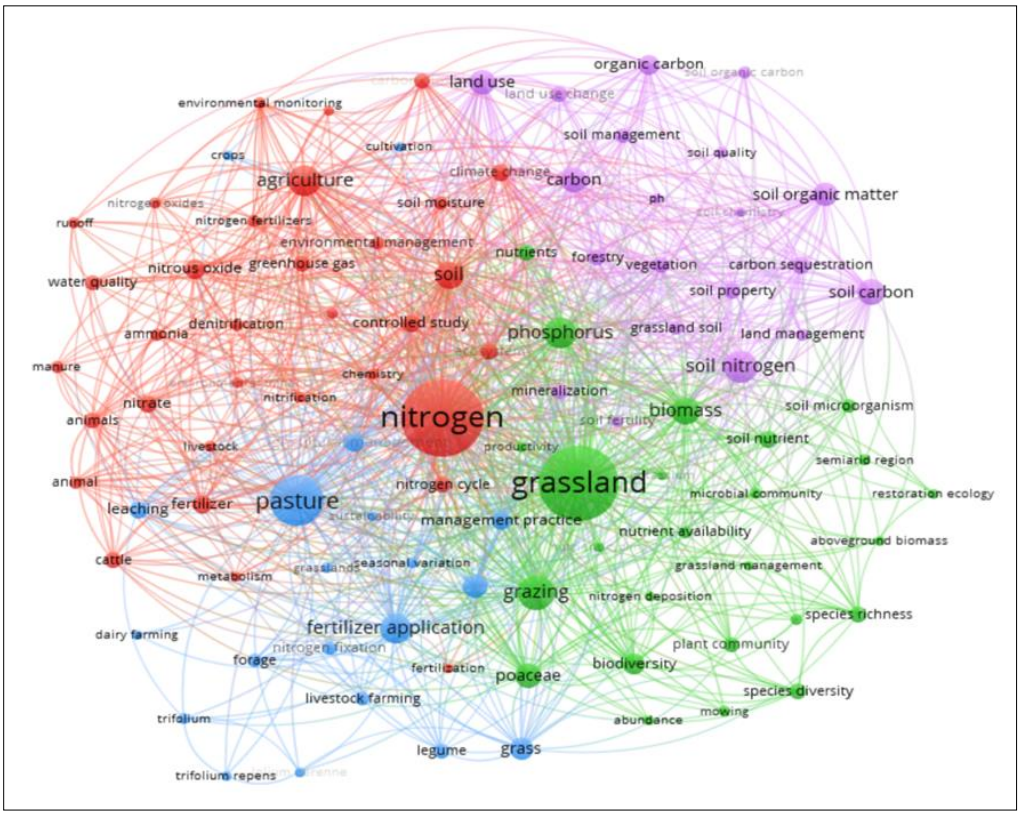

Figure 6. Network visualization based on co-occurrence of keywords

Cluster 1 (red colour) is dominated by keywords related to nitrogen, soil, fertilisers and agriculture. Leaching and greenhouse gases are also linked in this cluster. Water quality and runoff are present here with the lowest occurrence in this cluster 89 occurrences).

It is generally acknowledged that nitrate leaching from agricultural fields is considered a risk for the increased concentrations of nitrate in above and below ground waters. The evidence of nitrates losses from various land use systems and the possible factors affecting this process was reviewed by Di and Cameron (2002). The authors showed that leaching takes place by excessive nitrogen fertilizer use, incorrect applications (e.g. late autumn), ploughing pasture in early autumn. N returns in animal urine have a major impact on NO_3^- leaching in grazed pastures. The amounts leached vary by the following order: forest < cut grassland < grazed pastures, arable cropping < ploughing of pasture < market gardens. A range of management options for reducing NO_3 leaching is shown, including lowering nitrogen application rates, timing nitrogen supply according to plant requirements, cover crops using, a better timing of ploughing, appropriate stock management, applying precision farming and the development of regulatory measures.

Cluster 2 (violet colour) includes keywords related to soil chemistry and soil management. Carbon and carbon sequestration related to forestry ecosystems is as well present here.

The “behavior” of nitrogen is complex and is determined by a number of physical, chemical and biological processes that occur under the influence of various environmental factors. In nature, nitrogen is present mainly in air and soil. Atmospheric nitrogen is an important source, but it is not available to most plants. Only leguminous plants can use atmospheric nitrogen through biological processes with the help of bacteria. A small amount of atmospheric nitrogen is deposited in the soil by rain.

Estimates regarding the differences between the nitrogen input in the soil and its use by crops (nitrogen surplus) assume the realization of the feed-animal-manure balance. There are large differences between countries

regarding nitrogen surplus and this is of particular concern (van Eerdt and Fong, 1998). It is necessary to evaluate the efficiency of nitrogen in different types of animal farms, where different management systems are practiced, since the environmental factors acting on the microbiological processes in the nitrogen cycle and nitrogen losses are different in time and space, and experimental data cannot often be extrapolated (Rufino et al., 2014).

Different livestock production systems have different nitrogen budgets and varying levels of nitrogen use efficiency, determined by different feeding systems, farm sizes, and manure management (Xinpeng et al., 2021). Research conducted by Burton and Beauchamp (1986) in swine husbandry showed that the greater the exposure of the manure during storage, the greater the nitrogen losses. Reduced nitrogen loss is due to rapid incorporation into the soil, minimizing exposure to air and reducing volatilization (Salazar et al., 2005).

Most of the nitrogen in soil is in the form of organic matter. Organic matter is relatively stable and not directly available to plants. Nitrogen can be lost from the soil in several ways, by leaching, volatilization and denitrification.

Cluster 3 (green colour) contains 25 keywords with highest occurrence (105 times) for grassland. The network created is related to biomass, ecosystems, nitrogen cycle, biodiversity, plant and microbial community, species diversity and restoration ecology.

When dealing with cultivated crops, successful nitrogen management can optimize crop yields, improve profitability and minimize nitrogen losses to the environment. The timing of nitrogen application is one of the main concerns when deciding whether to apply a nitrogen fertilizer program. In intensive crop production systems, frequent application of nitrogen fertilizers, but in strictly limited doses, according to the needs of each crop, would be ideal.

It should be remembered that when growing cereals, when only a few applications of nitrogen fertilizers are made, it is the timing of application that is critical. Applying nitrogen too early risks losing it through leaching. It is necessary to apply nitrogen fertilizers before rains and in such a way that the highest dose of nitrogen fertilizer is applied before the stage of maximum absorption of nitrogen by the crop. However, there is also the risk of applying nitrogen "too late" if climatic or logistical conditions do not allow it to be applied at the scheduled time.

Nitrogen management becomes a bigger challenge when dealing with permanent grasslands.

Well managed grassland remains the lowest cost feed available for ruminant livestock. However, a wide variety of factors influence crop/grass growth including soil pH, availability of other nutrients, soil water, soil structure, solar radiation and the age/productivity of the sward. The high cost of manufactured nitrogen fertilizer makes it even more important to minimize the impact of other potentially limiting factors.

Cluster 4 (blue colour) includes 20 words and the central theme is pastures (105 occurrences and a total link strength of 3423). This cluster comprises terms related to livestock, grazing management, dairy farming, fertilizer application, forage, pastures composition.

In agricultural systems, in the transformations of nutrients from feed to manure, inevitable losses result. These systems convert plant protein to animal protein with an efficiency of 5-45%, and the remaining 55-95% nitrogen is in urine and dung and subject to loss (Oenema, 2006). For the animal component of the systems, input-output quantifications include the relationship between milk production and feed requirements, and for the plant component the relationship between production and nutrient (fertilizer) and water requirements (Hilhorst et al., 2001).

High nutrient losses are due to low nutrient use efficiency in the animal and soil subsystems (van Bruchem et al., 1999).

The conversion of nutrients from manure to feed and from feed to milk and meat needs to be maximized. It is necessary that all

components of the system to be taken into account, also limiting measures to apply, in order to minimize losses. Effective use of nutrients at all stages ensures an effective nutrient management (Aarts et al., 1992). To improve the nitrogen use efficiency, farms can apply different strategies, such as intensifying agricultural production to gradually rebalancing the entire system (Jeroen et al., 2006).

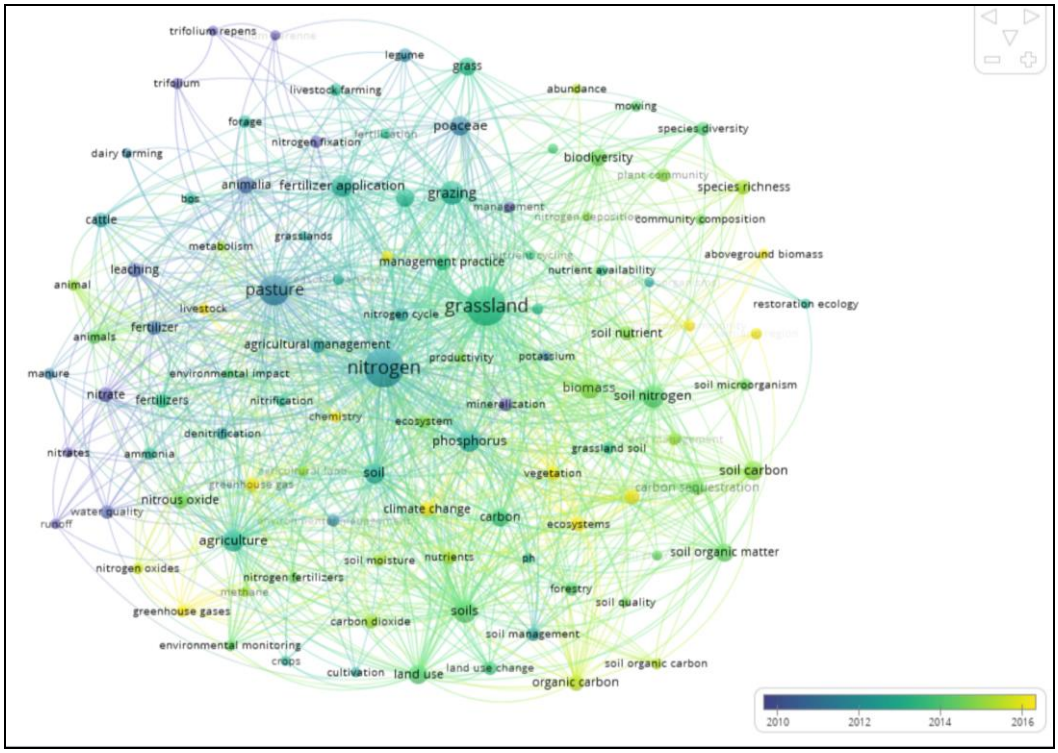

Figure 7. Dynamics over the years of research core themes by keywords

The dynamics over the years of the scientific interest on nitrogen management various themes was plotted in Figure 7. The research started from core areas such as mineralization, nitrates, leaching, water quality and runoff (violet color, starting with 2010) to climate change, greenhouse gases, ecosystems, carbon sequestration (yellow color).

Feed and manure management are important factors for the efficiency of nitrogen use in livestock farms. The application of natural fertilizers, compared to those of mineral origin, is an additional challenge, since organic fertilizers are not as precisely evaluated as mineral fertilizers. Consequently, the application of mineral fertilizers with nitrogen where there are also organic ones causes nitrogen losses in the environment (Rütting et al., 2018).

For improvement of efficiency of nitrogen use, the nitrogen budget can be used as an indicator and regulatory tool for nutrient management, thus providing insight into methods of reducing losses and increasing efficiency (Carswell et al., 2019). Assessment and control of agricultural nitrogen are necessary to reduce the impact on the degree of environmental pollution (Hayakawa et al., 2009).

Nitrogen production is also different from one region to another, also due to differences in climate. Research has shown that plant farms have a higher nitrogen use efficiency and a lower nitrogen surplus than animal farms. A higher level of NUE does not mean a reduced impact on the environment, as a high surplus of nitrogen has been found in some intensive agricultural systems (Quemada et al., 2018). The application of modern technologies in animal husbandry must take into account, as an essential condition, the impact they have on the environment. Animal feeding is varied and adapted to the available resources, which are variable both within a year and across years, so that several decisions are necessary in this regard (Chardon et al., 2012).

From the point of view of economic efficiency, the adoption of farm practices in which manure is used as a source of nitrogen, creates, at the same time, the opportunity for substantial cost savings (Porter and James, 2020). Increasing the efficiency of nitrogen use in animal farms can be achieved by introducing new technologies, improving nutrient supply management and applying appropriate management (Misselbrook et al., 2016).

CONCLUSIONS

The emergence of the regulatory framework for nitrogen management policies was a trigger for the emergence of research works in the field. Using the search query ”nitrogen management”, ”meadows” and ”pastures” indicated that 90% of the papers retrieved were English-language research articles indexed in the agricultural and biological sciences, followed by those in the environmental sciences. These articles had as themes the aspects of the ecosystem process, environmental management, land use, nitrogen fixation, organic nitrogen, soil structure, soil processing techniques.

The analysis of the most active authors revealed the identification of researchers who created working groups that intensively studied a certain field, becoming potential mentors for researchers of a certain phenomenon and whose evaluation of experimental results can substantiate some strategic decisions. The research areas on which the authors' activity was focused: the impact of grazing management on the distribution of nitrogen, phosphorus, potassium and sulfur in the soil, the cycle of nutrients in pastures, the stocks of carbon and nitrogen in the soil, etc. The top 3 most used keywords and their link strength are nitrogen, grassland and pasture.

Visualization of networks based on co-occurrence of keywords indicated that there is a cluster where keywords related to nitrogen, soil, fertilizer and agriculture are dominant; the second cluster includes keywords on soil chemistry and soil management; the third concerns biomass, ecosystems, nitrogen cycling, biodiversity, and the fourth includes topics on livestock, pasture management, milk production, fertilizer application, forage, pasture composition.

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