sociedade & natureza

DOI: 10.14393/SN-v36-2024-70461x
Received: August 15, 2023 | Accepted: November 29, 2023 | Published: January 10, 2024

Papers

Meta-Analysis of Scientific Production on Soils in the Municipalities of the Triângulo Mineiro and Alto Paranaíba in the Last 30 Years

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Keywords
Spatialization of Knowledge
Pedodiversity
Soil Science

Abstract
The geographical mesoregion of the Triângulo Mineiro and Alto Paranaíba has an economy strongly focused on agribusiness, with grain and sugarcane production levels that put them at the forefront of the economic and political scenario of the state of Minas Gerais, Brazil. However, scientific production focused on soil diversity in this region has long been undervalued compared to other regions of the state and country where the soils exhibit more diverse and, therefore, more intriguing geological and geomorphological characteristics. This paper aims to evaluate the evolution and spatialization of bibliographic production with the central theme of soils in the Triângulo Mineiro and Alto Paranaíba mesoregion. As such, papers from the last three decades within the municipalities of the studied region were selected from five important journals. The papers from the initial screening were analyzed for the following: the profile of the authors (gender and institutional affiliation); number of authors per paper; methods used; and distribution of these papers across the selected region. The results indicate a concentration of papers in four municipalities and a total lack of publications from another 40. Males heavily dominated scientific production in the analyzed segments. Despite the mesoregion having 11 public higher education institutions, most municipalities' soil research was incipient. Regarding the methods used by researchers, in municipalities where more institutional partnerships were made possible, there was an increase in the number of techniques and methods explored in investigating problems. Although the study area presents relative geological and geomorphological homogeneity that gives a monotonous aspect to the landscape, knowledge of its pedodiversity, and its economic significance for agriculture, justifies the need to resume soil studies in the Triângulo Mineiro and Alto Paranaíba, particularly by exploring methods and municipalities that are still little known.

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INTRODUCTION

The Geographical Mesoregion of the Triângulo Mineiro and Alto Paranaíba (TMAP) is recognized for its great strategic importance to the state of Minas Gerais, Brazil. Its economy accounts for more than 16% of the state's Gross Domestic Product (GDP), with the services, industrial, and agricultural sectors standing out (CEPES, 2023). In the latter sector, the region has undergone major transformations in recent decades, with emphasis on an increase in the area planted with soy, corn, and sugar cane (Anjos *et al.*, 2013; Brito; Reis, 2012).

One possible factor that explains this strong growth in agriculture is the development of technologies for cultivation in highly leached acidic soils with high aluminum saturation. These innovations included the participation of bodies such as the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA - Brazilian Corporation of Agricultural Research) and the collaboration of public universities across Brazil (Franco, 2001; Inocêncio; Calaça, 2010).

Since the 1980s, the region has had undergraduate courses with soil as one of their objects of analysis. The arrival of public universities in the region brought important changes to the production of geographic space, updating modes of production and developing local technologies with great adherence to the needs of the community (Hoff *et al.*, 2017; Ramos Filho, 2023). Brazil has highlighted the role of universities as agents of socio-environmental and socio-economic transformation in the regions in which they are located (Serra *et al.*, 2018).

Currently, 5 higher education institutions offer undergraduate and graduate courses in areas that contribute directly and indirectly to the development of Soil Science. These institutions are distributed across 11 campuses in the TMAP, producing new knowledge aimed at regional and national agricultural development. Of these institutions, it is worth highlighting that nine are federal (Federal Universities, Federal Institutes, and Federal Center for Technological Education of Minas Gerais), and two are state (Universidade do Estado de Minas Gerais - Minas Gerais State University).

However, this scientific production seems to have an irregular distribution in time and space. The main causes can be identified as municipal differences in territory and population size, Gross Domestic Product (GDP), access to higher education, and the presence of private research centers. As a result, scientific production may be privileged and segregated to only a few localities.

The hypothesis for such differences lies in the privileged choice of municipalities with already advanced research infrastructure, favoring the accumulation of primary data as well as reducing the cost of new work (Serra *et al.*, 2018; Macedo *et al.*, 2022).

Therefore, this paper aims to evaluate the evolution and spatialization of bibliographic production on the topic of Soil Science within the municipalities belonging to the TMAP in the time frame from 1990 to 2022.

MATERIAL AND METHODS

Location of the study area

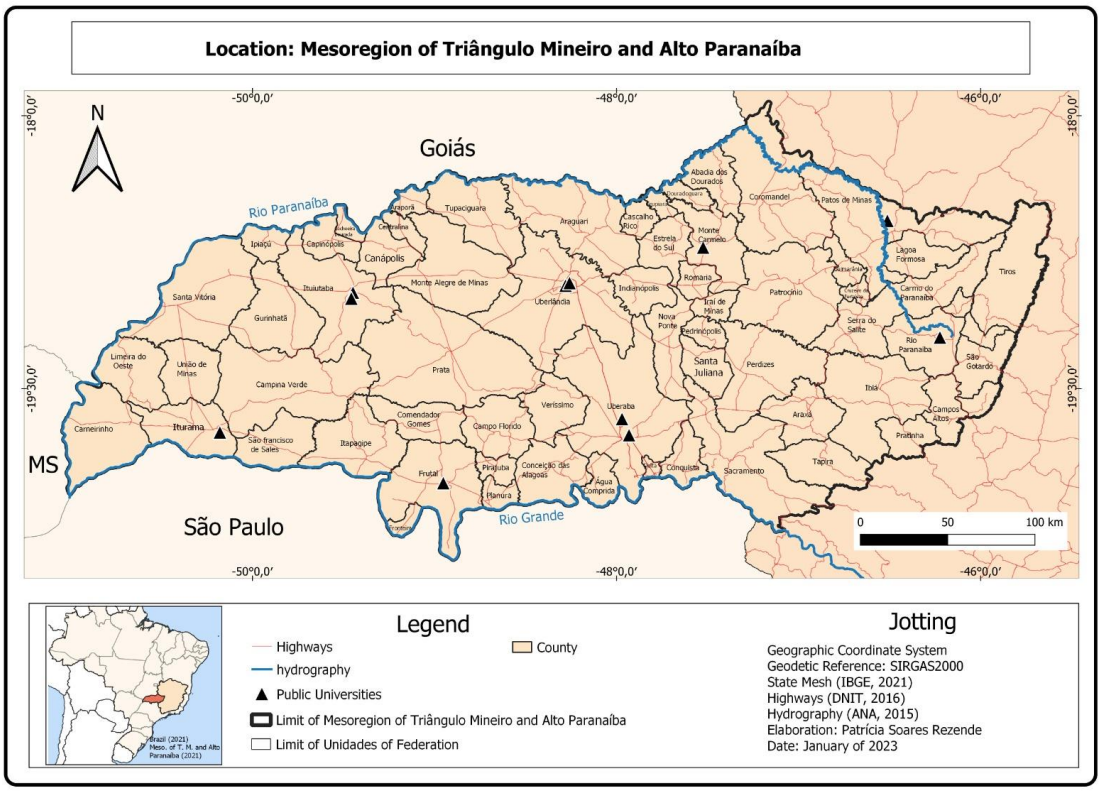
The Triângulo Mineiro and Alto Paranaíba Mesoregion are located in the west of Minas Gerais and consist of 66 municipalities with a population that already exceeds 2 million inhabitants (IBGE, 2022) (Figure 1). The peculiar triangular shape of this mesoregion is a result of being delimited by the Paranaíba River basin to the north and by the Rio Grande River basin to the south (Figure 1), the confluence of which gives rise to the Paraná River.

The geology of the region is less complex when compared to other mesoregions of the same state. Cretaceous sedimentary rocks give this landscape smooth contours with long hillsides and slopes that rarely exceed 20%. Among the most common lithologies, the Bauru Group in the westernmost section stands out, with eolian sandstones from the Vale do Rio do Peixe Formation and sandstones with carbonate cementation from the Marília Formation, succeeded by basalts from the Serra Geral Formation where there is greater fluvial notching (Batezelli, 2003). In the eastern section, the TMAP is composed of rocks from the Araxá and Canastra Group, corresponding to the highest and busiest areas of the relief (Rodrigues *et al.*, 2010; Seer *et al.*, 2001).

TMAP soils are characterized by their deep alteration mantle and oxidic mineralogy with a predominance of quartz, iron oxides, and aluminum oxides, and where the lithology provides a greater contribution of silica, there is the presence of kaolinite and micas at varying stages of degradation (Camêlo *et al.*, 2017; Rosolen *et al.*, 2017; Rolim *et al.*, 2019). In accordance with the Brazilian Soil Classification System, nine soil orders occur with spatial expression in the TMAP, excluding only the

occurrence of orders characterized by high-activity clays (Luvisols and Vertisols), soils with a high concentration of equivalent calcium carbonate (Chernozems) or Planosols (EPAMIG, 1980; Gomes *et al.*, 1982).

Figure 1 - Location map of the Triângulo Mineiro and Alto Paranaíba



Source: The authors (2023).

Meta-Analyses and Systematic Review

This study consisted of a systematic review and meta-analysis to understand the profile of Soil Science publications in the Triângulo Mineiro and Alto Paranaíba in the last three decades in national journals. The aim was to discover whether there is a homogeneous distribution of these studies or a privileged concentration in certain municipalities.

To achieve a satisfactory result, five national journals with an evident contribution to scientific development on the theme of soil, be it on a national scale or at the regional level of the TMAP, were selected. The journals chosen for analysis were the Revista Brasileira de Ciência do Solo (Sociedade Brasileira de Ciência do Solo - Brazilian Society of Soil Science), Bragantia (Instituto Agronômico de Campinas - Campinas Agronomic Institute), Pesquisa Agropecuária Brasileira (Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) - Brazilian Corporation of Agricultural Research), Bioscence Journal, and Sociedade e Natureza (both from the Universidade Federal de Uberlândia - Federal University of Uberlândia).

To select the papers for analysis, it was determined that soil should be the focus of the research and that the sampling areas should be totally or partially located within the TMAP mesoregion. Approximately 8,900 scientific papers were thus viewed, whereby, after selection, 99 were separated for meta-analysis.

The 99 papers were then reviewed with the aim of collecting data on the variables considered important in the systematic review. The variables are the number of papers per municipality, the profile of the authors (gender and institutional affiliation), the number of authors per paper, and the methods used in each paper. With the data systematized, graphs and statistics were organized using Excel 2021 software.

Keywords Cloud

The word cloud was organized based on the selection of keywords in each paper, excluding pronouns, prepositions, and papers that did not show an important relationship with the central theme. The resources offered by WordClouds (Wordclouds, 2023) were then used to create the

cloud. The visualization criteria follow the frequency of occurrence of each word within the selected cloud, whereby the keywords most used by scientific papers appear more prominently.

Scientific Relevance Index

To highlight the heterogeneity of scientific production, an index was created that relates the distance of researchers in relation to the studied municipality with the publications accumulated in each decade since 1990. It is understood that the greater the distance from which researchers originate in relation to the experimental area, the greater the municipality's relevance for the scientific community since it has enabled the formation of interinstitutional partnerships and the participation of researchers from Institutes of Higher Education (IHEs) outside the TMAP (Kretschmer, 2004). Also, in the same index, different weights were assigned to the accumulation of papers for each decade, meaning that more recent publications increase the relevance value of that municipality for the scientific production of Soil Science.

$$IP = \sqrt{(0{,}1 + dm) * (\frac{n_{90} + 1}{10}) * (\frac{n_{00} + 2}{10}) * (\frac{n_{10} + 3}{10}) * (\frac{n_{20} + 4}{10})}$$

Where:

IP = Scientific Relevance Index

dm = Sum of the distance between the municipalities where the authors are affiliated in relation to the studied municipality

n_{90}= number of papers published between 1990 and 2000

n_{00}= number of papers published between 2001 and 2010

n_{10}= number of papers published between 2011 and 2020

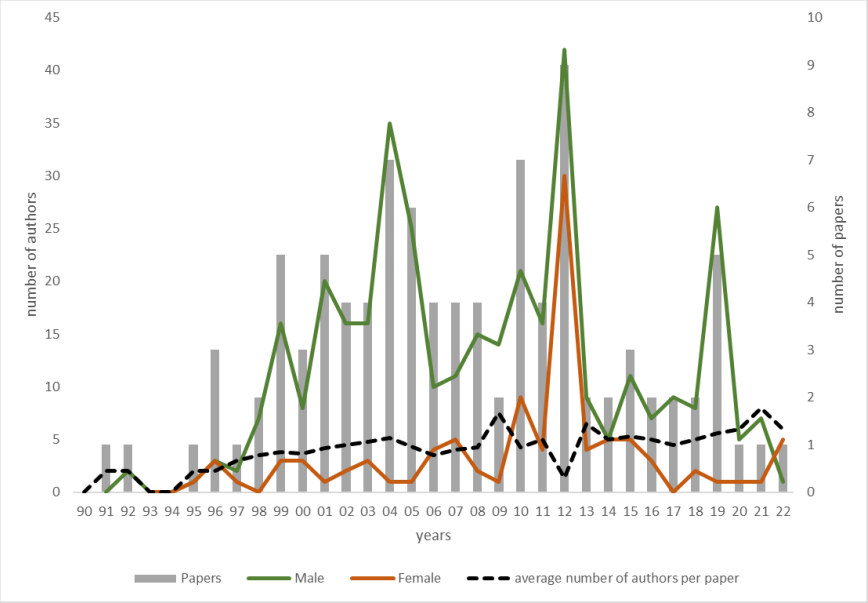
n_{20}= number of papers published between 2021 and 2023

To map the scientific relevance of each municipality, the index was normalized, corresponding to zero for the municipality that has no accumulated production in the period and one for the municipality that added the greatest number of recent papers and with greater participation of researchers from different parts of Brazil and the world.

RESULTS

Research on the soils of the TMAP began to gain prominence from the 2000s onwards, showing a growth of 300% in relation to the previous decade in the total number of papers published in the journals analyzed (Figure 2). 2012 was the stand-out year for scientific production in the region with the publication of nine papers and the participation of 72 authors from different locations.

Figure 2 - Total papers published in TMAP in the journals analyzed



Source: The authors (2023).

Although the number of authors did not show relevant differences between genders in the first decade studied, in subsequent decades, there was an evident increase in the number of male authors accompanied by relative stability in the number of female authors (Figure 2).

The average number of authors showed an increasing trend in the period analyzed, despite the almost yearly fluctuations in the total number of authors or even in the number of papers published (Figure 2).

When analyzing the journals individually, it is possible to notice the overwhelming majority of the Revista Brasileira de Ciência do Solo in the scientific production of soils in the TMAP, which was to be expected given the journal's specialization, as well as its importance on the national scene. However, female participation in this journal was low, presenting a percentage above only that of the Pesquisa Agropecuária Brasileira Journal (Table 1).

Sociedade e Natureza was the journal that presented the highest gender parity among authors as well as the lowest number of authors per paper (Table 1). Bioscience Journal had the highest average number of authors per paper, having its highest production of papers in the area in the 2010s (Table 1).

Although the Bragantia Journal is of great importance for the development of national Soil Science, it did not prove to be a relevant journal for understanding the regional dynamics of TMAP, with only two papers published in 30 years of database. Despite this journal not being specialized in Soil Science, it is an important scientific communication channel for the area of Agricultural Sciences. However, even with the geographical proximity of the editorial board to the studied mesoregion, as well as research on soils from every region in the country, this journal has not presented papers on TMAP for over 13 years (Table 1).

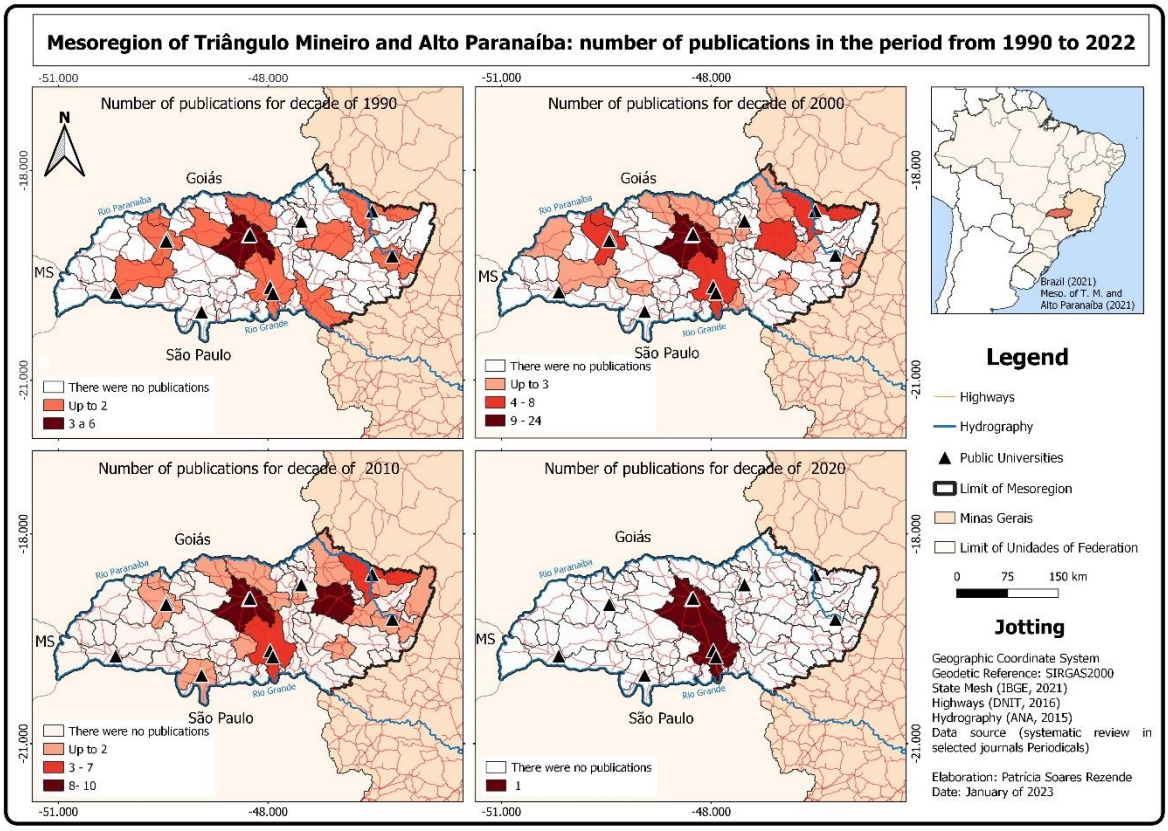
Table 1 - Profile of the journals analyzed

	accumulated papers per period				**total of authors (%)**		**average authors per paper**
Journal	**90-99**	**00-09**	**10-19**	**20-23**	**Men**	**Women**	
RBCS	6	30	21	1	87.6	12.4	4.7
Sociedade e Natureza	7	2	7	1	55.6	44.4	3.2
Bioscience Journal		3	9	1	74.6	25.4	5.5
PAB	1	7	1	0	90.9	9.1	4.9
Bragantia	0	2	0	0	75.0	25.0	2.0

RBCS - Revista Brasileira de Ciência do Solo; PAB - Pesquisa Agropecuária Brasileira
Source: The authors (2023).

In addition to varying over time, the publications also presented an uneven spatial distribution, favoring certain municipalities to the detriment of others (Figure 3). Among the municipalities with the most studied soils in their territory, Uberlândia, Uberaba, Patrocínio, Araxá, and Araguari stand out. On the other hand, 40 municipalities did not have any research on soils published in the journals analyzed (Table 2).

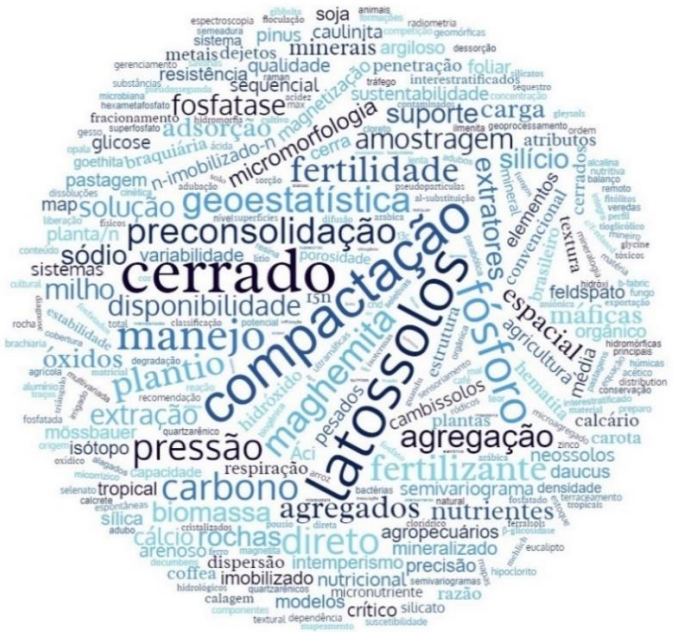
Figure 3 - Spatial distribution of published papers



Source: The authors (2023).

When analyzing the central themes of the papers, the publications presented a wide variety of focuses over time. However, from the analysis of the keywords chosen by the authors, it was possible to observe a certain preference for themes that involve aspects of the general characterization of soils, although there were also others that deepen knowledge on specific subjects, such as the availability of chemical elements of agronomic interest, primary minerals, and the behavior of phosphorus in the soil (Figure 4). Such themes corroborate with already known results of highly weathered oxidic soils found throughout the TMAP domain.

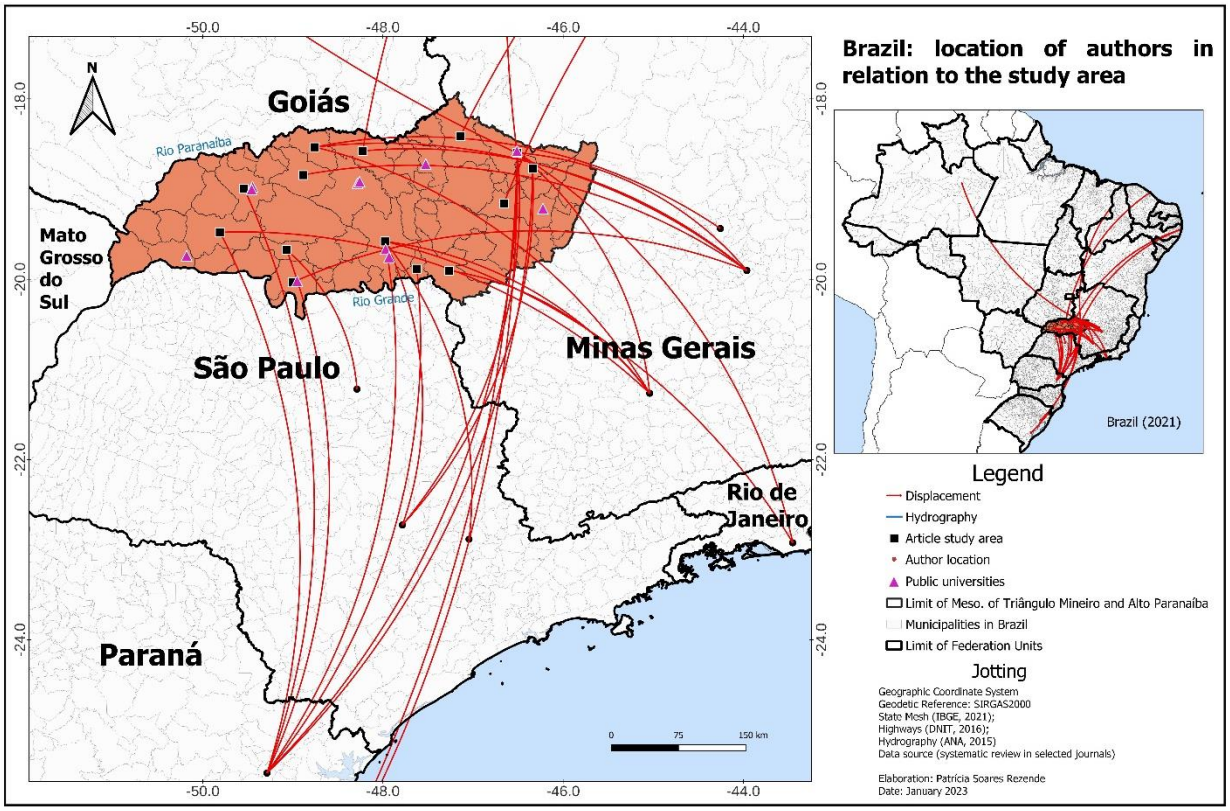
Figure 4 - Keyword cloud of selected papers



Source: The authors (2023).

The scientific production of these municipalities with the highest number of published papers brought the contribution of researchers from external institutions to the region, increasing the plurality of interpretations as well as methodological diversification. When analyzing the municipalities of origin of the authors who published in the TMAP, it is possible to note that Viçosa (Universidade Federal de Viçosa – Federal University of Viçosa), Lavras (Universidade Federal de Lavras - Federal University of Lavras), and Curitiba (Universidade Federal do Paraná - Federal University of Paraná) stood out in interinstitutional collaborations (Figure 5). Although discreet, there was international participation in papers published in the study area, featuring researchers from Germany (Institute for Soil Science and Soil Geography), Argentina (Universidad de Córdoba), Belgium (Katholieke Universitiet), Colombia (Universidad Nacional de Colombia), the United States (Everglades Research and Education Center), England (Tyndall Institute for Climate Change Research), and Nigeria (Federal University of Technology).

Figure 5 - Influence network map of TMAP municipalities

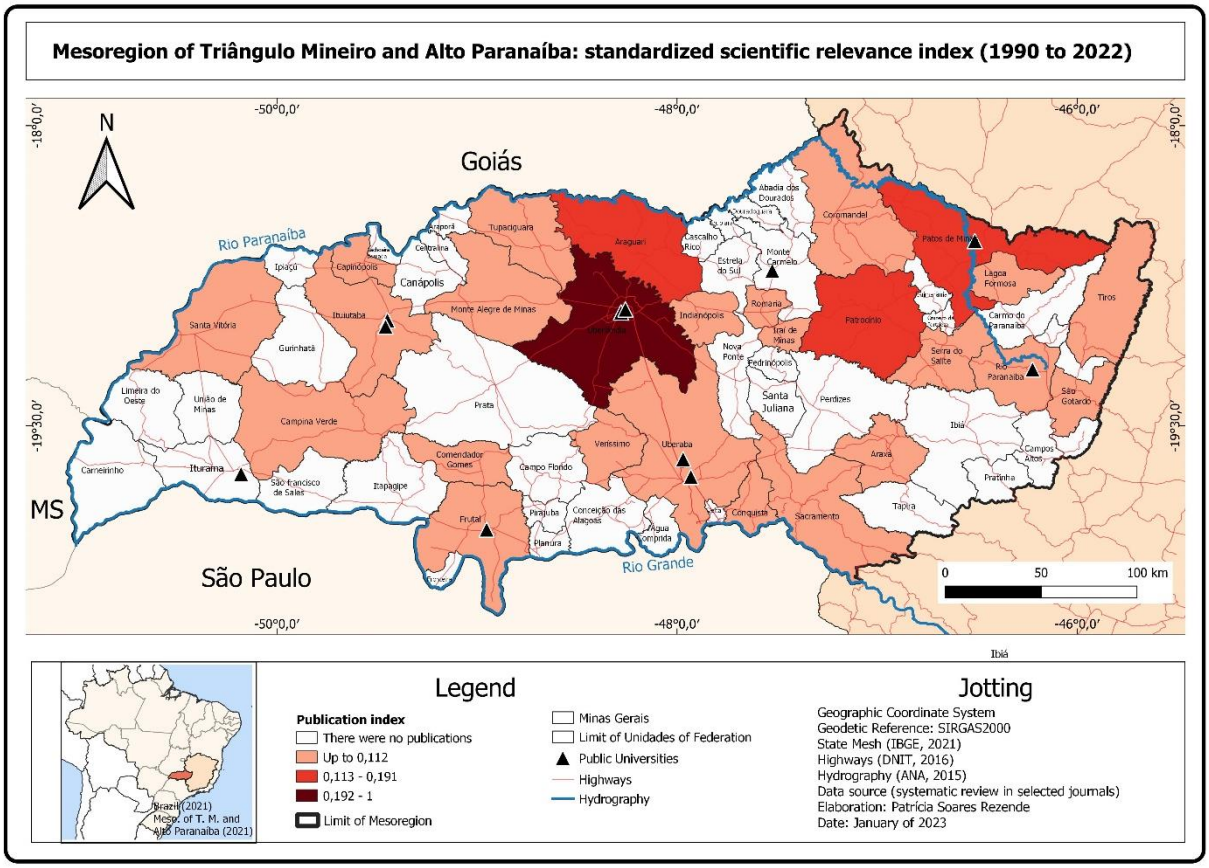


Source: The authors (2023).

Such partnerships between institutions and the number of authors per paper resulted in greater diversification of methodological techniques, contributing to the published papers presenting a greater number of types of soil analyses (Table 2).

Application of the scientific relevance index to each municipality demonstrates a noteworthy spatial contradiction in the TMAP region (Figure 6). Only the municipality of Uberlandia presented volume and consistency in the publication of papers that explored the local characteristics of its soils. The municipalities of Araguari, Patrocínio, and Patos de Minas approached a prominent condition, even though they do not have courses on Soil Science at their educational institutions, which include the Instituto Federal do Triângulo Mineiro (Federal Institute of Triângulo Mineiro) (Araguari and Patrocínio) and the Universidade Federal de Uberlândia (Federal University of Uberlândia) (Patos de Minas). All the other municipalities with publications were classified as low relevance, revealing that they are areas of study with little attractiveness for the development of research on this topic.

Figure 6 - Standardized scientific relevance index



Source: The authors (2023).

Table 2 - Correlation matrix between data extracted from the meta-analysis

	Total Papers	Total authors	Total distance between authors and the municipality studied	Number of different institutions involved	Number of methods explored in each municipality
Total Papers	1				
Total authors	0.9956	1			
Total distance between authors and the municipality studied	0.9211	0.9214	1		
Number of different institutions involved	0.9704	0.9743	0.8943	1	
Number of methods explored in each municipality	0.8778	0.8809	0.8113	0.8647	1

Source: The authors (2023).

DISCUSSION

Due to its mostly flat relief and a monotonous lithology over a large territorial space, the soils developed on the surfaces of the Triângulo Mineiro and Alto Paranaíba have ended up being neglected for research, which is corroborated by the small number of papers published in 32 years.

Of the 99 papers selected for meta-analysis, a greater concentration of efforts could be observed between the years 2000 and 2014 in terms of scientific production volume. This production still bears the marks of male-dominated science, even when analyzing the most current data for the study scope. The fact that the number of female authors remained constant throughout the study period contradicts a movement toward greater participation of women in science, even if less expressive in Engineering and Agricultural Sciences (Grossi *et al.*, 2016; Oliveira *et al.*, 2021).

There has been an increasing inclusion of women in postgraduate studies in Soil Science in recent years; however, the percentage of women working in teaching and coordination is still far below their level of representation as students (SBCS, 2017). When analyzing research in Soil Science, female participation as Research Productivity Grant (PQ) fellows is 22% for researchers in this subarea. When the level increases to 1A, women PQ scholarship holders remain at the same level (31%) as category 2 early career scholarship holders (29%) (SBCS, 2017).

The late entry of women into undergraduate and graduate courses, especially in the area of Soil Science, and the work/family balance may be among the factors that have contributed to women being a minority among Soil Science researchers. This, coupled with the low representation of women in teaching and coordination positions, may be among the main causes of the production of Soil Science papers still being concentrated among male authors. Even so, it is expected that today's more equal distribution in undergraduate courses in Agricultural Sciences will be reflected in a greater percentage at the highest levels a few years from now (SBCS, 2017).

Among all the papers analyzed, the number of female authors was greater than that of male authors in only one, published in Sociedade e Natureza in 2022. This journal was the one in which female participation showed greater equality between genders among the studied publications. As it is hosted within the Institute of Geography, this journal captures initial indications that lead us to believe that when compared to agricultural sciences, Geosciences are more open to female participation in research.

An important fact is that all the journals studied here have male editors-in-chief. However, perhaps this paper has the largest number of female authors published in 2022 is a sign of progress in greater participation of women in Soil Science in the TMAP region.

Regarding the number of authors per paper, the data obtained reflects greater collaboration between researchers, both internally, increasing the number of authors from the same institution, and institutionally, representing the approximation of graduate programs and the development of joint research projects. Such results demonstrate that the Mesoregion, albeit incipiently, is capable of fostering the formation of academic partnerships, which indicates an increase in the quality and innovation of papers (Newman, 2004; Lee; Bozeman, 2005).

When analyzing the production of papers by the municipality, it is possible to see that the municipalities of Uberlândia, Araguari, Patrocínio, and Patos de Minas concentrate on soil studies in the TMAP mesoregion. It can be deduced that spatial differences in the production of papers occur for two reasons: (i) municipalities with universities with consolidated graduate programs – Uberlândia and Araguari (proximity to Uberlândia); and (ii) rocks that add greater complexity to the landscape – Patrocínio and Patos de Minas.

The Universidade Federal de Uberlândia has had postgraduate programs in Agronomy and Geography since the beginning of the 2000s, which strongly influenced the largest number of papers being from this municipality and the nearby region. However, the tuffites from Patos de Minas and the metamorphic rocks from Domo Serra Negra de Patrocínio resulted in the genesis of soils with intriguing characteristics, which invariably aroused the scientific interest of several institutions. The Patos de Minas tuffites developed magnetic soils rich in Fe oxides and with the presence of the mineral magnesioferrite, which is unprecedented in Brazilian soils (Silva *et al.*, 2005). In Patrocínio, the intrusion that characterizes the Serra Negra Dome, of Cretaceous age, is found in a complex lithological context, composed of phyllites, sandstones, quartzites, slates, and siltstones (Machado, 2005). This lithological complexity means that there is a pedological diversity in this region that includes hydromorphic soils, Neosols, Cambisols, and Ferralsols (Neto *et al.*, 2009).

The methods used in the selected papers showed evolution and an increase in complexity as they advanced toward the present. Techniques such as scanning electron microscopy, differential thermal analysis to identify mineralogical phases, and soil micromorphology gained ground as tools for obtaining analytical data, while methodologies already established in Soil Science continued to be used for initial characterizations of the study areas. However, the underutilization of geoprocessing, remote sensing, and geostatistics to obtain information about the distribution and spatial differentiation of soils in this region is noteworthy, corroborating the status of landscape monotony of the flat lands of the sedimentary Cretaceous.

The scientific relevance index managed to demonstrate the spatial contradiction that exists in the interest of researchers when carrying out research in the TMAP municipalities. Those municipalities that have a research infrastructure and tradition in graduate programs related to Soil Science are privileged to the detriment of others that do not have such attractions. In the second half of the 2010s, this condition was reinforced by successive cuts in education and research, which made it even more difficult to develop work in places requiring displacement over large distances (Saraiva *et al.*, 2020).

The index also revealed that other municipalities with public universities, including higher education courses that dialogue with Soil Science, have low research attractiveness, as is the case of Ituiutaba, Monte Carmelo, Frutal, Uberaba, and Rio Paranaíba. The low-level research infrastructure may partly explain the low productivity of the Universidade do Estado de Minas Gerais (State University of Minas Gerais) campuses (Frutal and Ituiutaba), which were state campuses in the second half of the 2010s and have been undergoing processes of restructuring their laboratories. The Universidade Federal de Viçosa (Federal University of Viçosa) located in Rio Paranaíba and the Universidade Federal de Uberlândia (Federal University of Uberlândia) located in Monte Carmelo may have their low production explained by the young undergraduate population on their campuses (2006 and 2010 respectively).

FINAL CONSIDERATIONS

Increasing knowledge of the soils of a given region is directly related to the technical and scientific apparatus of local agriculture, enabling the development of technologies that meet specific characteristics and tend to guarantee the most rational use of this resource.

When analyzing the bibliographic production data from the Triângulo Mineiro and Alto Paranaíba, the lack of a more spatially distributed production is noteworthy. The papers meet localized demands and do not advance the understanding of the distribution and regional differentiation of these soils.

Thus, the concentration of studies in a few municipalities masks the great diversity and complexity of the soils of western Minas Gerais. There must be commitment and care from the graduate programs of local universities, as well as from researchers in Soil Science, to expand their areas of study to those 40 municipalities that have not yet been visited. The situation may change a little when considering production in international journals that are not part of the focus of this study, but this does not diminish the potential for discoveries and investigation that these new areas of study represent.

FUNDING SOURCE

The first author received funding from the Universidade do Estado de Minas Gerais in the modality “UEMG Productivity Researcher – PQ/UEMG”

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AUTHOR CONTRIBUTION

Henrique Amorim Machado conceived the study and wrote the paper. Patricia Soares Rezende prepared the maps and wrote the paper. Alcione Rodrigues Milagres wrote the paper and collected the data. Vinícius Nunes de Lima Gabriel collected the data in the Revista Brasileira de Ciência do Solo. Fabricio Cunha Fonseca collected data from the other journals analyzed.