Agricultural Tractor Test: A Bibliometric Review

Kléber Pereira Lanças 1*, Aldir Carpes Marques Filho 2, Lucas Santos Santana 3, Gabriel Araújo e Silva Ferraz 2, Rafael Oliveira Faria 2 and Murilo Battistuzzi Martins 4

1 Rural Engineering and Agricultural Mechanization Department, College of Agricultural Sciences, São Paulo State University—UNESP, Botucatu 18610034, SP, Brazil
2 Agricultural Engineering Department, Federal University of Lavras, Lavras 37200000, MG, Brazil; aldir@ufla.br (A.C.M.F.); gabriel.ferraz@ufla.br (G.A.e.S.F.); rafael.faria@ufla.br (R.O.F.)
3 Agricultural Engineering Department, Federal University of Vale Jequitinhonha e Mucuri, Unaí 38610001, MG, Brazil; santana.santos@ufvjm.edu.br
4 Cassilândia University Unit, Mato Grosso do Sul State University—UEMS, Cassilândia 79540000, MS, Brazil; murilo.martins@uems.br
* Correspondence: kp.lancas@unesp.br

Abstract: Agricultural tractors are an essential agricultural power source. Therefore, the scientific literature tests have described agricultural tractors’ evolution over time and determined future trends. This paper uses bibliometric tools to assess the agricultural evolution of tractor testing from 1969 to 2022 to ascertain the publication’s scientific perspective on operational, ergonomic, and energy performance. We searched for relevant research in the Scopus and Web of Science (WOS) databases. The data were processed in RStudio software version 4.4.1, and we used elaborated bibliometric maps to research evolution, major journals, studies, countries, and keywords. The first research mainly concerned the development of new wheelsets, more efficient engines, and fuel consumption prediction models. After the 2000s, environmental protocols contributed to increasing publications on biofuels and renewable energies. Recently, an intense process of robotization in autonomous vehicles has improved to allow the replacement of combustion engines. Ergonomics and safety have been less recurrent topics in recent years, indicating a stable level in the actual research. New machine control models involving artificial intelligence are currently applied to obtain test results without using the machine in the field. These virtual models reduce costs and optimize resources. The most common terms were “tractor” and “agricultural machinery”. The terms “Electric tractor”, “agricultural robots”, and “Matlab” indicate solid trends for future research.

Keywords: agricultural machinery; tractors homologation; traction test; fuel efficiency; electric tractor; agricultural robots

1. Introduction

Agriculture tractors have become the prominent moving source of power in agriculture [1–3]. These machines serve as propellers for agricultural implements, applied in operations from soil preparation to harvesting [4–7].

The first traction machines were equipped with external combustion engines from old railway locomotives equipped with metallic wheels used to pull moldboard plows and machine stationery, activating the implements through belts. During machine evolution, new technologies appeared to equip the tractor over this machine’s one hundred years of existence [1]. Nowadays, self-propelled and electric models have arrived on farms. However, some old performance problems must be resolved entirely, especially in combustion-powered tractors.

After the first agricultural tractors’ emergence, standardized tests were needed to understand their performance [8,9]. Initially, tests on tractors sought to evaluate characteristics such as power availability and operational performance. Initially, North
American farmers were dissatisfied with purchasing some tractor models, feeling deceived, and decided to create rules and test methodologies to regulate the marketing of machines with low performance [1].

However, with machine modernization, tests evolved to consider new research factors, such as ergonomics [10], safety [11,12], types of wheelsets [13–17], combustion engine performance [18], traction efficiency [2,5,6,19,20], energy demand [3,5,21], electric propulsion [22–25], hydraulic lift capacity [26], and emission reduction [27,28].

Agricultural operations with tractors can pose risks to human health due to functional exposure to noise, operator’s station vibrations, exposure to smoke and toxic gases, and even failures in the external machine’s safety signs [5]. Several studies address seat development, suspension systems, cabins, and wheelsets to improve operator comfort; this contributes to reducing work pathologies [29–31].

Tractor wheelsets, as a source of propulsion and conversion of engine power to wheelset in interaction with the ground, have been the subject of a significant number of studies involving factors such as machine traction performance [14], carrying capacity [32], and the impacts of wheelset on soil [20]. The interest in the applied load to soil compaction arose when tractors became heavier due to the power gain needed to carry out large-scale agricultural operations.

With the wealth of information available on performance tests with tractors, bibliometric analysis can dynamically map the evolving theme. This approach identifies key players in scientific production (research, researchers, and institutions), revealing trends and their associations with specific regions. Bibliometric analyses employ quantitative and qualitative measures to evaluate scientific impacts using metrics like citation counts, author production lists, thematic bibliographies, and publication patterns [33].

Systematic reviews aim to address a specific research question through a methodological approach that involves synthesizing related literature [34]. Citation tracking involves identifying the most relevant journals for a particular area, which is crucial to initiating scientific research [35]. Bibliometric methods aid the research process [36,37] by utilizing research metrics such as citation numbers, publication volume, and relevant journals; this facilitates the scientific understanding of a given topic [38]. Bibliometric analysis allows for identifying dynamics and potential trends in scientific production [39,40]. Furthermore, it categorizes the existing literature, displaying the trajectory of traditional and emerging publications [41,42], thereby enabling the determination of future investigation trends and the utilization of terms employed by research groups [43,44]. These studies establish explicit and rigorously applied criteria, simplifying their subsequent replication [45]. Although the use of systematic reviews in agriculture is recent, this technique has grown in popularity due to its effectiveness in synthesizing knowledge on the subject [46].

Mapping global scientific research involving tests with agricultural tractors has become important due to the relevance of this machine to agricultural energy consumption, pollutant emissions, and impacts on the soil and the environment. The results of these studies are scattered across different scientific bases and need more systematization. In this way, new investigative paradigms can emerge for future approaches.

This study aimed to explore the evolution of agricultural tractor testing from 1969 to 2022 through bibliometric tools, observing scientific publications on operational, ergonomic, and energy performance. Specifically, the investigation brought together a global research vision regarding the future trends of tractor tests in the scientific bases of Scopus and the Web of Science (WOS).

The research is presented as follows: In Section 2, Material and Methods, we describe in detail the application of bibliometrics and the search parameters in the databases. In Section 3, Results and Discussion, the results are presented in the following order: Section 3.1, research evolution; Section 3.2, top journals’ research; Section 3.3, top countries’ research; Section 3.4, keyword mapping; Section 3.5, trend mapping. Finally, the main conclusions are presented in Section 4 of this study.
2. Materials and Methods

Search procedures in bibliometric analysis begin with the definitions of search terms in each explored database. The scientific bases Scopus and Web of Science were selected for this research, aiming at a representative number of metadata. Bibliometric scientific approaches generally use the Scopus and Web of Science databases due to the presence of research quality indicators [47,48]. Research on different scientific bases is essential for adequately applying bibliometric indicators in scientific research evaluation [49]. This technique makes the search comprehensive [50].

After delimiting the bases to be explored, keywords were selected for representative searches about the theme of agricultural tractor tests. In this step, we tried to eliminate words that promoted results generalization. Also, it is necessary to choose enough key terms so as not to restrict or include related searches [51]. The procedures used in this study are summarized in the flowchart in Figure 1.

![Figure 1. Search procedure and bibliometric review details.](image)

2.1. Research Characterization

In bibliometric research, trends can occur, so it is essential to emphasize the criteria adopted during the systematic search and results interpretation. In our research, PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) were adopted and met through a specific checklist to promote transparency and accuracy in the review process [52]. For bibliometric research characterization involving the tests and historical applications of agricultural tractors, the keywords were defined as follows. Scopus: TITLE-ABS-KEY (agriculture OR agricultural) AND TITLE-ABS-KEY (tractor AND efficiency AND test) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")). Web of Science: (TS = (agriculture OR agricultural)) AND TS = (tractor AND efficiency AND test). The results were limited to scientific articles and reviews.

In the Scopus database, 419 results of articles related to the search terms were found. After filtering the materials, 127 conference materials and conference abstracts were discarded, totaling 292 valuable papers, including reviews. In the Web of Science base—(Clarivate Analytics), 177 related documents were found, of which 148 were used and 29 were discarded among abstracts and conference texts.
2.2. Selection and Adjustments in Databases

The files downloaded from the bases were merged into a single file using RStudio software by Bibliometrix Biblioshiny R-package developed by Aria and Cuccurullo [53]. Duplicate papers were excluded, and only one research file was maintained, containing all studies covering the theme. For the creation of bibliometric maps of the author’s keywords and total keywords, the terms “agricultural (tractor)” and “tractor (truck)” were unified to represent only the word “tractor”.

2.3. Bibliometric Mapping

Journal research quality criteria for citations and scientific impact were as reported by [54]. This pattern was used to construct a bibliometric map of the annual evolution of publications, citations, primary searches, prominent journals, most influential countries by published article number, main keywords by authors, and main keywords in the most important publications, and central knowledge areas involved trends and indication terms for future research.

The bibliometric maps of co-occurrence between authors and words were built using multidimensional relationships between search parameter’s main terms. In this step, the VOSviewer Software version 1.6.20 was used, which locates the words in a dimensional space, portraying the distance between the items according to their similarity degree.

The results were presented in circle form, representing the items found in the search. Then, these items were grouped and represented by colors, forming a bibliometric map [55]. Search evolution, authors’ relevance, countries’ importance, search relevance, and a keyword trend map were constructed using Bibliometrix’s R software and the Biblioshiny package [53].

3. Results and Discussion

3.1. Research Evolution

The keywords selected showed 440 articles published on testing tractors in agriculture between 1969 and 2022. A temporal evolution in Figure 2 shows the articles found each year showed significant growth in scientific production relating to tractor tests from the early 2000s, which may be related to the internet popularizing access to global research. Given the results, we realize stable analysis from 1969 to 1998, with a slight increase in the early ‘90s.

Figure 2. Scientific studies on agricultural tractor tests in time scale. The blue line represents the number of articles over the period investigated.
The starting point for research into efficient production processes occurred at an event discussing world energy. Founded in 1924 by Daniel Dunlop, the World Energy Council brought together the world’s most outstanding leaders since the First World War ended to discuss how the market increased production process efficiency. In 1930, Albert Einstein attended this conference, discussing his theories of space, field, and ether in physics. That year, theoretical physicists investigated applying subatomic energy to propel machines previously powered by coal and oil [56].

The first scientific period for researching tractors, from 1950 to 1970, tried to solve problems with wheelsets, engine efficiency, fuel consumption prediction [57], and the relationships between machine mass and traction capacity [58]. After the 1970s, alternative fuels with new energy sources were incorporated as research topics. Additionally, problems related to high energy demand in soil preparation operations are evidenced, which also occurs with tire efficiency studies [13].

The 1977 World Energy Congress, held in Istanbul, featured prominent world leaders addressing clean energy sources. Oil-producing countries, including Saudi Arabia, boycotted this edition. This conference was an essential milestone for guiding the search for alternative energies to oil, coal, and natural gas [56]. Alternative energies marked tractor research from the late 1970s through the entire decade from 1980 to 1990.

Embedded electronics and communication protocols began to be implemented in the 1980s on tractors and agricultural machines, allowing for more research at the end of that decade. During this period, the CAN (Controlled Area Network) language was also created, focusing on automating control processes in self-propelled machines. Initially, the technological novelty of CAN was installed in trucks and cargo vehicles; later, it was made available in agricultural machines. Embedded systems have evolved intensely in recent years and machine electronics have evolved into modern telemetry systems [59].

At the end of the 1980s, studies addressed pollutant emissions. Environmental performance results were released, driven by discoveries on productive models such as precision and sustainable agriculture. In the early 1990s, government pressure reduced pollutant emissions and corrected the management of radioactive elements, and thus, efficient energy models were evident. It culminated in the Kyoto Protocol, signed in 1997, outlining several demands related to sustainability [56].

New engine models emerged after the 1990s, equipped with devices to reduce polluting gas emissions as well as alternative propulsion systems. These technologies include exhaust gas recirculation systems (EGR—Exhaust Gas Recirculation). These systems insert the burned gases into the compression chambers, reducing atmospheric pollutants emissions. There are also SCR (Selective Catalytic Reduction) systems with selective catalytic reduction gas emissions after fuel combustion, generally based on exhaust gases’ reaction with organo-nitrogen chemical agents.

Computing associated with embedded electronics in agricultural machines and tractors substantially boosted scientific research after the 2000s. Environmental protocols signed by countries, assuming the commitment to reduce greenhouse gas emissions [27], contributed to increased research on this topic. From 2018 to 2019, there was a strong process of robotization in agriculture aided by intelligent machines [22].

### 3.2. Top Journals’ Research

The most relevant journals are Nongye Gongcheng Xuebao—Transactions of The Chinese Society of Agricultural Engineering (CSAE), Applied Engineering in Agriculture—American Society of Agricultural and Biological Engineers (ASABE), and Journal of Ter-ramechanics. Next, Biosystems Engineering and Fuel are both Elsevier base members. The leading journals found have, in their scope, innovative research areas in engineering and agricultural systems’ machine development. They are journals with interdisciplinary profiles exploring engineering’s interaction with biological systems.

The Fuel journal publishes studies on energy sources such as fuels and derivatives. Recently, it has addressed topics such as pollutant emissions, biofuel performance, and
alternative energy. Over more than 90 years, this journal has contributed to the environmental and energy fields. New environmental protocols and climate change have hastened new energy sources and sustainable production systems research.

Several studies on agricultural tractor performance are directly related to machine efficiency in field operations, which has remained relevant from the early tractor testing days to the present. Some engine models to equip agricultural tractors still show a divergence from the data reported by manufacturers regarding field performance [18].

Energy, Journal of Terramechanics, and Soil and Tillage Research occupy relevant positions, justified by their scopes, related to machines’ performance in agricultural systems. These journals represent significant, high-impact research on tractors’ performance in agricultural field operations, machine–soil interaction, and new wheel models.

The Journal of Cleaner Production, Computer and Electronics in Agriculture, and Biomass and Energy present topics related to clean energy application, sustainability, onboard electronics, and waste use. However, these periodicals also publish studies on machines interacting with environmental agents, automation machine systems, and residual biomass in agriculture.

Journals with open access have a greater impact, which provides greater dissemination and eases access to research findings (Table 1). Relevant publication studies in open-access databases allow for greater scientific dissemination [60]. The h-index is a proposal to quantify the productivity and impact of individual or group research based on the most cited articles (papers) and the number of citations. Thus, an h-index of 10 means that a given author has 10 articles cited at least 10 times. The g-index is calculated based on the distribution of the citations from a given researcher’s publications. The g-index is the most significant single number, so the main g articles received at least g2 citations. Therefore, a g-index of 10 indicates that the 10 leading publications of an author were cited at least 100 times (10 squared).

**Table 1.** Top journals by articles published.

<table>
<thead>
<tr>
<th>Journal</th>
<th>H_Index</th>
<th>G_Index</th>
<th>C</th>
<th>NP</th>
<th>PY_Start</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nongye Gongcheng Xuebao—CSAE</td>
<td>15</td>
<td>18</td>
<td>596</td>
<td>55</td>
<td>2006</td>
</tr>
<tr>
<td>Applied Engineering in Agriculture—ASABE</td>
<td>10</td>
<td>16</td>
<td>257</td>
<td>17</td>
<td>1989</td>
</tr>
<tr>
<td>Journal of Terramechanics</td>
<td>9</td>
<td>11</td>
<td>205</td>
<td>11</td>
<td>1988</td>
</tr>
<tr>
<td>Biosystems Engineering</td>
<td>8</td>
<td>13</td>
<td>199</td>
<td>13</td>
<td>2003</td>
</tr>
<tr>
<td>Nongye Jixie Xuebao—CSAE</td>
<td>7</td>
<td>9</td>
<td>95</td>
<td>12</td>
<td>2013</td>
</tr>
<tr>
<td>Computers and Electronics in Agriculture</td>
<td>6</td>
<td>9</td>
<td>100</td>
<td>9</td>
<td>1990</td>
</tr>
<tr>
<td>Soil and Tillage Research</td>
<td>6</td>
<td>6</td>
<td>183</td>
<td>6</td>
<td>2004</td>
</tr>
<tr>
<td>Transactions of ASAE</td>
<td>6</td>
<td>10</td>
<td>102</td>
<td>10</td>
<td>1977</td>
</tr>
<tr>
<td>Energy</td>
<td>4</td>
<td>5</td>
<td>85</td>
<td>5</td>
<td>2014</td>
</tr>
<tr>
<td>Agronomy</td>
<td>3</td>
<td>3</td>
<td>15</td>
<td>3</td>
<td>2020</td>
</tr>
</tbody>
</table>

H_index and G_index: research citation impact; C: citations; NP: number of papers; PY: beginning year.

Among the top 10 journals by publications, 50% of the most relevant journals account for 47% of total citations. Chinese journals Nongye Gongcheng Xuebao and Nongye Jixie Xuebao present 37% of the total citations, showing China’s recent accelerated evolution in world research, notably in the areas of tractor development and autonomous vehicles for agriculture, mainly between 2006 and 2013.

The journals Transactions of ASAE, currently Transactions of ASABE and Applied Engineering in Agriculture, have been pioneering sites for publishing articles related to tractor testing for more than 50 years. This association was influenced by American universities in the standardization and carrying out of critical evaluations on agricultural
machines. The University of Nebraska is a pioneer and one the most important centers of study, maintaining a specialized center for evaluating agricultural machines (NTTL).

The highest h-index research is found in the Nongye Gongcheng Xuebao—CSAE (15), followed by the Applied Engineering in Agriculture Journal—ASABE (10). An h-index metric is constructed to measure citations across journal publications. Still, essential subject studies are not sometimes gathered in the same journal, an occurrence explained by productive research groups performing high self-citations (Figure 3).

![Figure 3. Total cites and self-cites in the top journals.](image)

According to Kelly and Jennions [61], the indicator has some limitations, including factors effects such as self-citations, co-authorship count, and the nature of review articles with high citations. According to Naderbeigi et al. [62], self-citation in all knowledge areas is accepted, as they are oriented to the research theme in the same group for several years. In these cases, it is apt to highlight researcher occurrences of high scientific impact when highlighting top journals or authors. Self-citation cases in agriculture may be linked to specific regional problems, whether geographical, social, or economic. These are cases in which keywords are world-used but solve local problems. The relationships to leading journals from the co-citations number are described in Figure 4.
Figure 4. Relationship to citations and research in major journals. Colors and thicknesses of the cluster lines indicate relationships between words.

Co-citations within the same journal result from the bias of each research group. Therefore, researchers and groups that use a particular journal as the basis for their studies tend to publish and cite the same journals during the investigation development period, increasing the co-citations.

Quantitative measures demonstrate the potential impact of a researcher’s work or journal articles, making them preferable to subjective measures. Citations are often considered the most influential [63]. Table 2 displays the primary relevant scientific articles based on citation count.

Table 2. Main articles published by relevant citations.

<table>
<thead>
<tr>
<th>Paper</th>
<th>DOI—Title</th>
<th>TC</th>
<th>TC Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liu et al., 2008</td>
<td>10.1016/j.ejor.2007.06.032—On solving multiobjective bin packing problems using evolutionary particle swarm optimization</td>
<td>112</td>
<td>7.47</td>
</tr>
<tr>
<td>Kheiralla et al., 2004</td>
<td>10.1016/j.still.2003.12.011—Modelling of power and energy requirements for tillage implements operating in Serdang sandy clay loam, Malaysia</td>
<td>77</td>
<td>4.05</td>
</tr>
<tr>
<td>Grisso et al., 2004</td>
<td>10.13031/2013.17456—Field efficiency determination using traffic pattern indices</td>
<td>69</td>
<td>3.63</td>
</tr>
<tr>
<td>Hameed et al., 2016</td>
<td>10.1016/j.robot.2015.11.009/Side-to-side 3D coverage path planning approach for agricultural robots to minimize skip/overlap areas between swaths</td>
<td>61</td>
<td>8.71</td>
</tr>
<tr>
<td>Molari et al., 2012</td>
<td>10.1016/j.biosystemseng.2011.10.008—Performance of an agricultural tractor fitted with rubber tracks</td>
<td>60</td>
<td>5.45</td>
</tr>
<tr>
<td>Sun et al., 2017</td>
<td>10.3390/rs9040377—In-field high-throughput phenotyping of cotton plant height using LiDAR</td>
<td>54</td>
<td>9.00</td>
</tr>
<tr>
<td>Battiauto &amp; Diserens, 2017</td>
<td>10.1016/j.still.2016.09.005—Tractor traction performance simulation on differently textured soils and validation: A basic study to make traction and energy requirements accessible to the practice</td>
<td>48</td>
<td>8.00</td>
</tr>
<tr>
<td>Tomić et al., 2013</td>
<td>10.2298/TSCI111122106T—Effects of fossil diesel and biodiesel blends on the performances and emissions of agricultural tractor engines</td>
<td>45</td>
<td>4.50</td>
</tr>
</tbody>
</table>
Liu et al. [32], members of the Department of Electrical and Computer Engineering, National University of Singapore, achieved the highest number of citations, studying a mathematical model to determine the loading capacity of transport vehicles. This research applied to several areas of knowledge, which may explain its high citation impact.

In the second position, Kheiralla et al. [64], in Faculty of Engineering, University of Khartoum, evaluated the power and energy requirement for soil preparation, comparing the energy demands with the estimation methods proposed by American Society of Agricultural Engineers (ASAE) as standard and inferred that this methodology overestimates fuel consumption by 17 to 33%. Grisso et al. [65], at Virginia Polytechnic Institute and State University, published the first models for predicting fuel consumption in agricultural tractors. Based on reports published by Nebraska Tractor Test (NTTL), this research was updated in 2008 and 2010, encompassing new machine models and prediction patterns.

Serrano et al. [66], of the Engineering Department, University of Évora, related to fuel consumption in different implement combinations, where power demand varies depending on soil type and depth work. The authors stated that, in order to obtain better tractor energy yields, the tractor should operate at a regime rotation from 70 to 80% of the rated engine rotation, preferably in higher gears, to reach ideal working speeds in a low engine rotation.

Kim et al. [20], at the Smart Bio-industrial Mechanical Engineering Department, Kyungpook National University, evaluated the tractor’s traction performance in soils with different water contents; the authors found that soil water content can affect the tractor’s traction efficiency improves severely in dry soils. The transit of heavy machinery on high water-content ground impairs traction performance and affects the soil’s physical quality. Del Rey et al. [67] of the Córdoba e Sevilla University group compare RTK (Real Time Kinematic) and RTX (Real Time Extended) positioning correction systems in tractor steering. For straight paths, the RTK system offered an average error of 1.43 cm and RTX of 2.55 cm; this study opened new investigations in machine-controlled traffic and soil compaction.

Research by [20,66], evaluating tractors’ traction capacity and energy capacity, indicates that traction performance issues remain evident in current scientific research. Hameed et al. [68], at the Norwegian University of Science and Technology, addressed machine steering and overlapping work lanes for autonomous vehicles. Molari et al. [14], at the Department of Agricultural Economics and Engineering, Bologna University, pioneered a study on belting rubber mats in agricultural tractors to reduce soil impact and improve traction. This research opened the way for new investigations relating to distribution mass, fuel consumption efficiency, and wheelsets to preserve soil physical structure.

Sun et al. [69], of the University of Georgia, built an elevation model applying “Light Detecting and Ranging” (LiDAR) technology in cotton crops, adapting a LiDAR system to determine plant volume characteristics under natural lighting in an agricultural tractor. The research opened new possibilities for a sensor in tractors unifying operations in precision agriculture for data collection.

Battiato and Diserens [70], at the Institute for Sustainability Sciences, Switzerland, studied soil wheel interaction models in different soil profiles and dynamic loads on tractors. The model proposed by the authors estimates the active machine rolling radius, allowing the prediction of traction in different soils and wheel loads. The authors created a
spreadsheet application (TASC v3.0) allowing decision-making for tractor configuration in various operations and agricultural conditions.

Tomić et al. [71], at the University of Novi Sad, Faculty of Agriculture, investigated biodiesel blends in diesel engines, measuring pollutant emissions and performance. Blends with biodiesel increased engines’ thermal efficiency, reducing CO (Carbon monoxide), CO₂ (Carbon dioxide) and greenhouse gas emissions. However, NO (Nitrous oxide) emissions are increased. Similar results were obtained by Emaish et al. [28], highlighting the importance of pollutant reduction achieved in recent years.

3.3. Top Countries’ Research

Evaluating scientific production by country verifies the country’s presence in a global agricultural representation, starting with China, the United States, and Brazil, highlighting the importance of these localities (Figure 5). Then, Italy, India, and South Korea appear in the spotlight. Germany, France, Poland, and Japan complete the countries with representativeness in agricultural tractor research.

![Figure 5. Tractor test: Main countries with scientific production.](image)

Bibliometric reviews on agricultural activities highlight China, the United States, and Brazil as the most relevant countries in agricultural knowledge production. In addition to developing agricultural technologies, China has significant policy incentives for improving crop efficiency [72]. The United States is a pioneer in tractor performance standards; from this country came the basis of current test codes [1]. Brazil, a traditionally agricultural country with strong mechanization, has conducted significant research on machine energy consumption and systems engineering for tropical agriculture.

In Figure 5, important countries such as Spain, Australia, the Netherlands, Russia, and the United Kingdom are impossible to observe. However, this does not indicate that these regions are not significant in research on tractors; they are just not in the database investigated. Researchers from these countries may not adopt the keywords addressed at the beginning of this research. Another factor is that some countries do not disseminate their research through indexed papers, harming the research’s dissemination performance.
The significant presence of strong agricultural countries with high commodity production and exports occupies a prominent research position in regard to agricultural tractors. The non-representation of countries on the African continent can be related to the incipient technological level of agriculture in most of the territory, extending to its incipient mechanization.

3.4. Keyword Mapping

Figure 6 describes the general keywords’ co-occurrence. The terms tractor and fuel consumption (red group) are highly engine-related, including engine speed, efficiency, and traction. This relationship between traction and engine speed performance or machine energy performance can be proven in the research by [5,6,18].

In the green group are general keywords; the mid-term is “agricultural machinery”, related to optimization, testing, experiments, crops, harvesters, sensors, and control. The group’s common characteristic is an agricultural application, including specific cultivation terms such as “potato” and “crops”. This word group is characterized by the generic term “test”, which indicates the procedure application is usually standardized to measure systems performance. This relationship is apparent in connection to “optimization” and “control”.

The third word cluster with high interaction is located on the left map side (blue). This group lists agricultural tractors as a mid-term, relating to tillage depth, flow efficiency, biodiesel, diesel engine, engine performance, and finally, emissions. This research group tends to investigate energy performance, highlighting new fuels and mixtures [27] to optimize energy performance or reduce pollutant emissions.
The cluster energy investigation performance relates to mechanization area researchers. The soil preparation performance equipment requires high energy demand [7]. The words “tractor” and “agricultural machinery” can be seen in the interaction map center. There is a high relationship between “agricultural tractor” and “fuel efficiency, biodiesel and fuel consumption”, highlighting the cluster’s energy efficiency character (blue).

The groups researching tractors’ energy investigate fuel efficiency and engine systems (blue cluster); there are links with research investigating traction efficiency, fuel consumption (red group), and soil operations (yellow cluster). These correlations are closely linked to energy efficiency, fuel consumption, and alternative fuels (biodiesel). After all, biofuels can mitigate alternative energy resources’ dependence on petroleum derivatives.

The words most used by the authors were “tractor” and “agricultural machinery”, the latter being more strongly related to control systems’ development groups, experiments, sensors, and design. The term “tractor” is described in several studies as “agricultural machinery” and stems from the essential characteristic of the tractor in operations, serving as a mobile power source and always requiring coupled machines to carry out agricultural work effectively.

The oriented map highlights the authors’ keywords and their relationships: the energy bias research (blue cluster), the words tractor, fuel efficiency, and fuel consumption, and the experimental field research, represented by the phrase “agricultural machinery” and experiments (orange cluster). The main words are still related to traction, efficiency, and biodiesel (Figure 7).

![Figure 7. Keywords map used by the authors: (a) relationships with the keyword “tractor”; (b) relationships with the keyword “fuel efficiency”; (c) details of the strong relation with the electric tractor word. Colors and thicknesses of the cluster lines indicate relationships between words.](image-url)

The electric tractor, field test, and traction performance terms (green cluster) are related to study groups addressing the word “design” (red collection), showing the
incipient nature of technologies in agricultural research scenarios. Research in this line is currently under development in agriculture.

The term “design” is also related to developing machines with better ergonomics and safety. In research for developing new seat models for tractor protection systems, the keyword most used by the authors was “design”. According to Hoy and Kocher [1], the development of tractors safer with lower levels of noise and vibration for operators was driven by compulsory tests on tractors proposed by the Nebraska Tractor Test Laboratory (NTTL) and international standards from the Organization for Economic Cooperation and Development (OECD).

3.5. Trend Mapping

The trend map shows the scientific research’s paths over the years (Figure 8). This Figure allows researchers to understand the research directions over the period studied.

![Figure 8. Trend map keywords research from 1969 to 2022.](image)

From 1969 to 1999, the tractors term, agricultural tractors, and mathematical models were the most discussed in the first research years. However, the research cluster that investigated “tractors” in 1969–1999 began to use, from 2001 to 2015, the terms agricultural tractors, friction tractors, and spraying. This fact is interesting because after the research was dedicated to tractors in isolation, new research fronts were opened, and field operations began to be studied, such as phytosanitary products’ application.

The terms spraying and agricultural engineering occurred in the second research period, between 2001 and 2015, a period marked by relevant technological transformations in the world of agriculture. New agricultural inputs were created, and there was a massive implantation of crops with genetically improved cultivars resistant to certain herbicides, such as glyphosate. Therefore, management with agrochemicals significantly increased worldwide.

Research in agricultural tractors from 1969 to 1999 continued from 2001 to 2015 using the same word, adding the “fuel consumption” term. Between 2001 and 2015, the group that applied mathematical models turned its research attention to the term traction...
(friction), which indicates the mathematical model's application to theories that explain traction machines and wheel–soil interaction.

Between 2001 and 2015 and 2016 and 2022, significant changes occurred to the terms applied by each research cluster, which may indicate a period with paradigm shifts in science toward agricultural mechanization. The term “Agricultural Tractor” continued to be used by researchers in phytosanitary product applications, traction performance studies, fuel consumption [5], and hydraulic systems.

New terms emerged from 2016 to 2022, such as energy, performance, development applications, and agricultural machinery. These terms portray a research phase of new paradigms in energy performance [7] and new tractors’ performance development [6,24,73]

Figure 9 shows the term’s frequency and its application trends in scientific research. The topics demonstrate strong trends in their actual research application to electric tractors [22] and agricultural robots. Matlab occurs in sequence, where mathematical simulation prototyping passes through the previous modeling phases to subsequent terms under development.

Software application allied to mathematical simulation tools has been evidenced in recent years of research on agricultural tractors [25,74–76]. Modern computational resources, such as forecast models, allow new projects to be quickly developed at an affordable cost. This usually occurs before starting the evaluation and the physical development projects, reducing the cost of establishing technologies by accelerating research results.

Some terms related to traction efficiency, tires, and fuel efficiency have continued to be used frequently in recent years. This demonstrates that some research demands in these areas still need to be fully resolved. New tractor models and propulsion systems may require new research and development approaches.

The search term “tractors (agricultural)” indicates a high application frequency between 2012 and 2020, while the term “electric tractors” started to be applied after 2019; curiously, the term “agricultural robots” started in 2013, when the first research began to be carried out.

In recent years, “computer simulation” may have evolved into more synthetic terms such as “Matlab”. The same can happen with new simulation software when applied to computational modeling. The direct software mention or application name makes the search approach in keywords natural and synthetic. New control models for agricultural
machinery involving artificial intelligence have been widely discussed in scientific circles. These models can obtain test results without applying the machine directly in the field. These simulations present comparative results based on previous test databases, with predictive algorithms close to those obtained from real tests.

Current artificial intelligence models are still in the early stages of development. However, due to their high learning rate, they will be exponentially improved, perhaps generating more assertive answers than those obtained in real tests with agricultural tractors.

Future research trends indicate a strong relationship between agricultural machinery, tractor design, experiments, fuel consumption, and agricultural tractor, applying these words in future studies (Figure 10). These terms can be associated with each research’s specific terms, allowing greater study penetration to base and research clusters.

![Figure 10. Future trends map and relevant keywords topics by author.](image)

Before reaching autonomy in completely electric components, the tractor’s propulsion will be directed to a previous phase of hybridization of their engines with mechanical variable transmission systems [77] and combustion engines. Relevant studies were carried out by [25,78]. While in some regions, methods are still being studied to increase traction capacity in agricultural tractors powered by combustion [73], others are dedicated to improving the practical battery life and mass of tractors for workability.

Research by Baek [22] discusses improvements in electric propulsion systems in tractors and opens new research possibilities. The authors evaluated the electric tractor’s performance on a standardized traction surface. They proposed an algorithm for traction tests with electric tractors by reading variables obtained from the electric motor’s torque and current output data.

Melo et al. [2] developed a system of slippage control for electric tractors since the traction coefficient systems are still lower than traditional systems. Liu et al. [23] complemented studies on electric motor performance in tractors and specific algorithms based on the response to multiobjective operation factors, thereby achieving greater operational efficiencies.

The new agricultural tractors gradually incorporate advanced technological resources, such as embedded computing, artificial intelligence, and telemetry. As it is still the main machine in agriculture, the tractor needs new performance evaluation protocols [9], so there is room for research and development in this field.
Challenges related to the low speeds of the wide range of operating tractors in the field have led researchers to study new power systems and speed transmissions in electric tractors, as in the research of Wen et al. [24] and Xie et al. [25], who developed new testing systems, solving operational problems for electric tractors, and increasing their efficiency. In the same way that occurred with combustion-powered tractors in the 1950s and 1960s, essential aspects of implementing electric technology in tractors are currently being studied to increase their efficiency and standardization.

Research addressing electrical and self-propelled systems has grown significantly in recent years. Tractors have reached their power peak, causing severe problems regarding soil structure and inefficient energy and for the environment. The future trend is the agricultural machines’ downsizing and robotization in situ. Applying keywords such as electric tractors, agricultural robots, and energy efficiency can allow greater penetration for future studies.

4. Conclusions

The bibliometric analysis allowed us to see the test evolution of tractors over half a century of research and the future trends in this subject. The leading journals, studies, and countries were listed and organized according to their relevance and scientific impact.

There was a significant increase in studies published in the 1990s. The bibliometric maps showed, after decades of research addressing steering models, wheelset types, ergonomics, and more efficient energy systems for tractor propulsion, a research trend has been directed towards electric models that are autonomous and robotic in agriculture.

Combustion-powered tractors remain in the research scenario, but models trend towards hybridization, propulsion engines, and new transmission variable systems. Ergonomics and safety are less recurrent topics in recent research, indicating a stability related to research problems.

The research trend is towards mathematical simulations, artificial intelligence, and new standardized tests for evaluating performance. New control models for agricultural machinery involving artificial intelligence are currently applied, making it possible to obtain test results without using the machine in the field. These virtual models should be vastly improved in the future, reducing costs and optimizing resources. The trend maps showed current research solving traction issues, design, batteries, connectivity, and steering systems for electric tractors. Some of these topics have been studied for traditional combustion-powered tractors, as they are still obstacles for electric and autonomous tractors.

New lines of investigation must be considered to evaluate alternative energy technologies more accurately in agricultural tractors, such as ethanol, biodiesel, hydrogen, and electricity propulsion. These technologies require new rules and conditions for comparative testing related to traditional combustion tractors.

The correct keywords used in the research knowledge area can allow gains in scientific dissemination and unite research pairs around each investigated theme or research cluster. The most cited general words were “tractor” and “agricultural machinery”. The most used recurrent terms in recent years were “electric tractor”, “agricultural robots”, and “Matlab”, indicating significant trends for future research.

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Keypoint 1


Keypoint 2


Keypoint 3


Keypoint 4


Keypoint 5


Keypoint 6


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