DOI: 10.65322/j.srd.05192026.37

EVOLUTION AND EMERGING RESEARCH DIRECTIONS IN AGRICULTURAL TRACTOR VIBRATIONS AND DYNAMICS: A COMPREHENSIVE SCOPUS-BASED BIBLIOMETRIC ANALYSIS

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Abstract. *Vibrations and dynamic loads of agricultural tractors determine operator health, ride comfort, structural reliability, stability and the impact on soil. This study maps the research landscape using a Scopus export of 545 documents published in 1965–2026 (retrieved 21 September 2026). Publication dynamics, document and source types, geography, authorship, citation impact, keywords and thematic structure were analysed. Output has grown steadily: 72.7% of the documents appeared after 2010, with a peak of 37 documents in 2022. China (86 documents), the United States (72), Canada (41), Italy (39), India (37) and Ukraine (36) lead the field, while only 19.8% of documents with affiliation data are internationally co-authored. The corpus has received 6095 citations (h-index 37), concentrated in whole-body vibration, ride-comfort and suspension studies. Thematic analysis shows that modelling and simulation (55.0% of documents), suspension and ride comfort (51.6%) and tyre/track–soil interaction (44.4%) dominate, whereas autonomous platforms, optimization and AI methods, and energy efficiency have grown fastest since 2010. Only 12 documents (2.2%) mention chassis geometry (wheelbase, track width, ground clearance) in their title, abstract or keywords, and few of them study its effect on tractor oscillations, which points to a gap for experimental field studies.*

Аннотация. *Вибрации и динамические нагрузки сельскохозяйственных тракторов определяют здоровье водителя, удобство езды, конструктивную надежность, устойчивость и воздействие на почву. Данное исследование отображает картину исследования с использованием экспорта Scopus (545 документов, опубликованных с 1965 по 2026 год) (доступно 21 сентября 2026 года). Проанализированы динамика издания, типы и источники документов, география, авторство, влияние цитат, ключевые слова и тематическая структура. Производство неуклонно росло: 72,7% документов появились после 2010 года, пик - 37 в 2022 году. Лидируют Китай (86 документов), США (72), Канада (41), Италия (39), Индия (37) и Украина (36), а международное соавторство составляет всего 19,8% документов. Корпус получил 6095 цитат (h-индекс 37), собранных по исследованиям вибрации всего тела, удобства ходьбы и подвески. Тематический анализ показывает, что преобладают моделирование и симуляция (55,0% документов), подвеска и удобство передвижения (51,6%) и взаимодействие шина/дорога-земля (44,4%), в то время как автономные платформы, методы оптимизации и искусственного интеллекта, а также энергоэффективность выросли быстрее всего с 2010 года. Лишь в 12 документах (2,2%) геометрия шасси (база колес, ширина колеи, зазор на земле) упоминается в названии, аннотации или ключевых словах, и лишь немногие из них изучают ее влияние на колебания трактора, что указывает на наличие пробелов для экспериментальных полевых исследований.*

Annotatsiya. *Qishloq xo‘jaligi traktorlarining tebranishlari va dinamik yuklamalari haydovchining salomatligini, yurish qulayligini, konstruktiv ishonchliligini, barqarorligini va tuproqqa ta’sirini belgilaydi. Ushbu tadqiqot 1965-yildan 2026-yilgacha nashr etilgan 545 ta hujjatning Scopus eksportidan foydalangan holda (2026-yil 21-sentyabrda olingan) tadqiqot manzarasini xaritalaydi. Nashr dinamikasi, hujjat turlari va manbalari, geografiyasi, muallifligi, iqtiboslar ta’siri, kalit so‘zlar va mavzuiy tuzilishi tahlil qilingan. Ishlab chiqarish barqaror o‘sdi:*

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hujjatlarning 72,7 foizi 2010-yildan keyin paydo bo‘ldi, eng yuqori ko‘rsatkich 2022-yilda 37 tani tashkil etdi. Xitoy (86 ta hujjat), AQSH (72), Kanada (41), Italiya (39), Hindiston (37) va Ukraina (36) yetakchilik qilmoqda, xalqaro hammualliflik esa hujjatlarning atigi 19,8 foizini tashkil etadi. Korpus 6095 ta iqtibos oldi (h-indeks 37), butun tana tebranishi, yurish qulayligi va suspenziya tadqiqotlari bo‘yicha to‘plangan. Mavzuli tahlil shuni ko‘rsatadiki, modellashtirish va simulyatsiya (hujjatlarning 55,0 foizi), osma va yurish qulayligi (51,6 foiz) hamda shina/yo‘l-tuproq o‘zaro ta’siri (44,4 foiz) ustunlik qiladi, avtonom platformalar, optimallashtirish va sun’iy intellekt usullari hamda energiya samaradorligi esa 2010-yildan beri eng tez o‘sdi. Faqat 12 ta hujjatda (2,2%) shassi geometriyasi (g‘ildirak bazasi, iz kengligi, yer ustidagi tirqish) o‘z nomi, annotatsiyasi yoki kalit so‘zlarida tilga olingan va ularning kamchiligi uning traktor tebranishlariga ta’sirini o‘rganadi, bu esa eksperimental dala tadqiqotlari uchun bo‘shliq borligini ko‘rsatadi.

Keywords: *agricultural tractor; vibration; ride comfort; whole-body vibration; vehicle dynamics; bibliometric analysis; Scopus.*

Ключевые слова: *сельскохозяйственный трактор; вибрация; комфорт вождения; вибрация всего тела; динамика транспортного средства; библиометрический анализ; Scopus.*

Kalit so‘zlar: *qishloq xo‘jaligi traktori; tebranish; yurish qulayligi; butun kuzovning tebranishi; avtomobil dinamikasi; bibliometrik tahlil; Scopus.*

1. Introduction

Agricultural tractors operate on uneven soil surfaces and under variable traction loads, so their running systems are continuously exposed to dynamic excitation. The resulting vibrations affect operator exposure to whole-body vibration [1–3], the applicability of ride-comfort standards to off-road machines [4], lateral stability and overturn risk [5], and the stress transmitted to the soil [6]. Research on these problems is carried out in several disciplines (vehicle dynamics, terramechanics, ergonomics, agricultural engineering) and is spread over many journals and conference series, which makes it difficult to see which problems are well covered and which are not.

Bibliometric analysis offers a reproducible way to describe such a field. The aim of this study is to analyse the Scopus-indexed literature on tractor and off-road vehicle vibrations and dynamics: its growth, sources, geography, most influential works and thematic structure, and to identify under-researched topics, with particular attention to the influence of chassis geometry (wheelbase, track width, ground clearance) on tractor oscillations.

2. Data and methods

The analysis is based on a Scopus export (CSV, 45 fields) containing 545 records with publication years 1965–2026, retrieved on 21 September 2026; data for 2026 are therefore incomplete. [TITLE-ABS-KEY ((tractor* OR "agricultural tractor*" OR "farm tractor*" OR "agricultural vehicle*" OR "off-road vehicle*") AND (vibration* OR oscillation* OR "dynamic response*" OR "dynamic behavior*" OR "dynamic behaviour*" OR "ride vibration*" OR "ride comfort") AND (vertical OR horizontal OR longitudinal OR lateral OR "vertical vibration*" OR "horizontal vibration*" OR "longitudinal vibration*" OR "lateral vibration*")) AND (LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "AGRI") OR LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "ENER")) AND (LIMIT-TO (LANGUAGE , "English") OR LIMIT-TO (LANGUAGE , "Russian")) AND (LIMIT-TO (PUBSTAGE , "final"))]

The records were processed in Python (pandas, matplotlib). Documents were counted by year, document type, language, source title and open-access status. Countries were taken from the affiliation field, each country being counted once per document. Authors were counted by name

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as exported by Scopus, without additional disambiguation. Author keywords (available for 322 documents, 59.1%) were converted to lower case and the most frequent spelling variants were merged (e.g. “whole body vibration” and “whole-body vibration”). Citation indicators (total, mean, median, h-index, share of uncited documents) were calculated from the “Cited by” field as of the export date.

The thematic structure was assessed with nine themes, each defined by a set of keyword rules applied to the title, abstract, author keywords and index keywords of every record. A document may belong to several themes. Theme shares are reported for the whole corpus and for four periods (up to 1999, 2000–2009, 2010–2019, 2020–2026), relative to the number of documents in each period.

30 records have no author data (mostly proceedings volumes) and 39 have no affiliation data; they were kept in the counts by year, source and theme but excluded from author and country statistics. The retrieved set also contains a few records that are only loosely related to tractor dynamics (for example, studies of bridge dynamics); they were not removed because the aim was to describe the export as retrieved.

3. Results

3.1. Publication dynamics

The documents span the years 1965–2026 (Fig. 1). Output was sporadic until the 1990s (94 documents up to 1999), amounted to 55 documents in 2000–2009, and rose to 189 in 2010–2019 and 207 in 2020–2026 (the last period covers data only up to 21 September 2026). Altogether 396 documents (72.7%) were published in 2010 or later. Five-year totals grew from 97 (2011–2015) to 108 (2016–2020) and 156 (2021–2025); the highest annual output, 37 documents, was recorded in 2022.

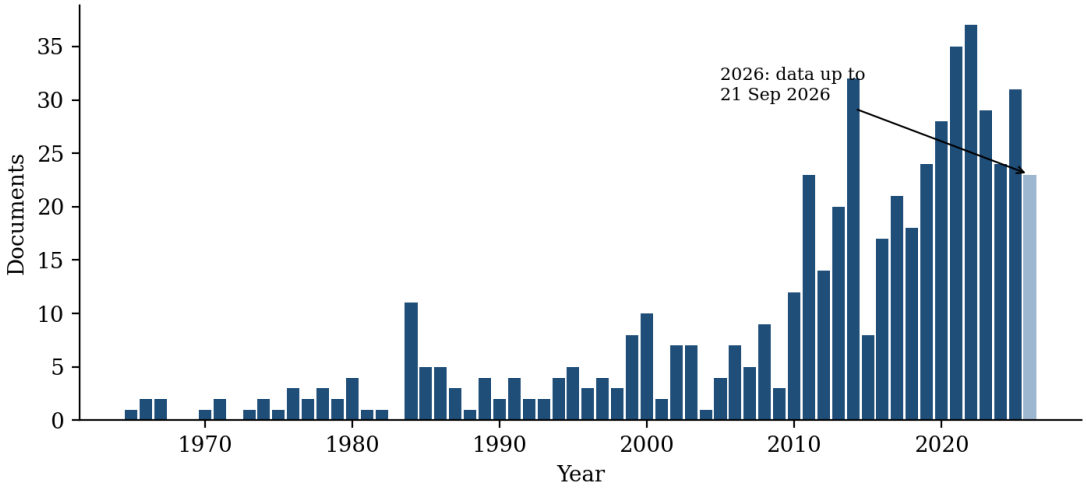

Fig. 1. Number of Scopus documents per year, 1965–2026 (2026: data up to 21 September)

3.2. Document types, language and sources

Journal articles account for 309 documents (56.7%) and conference papers for 195 (35.8%); the remainder are conference reviews (29), book chapters (6), reviews (5) and one letter. English is the language of 532 documents (97.6%), followed by Russian (12) and German (1). 28.8% of the documents are open access. The publication outlets are fragmented (Table 1): SAE Technical Papers is the largest source (54 documents), followed by the Journal of Terramechanics (20) and the book series Lecture Notes in Mechanical Engineering (18). The large share of conference outlets (e.g. ASME IMECE 2011 with 11 documents) means that a considerable part of the field is published in proceedings.

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Table 1

Ten most productive sources

Source title	Documents
SAE Technical Papers	54
Journal of Terramechanics	20
Lecture Notes in Mechanical Engineering	18
Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering	13
Journal of Agricultural Engineering Research	13
ASME 2011 International Mechanical Engineering Congress and Exposition, IMECE 2011	11
Computers and Electronics in Agriculture	10
Engineering for Rural Development	9
Vehicle System Dynamics	9
Tractors and Agricultural Machinery	8

3.3. Geography and authorship

Authors from 85 countries and regions contributed to the corpus (Fig. 2). China (86 documents), the United States (72), Canada (41), Italy (39), India (37) and Ukraine (36) are the most productive, followed by the Russian Federation (28), the United Kingdom (25), Japan (18) and South Korea (17). International co-authorship is limited: 19.8% of the 506 documents with affiliation data involve authors from more than one country. Uzbekistan is represented by six documents (1.1%), published in 2019–2026, mainly on mathematical modelling of tractor vibrations and on controllability.

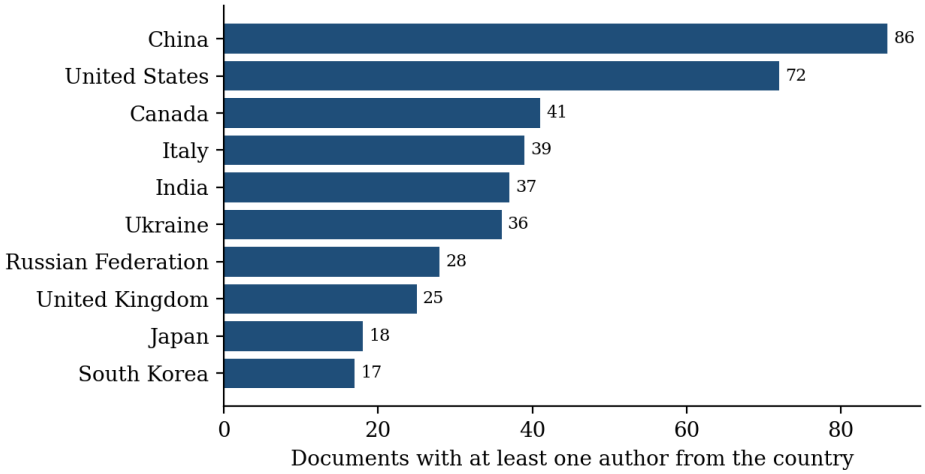

Fig. 2. Ten most productive countries and regions (documents with at least one author from the country)

The corpus includes 1356 distinct author names. The most productive are Bulgakov V. (24 documents), Rakheja S. and Nadykto V. (15 each), Ivanovs S. and Ramon H. (11 each), and Adamchuk V., Olt J. and Singh A. (10 each).

3.4. Citation impact

The documents have received 6095 citations in total (mean 11.2, median 3); the h-index of the corpus is 37 and 25.3% of the documents are uncited. The most cited works (Table 2) are devoted to whole-body vibration in vehicles, ride comfort of off-road vehicles and vibration

DOI: 10.65322/j.srd.05192026.37

emission of agricultural tractors, which confirms the central role of operator exposure and ride comfort in the field.

Table 2

Most cited documents in the corpus

Ref.	First author, year	Source	Citations
[7]	Paddan et al., 2002	Journal of Sound and Vibration	283
[8]	Uys et al., 2007	Journal of Terramechanics	186
[1]	Scarlett et al., 2007	Journal of Terramechanics	170
[9]	Paddan et al., 2002	Journal of Sound and Vibration	137
[10]	Kong et al., 2017	Journal of Bridge Engineering	119
[4]	Els, 2005	Journal of Terramechanics	116
[11]	Servadio et al., 2007	Biosystems Engineering	78
[12]	Kim et al., 2018	Applied Ergonomics	77

The fifth item [10] *concerns bridge dynamics and is only loosely related to tractor dynamics; it was retained because it is part of the retrieved set.*

3.5. Keywords and thematic structure

Author keywords are available for 322 documents and contain 1288 different terms, i.e. the vocabulary is highly dispersed. The most frequent keywords (Fig. 3) are “tractor” (26 documents), “whole-body vibration” (25), “vibration” (24), “ride comfort” (21) and “off-road vehicle” (17), followed by “agricultural tractor”, “mathematical model”, “oscillations” and “vehicle dynamics”.

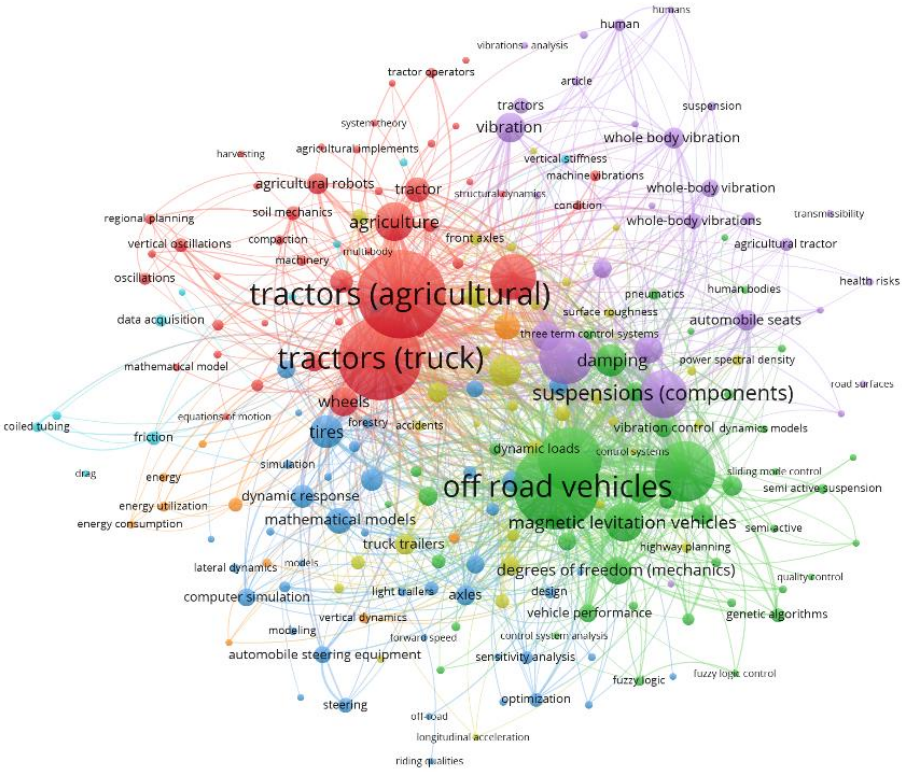

Fig. 3. Keyword co-occurrence network. Source: compiled by the authors based on Scopus data (VOSviewer)

Over the whole period (Table 3), the most common themes are modelling and simulation (55.0% of documents), suspension and ride comfort (51.6%) and tyre/track–soil interaction

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(44.4%), followed by operator exposure (31.9%) and stability and handling (29.5%). The themes changed over time (Fig. 4).

The share of operator-exposure studies peaked in 2000–2009 (49.1%), while the share of tyre/track–soil interaction rose from about one third before 2010 to 50.8% in 2010–2019 and 47.3% in 2020–2026. The fastest growth is observed for autonomous and precision-agriculture platforms (0% up to 1999, 16.9% in 2020–2026), optimisation and AI methods (7.3% in 2000–2009, 19.8% in 2020–2026) and energy and fuel efficiency (1.1% up to 1999, 10.1% in 2020–2026).

Table 3

Thematic structure of the corpus: number of documents and share (%) by period

Theme	Docs	% all	≤1999 (n=94)	2000–2009 (n=55)	2010–2019 (n=189)	2020–2026 (n=207)
Operator exposure (whole-body vibration, seat, ergonomics)	174	31.9	27.7	49.1	29.6	31.4
Suspension and ride comfort	281	51.6	43.6	60.0	54.0	50.7
Modelling and simulation of vehicle dynamics	300	55.0	44.7	52.7	61.9	54.1
Tyre/track–soil interaction and terramechanics	242	44.4	31.9	32.7	50.8	47.3
Stability, handling and rollover safety	161	29.5	26.6	29.1	28.6	31.9
Optimisation and AI methods	84	15.4	7.4	7.3	16.9	19.8
Autonomous / precision-agriculture platforms	52	9.5	0.0	3.6	7.9	16.9
Energy and fuel efficiency	35	6.4	1.1	3.6	5.8	10.1
Chassis geometry (wheelbase, track width, clearance)	12	2.2	2.1	1.8	3.2	1.4

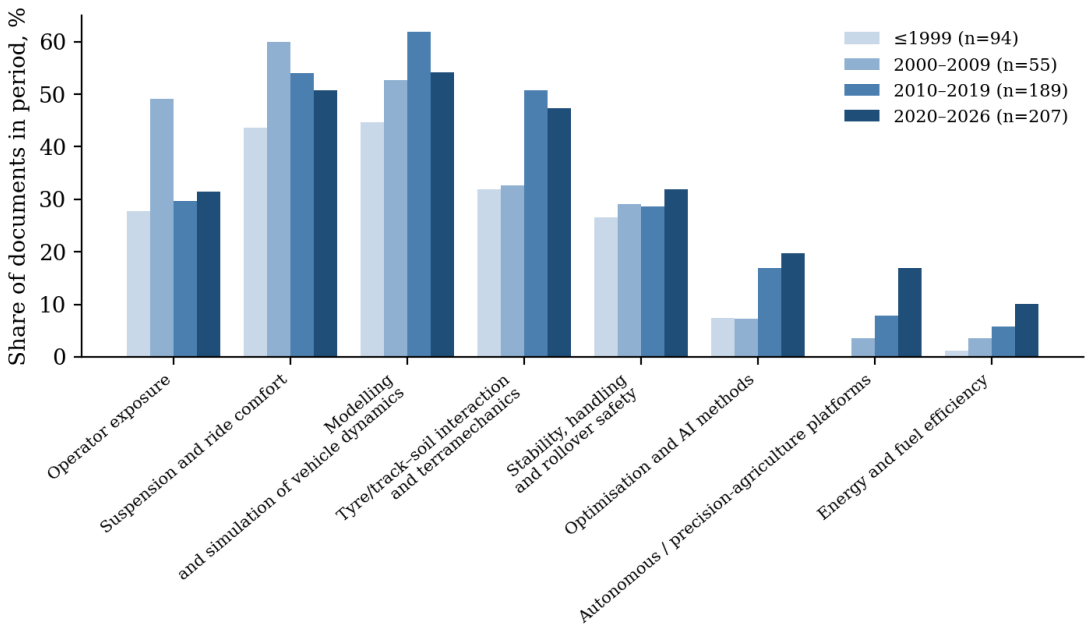

Fig. 4. Share of documents by theme and period (chassis geometry, 2.2% of documents, is discussed in Section 4)

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4. Discussion

The results show a field that grew mainly after 2010 and that remains concentrated on a few established questions: operator exposure to whole-body vibration, seat and cab suspension, and ride comfort of off-road vehicles. These topics supply the most cited works [1], [4], [7–9], [11], [12]. Since 2010 the research agenda has broadened toward tyre/track–soil interaction [6], optimisation and AI methods, autonomous platforms and energy efficiency, which suggests that vibration is increasingly studied as one factor in the design and control of agricultural machinery rather than as an isolated problem.

Chassis geometry stands out as an under-represented topic. Only 12 documents (2.2%) mention wheelbase, track width or ground clearance in their title, abstract or keywords, the share did not increase after 2010 (3.2% in 2010–2019, 1.4% in 2020–2026), and a screening of titles shows that only a few of these documents study the effect of such parameters on tractor dynamics, for example the sensitivity of lateral stability to tractor parameters [5] and the effect of geometric configuration on stability [13]. Field and laboratory-field studies that vary wheelbase, track width and clearance and measure the oscillations of the front and rear axles are therefore rare in the Scopus-indexed literature, although these parameters are the main design and adjustment variables of the running system.

The geographical picture shows strong contributions from China, the United States, Canada and Italy, and a large group of documents from Ukraine and the Russian Federation; international collaboration is weak. Uzbekistan is represented by six documents, which are mostly mathematical modelling studies, so experimental data from the region could fill both a thematic and a geographical gap.

The study has limitations. First, only Scopus was used, and the retrieval query determines the boundaries of the corpus. Second, theme assignment is based on keyword rules and can produce false positives (for instance, the generic term “operator”) and false negatives; the rules should be regarded as an approximation. Third, author names were not disambiguated, 2026 is incomplete, and citation counts favour older documents.

5. Conclusions

The conducted research shows that more than 500 publications on the vibration and vibration dynamics of agricultural tractors have been published, 72.7% of which were published after 2009, and in 2022, the number of annual publications reached 37. Countries and regions such as China, the USA, Canada, Italy, India, and Ukraine lead the research, while international co-authorship is limited. Key topics include all-body vibration, driving comfort, modeling and simulation, suspension systems, and tire-to-road interactions, with areas such as autonomous platforms, optimization, artificial intelligence, and energy efficiency expanding recently. However, the influence of the wheelbase, track width, and agrotechnical clearance on the vibration and steering of the tractor has not yet been sufficiently studied, which represents the main shortcomings of these studies.

Data availability: The Scopus export used in this study (retrieved 21 September 2026) and the derived tables are available from the authors on request.

Conflict of interest: The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper

Acknowledgement and funding: The authors would like to express their sincere gratitude to their colleagues for valuable guidance and insightful discussions throughout this research. Special thanks are extended to the Institute of Mechanics and Seismic Stability of Structures named after M. T. Urazbaev, Uzbekistan Academy of Sciences, for providing the necessary facilities and computational resources. This research was also financially supported by the same Institute, which funding made the successful completion of this work possible.

DOI: 10.65322/j.srd.05192026.37

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