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Review

Noise Exposure, Prevention, and Control in Agriculture and Forestry: A Scoping Review

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Abstract: Noise is a major physical hazard in agricultural activities, and numerous research activities have managed to detect its effects, resulting in surveys and measurements which help to define exposure limits, prevention methods, and control strategies. This review aims to collect and analyse the data from research studies and to provide a comprehensive overview on the subject. Thus, a set of 81 papers, gathered from the *Scopus* and *PubMed* scientific databases, has been analysed to provide information regarding the evolution of noise exposure levels over time, to highlight findings on noise-induced hearing loss (NIHL), and to list strategies for noise prevention and control in agriculture. Bibliographic research showed that noise measurements between 1991 and 2022, included in scientific research on farming, forestry, and animal husbandry, mainly reported values beyond the threshold of 85 dB(A); furthermore, several research activities on NIHL showed that farmers' family members and children are often exposed to high levels of noise. Lastly, an analysis of the prevention and control strategies over time is provided, focusing on prevention programmes, screening, and the use of hearing protection devices (HPD). The identified literature suggests that additional efforts are required in regards to machinery design relating to the socio-technical aspects of agricultural activities and that side-effects of NIHL, as well as the negative impact of noise on other risks, might deserve further investigation.

Keywords: noise; agriculture; forestry; animal husbandry; NIHL; safety

Citation: Cecchini, M.; Assettati, L.; Rossi, P.; Monarca, D.; Riccioni, S. Noise Exposure, Prevention and Control in Agriculture and Forestry: A Scoping Review. *Safety* **2024**, *10*, 15. https://doi.org/10.3390/safety10010015

Academic Editor: Raphael Grzebieta

Received: 29 November 2023
Revised: 22 January 2024
Accepted: 30 January 2024
Published: 1 February 2024

1. Introduction

Noise exposure assessment is a key aspect in agricultural safety. Since most agricultural equipment used for heavy-duty activities generates high levels of sound, protecting agricultural workers against such hazards is vital, and monitoring for latent hearing loss issues must be carried out, even after retirement from these professions. Exposure levels to noise can even lead to severe damage, especially when workers do not wear any hearing protection during the most hazardous or prolongated jobs, indicating that often, they might be unaware of the consequences of such noise exposure.

The first research work to mention noise as a machinery hazard in agriculture is dated 1969 [1]; this study showed that 50% of agricultural workers suffered from noise-induced hearing loss; tractor cabs can sometimes even increase the effect by another 5% in the 500–2000 Hz octave frequency range, affecting driver fatigue. Years later, in 1971 [2], a study analysed the noise-induced permanent threshold shift (NIPTS) as a form of NIHL in regards to irreversible hearing damage. In 1971, occupational hearing loss was not even a prescribed occupational disease under the Industrial Injury Act (USA), but a method for predicting permanent risk to hearing was available. If a 95% protection level for noise-induced disability is assumed, the noise criterion would be 85 dB(A). In 1976 [3], for the first time, a study associated certain noise exposure levels with hearing damage risks, detecting which agricultural working activities were the noisiest and then ranking them by type (with harvesting in first place); hours of noise exposure; and daily, weekly, or seasonal exposure. Starting from the first research outcomes regarding hazards related to noise exposure, risk analyses and information activities began appearing in the 1980s [4], with the implementation of the first training workshop on agricultural noise, and continued into the 1990s, showing that the prevalence of hearing loss among farmers was twice that observed among workers who were not exposed to noise [5], that agriculture and mining workers were the labourers most exposed to hearing loss, with a 17.2% positive rate for hearing loss in screening audiometry at 4 kHz [6], and that forestry operators were significantly at risk for hearing loss, when compared to other workers [7].

A previous review on noise [8], published in 2002, focused on NIHL and showed that studies did not describe the development of the problem, and that despite a large number of prevalence studies involving workers, the scarcity of studies in this population did not allow for an estimation of the overall prevalence. Studies regarding agricultural noise exposure and hearing loss have been limited by a lack of measurements for farms, a lack of comparison of occupational to non-occupational noise exposure, differing definitions of hearing loss, different noise thresholds, and a lack of information on the reliability of audiometers. The exposure to livestock noise and the effects of hearing protection devices (HPDs) on hearing preservation have not been covered by any study. All these biases diminish the progress in reducing noise-induced hearing loss. Recommendations include better methods for noise measurement, investigating the short- and long-term effectiveness of newer HPD designs, and the implementation of techniques for farmers to detect and reduce high levels of noise exposure.

After 2002, several nations started to develop specific guidelines [9] to control noise emissions in agriculture, but various aspects were yet to be defined. Exposure duration, frequencies [10], health and lifestyles [11], combined impact with other occupational hazards, like hand-arm vibration [12], the absence of personal protection equipment, age correlation to exposure levels, and the safety assessment of people, i.e., farmers' family members, who were indirectly exposed to noise remained unaddressed. Another key issue is that personal protection devices are often not in use because workers and family members fear they might not hear each other during activities [13], or the devices are not employed, simply because the workers do not perceive the hazards related to their activities [14], despite the fact that hearing impairment appeared to be common among farm family members.

Noise measurement has also changed significantly to track both the mean daily and weekly exposure and any fluctuation in exposure due to specific activities that are carried out for a short period of time [15]. Despite a declining trend of noise emissions in industrial environments [16], research from recent years also shows the absence of any decreasing trend in noise risk reduction in agriculture [17], regardless of the specific activities carried out in the field [18], and at the same time, the presence of noise is still seen by workers as one of the most harmful working conditions [19], meaning that mitigation countermeasures might not be as effective as they were meant to be.

This scoping review is meant to gather noise measurements and data from research articles on noise in agriculture, forestry, and animal husbandry, including those related to evidence of NIHL in farm workers and any research study regarding prevention methods, control procedures, and protection devices. From information gathered regarding noise in agriculture and forestry, it would be possible to further analyse specific aspects of this issue, which might result of interest from a medical point of view or in regards to the design of agricultural machinery.

2. Methods

Given the large number of aspects that have been explored regarding the effects of noise in agricultural contexts and the absence of a review protocol on the subject, a wide-range research has been carried out using the *Scopus* and P*ubMed* abstract databases in order to identify the most valuable works, in the English language, regarding noise safety assessments, noise exposure measurements, noise-induced hearing loss, prevention and protection programmes that have been developed since the 1960s, with a focus on research outcomes from the years 1991 to 2022. The authors limited the research to peer-reviewed articles and conference papers, performing searches in abstract databases that allowed for result filtering and the full interoperability of search results. Given the large number of keywords and the need to limit the results to particular sectors, the authors opted to avoid scientific search engines because even though their search results may have been more extensive, there would have been limited control over the possibility of filtering them and as a consequence, there would have been a higher risk of reducing the quality of the scoping review. Specific guidelines for scoping reviews have been followed [20,21], and the details of the specific and detailed query are provided in the text and shown in Table 1. The search fields, including the abstract name, the article name, and keywords, have been searched with the aim to include most of the aspects related to noise hazards in agriculture and forestry, while filters have been included to avoid those research fields that were out of this scope.

Table 1. Keywords and logic used in the bibliographic research of the abstract databases.

Logic	Keyword	*Scopus*	*PubMed*
	("agriculture" OR "agricultural" OR "tractor" OR "agricultural machines" OR "harvesting" OR "harvester") AND ("sound power" OR "noise, vibrations" OR "chemical agents, noise" OR "noise, posture" OR "noise exposure" OR "noise risk" OR "noise measurements")	356	132
AND	"ergonomic aspects" OR "risk factors" OR "occupational health" OR "safety" OR "risk"	142	77
AND NOT	noise pollutants OR "wind farm" OR ("automobile" AND "traffic") OR "waste management" OR "urban traffic" OR "airplane pilot" OR "musicians" OR "energy harvesting"	140	68
AND NOT	"heat stroke risk" OR "heat-stroke risk" OR "Predict heat strain" OR "myocardial"	138	66
AND NOT	processing AND manufacture	136	65

Given the high number of results from these keywords, the search findings required additional refining to remove duplicates, to manually exclude articles that did not fit the given criteria, and to remove papers which followed a overly generalised approach or referred to particular sectors in which noise has also been analysed but which are not considered as agricultural or forestry activities (e.g., fishing activities, fishing vessels, etc.). These filters and selections will be further presented in the Results section, along with analysis criteria that will be used to analyse the results of research activities and their impact on the subject.

3. Results

The search results included a large number of articles, but given the possibility of finding the same research items on both databases, additional actions were required before analysing the data. Besides merging results and removing duplicates, additional refining was required to filter out those articles related to fishing, which is not discussed in this scoping review. Subsequently, articles that covered marginal agricultural activities were identified and excluded.

The results of the refining activities on the abstract database outcomes are shown in Table 2.

Table 2. Bibliographic research refining of outcomes from abstract databases.

Authors' Filter on the Abstract Databases' Search Results	Papers Remaining
Merge results and duplicate removal	147
Removal of articles that did not fit the purpose of the review	110
Removal of articles covering general aspects	81

As a consequence, a set of 81 articles was selected and deeply analysed. A flowchart of the process of elimination of articles falling outside the scope of this review is shown in Figure 1.

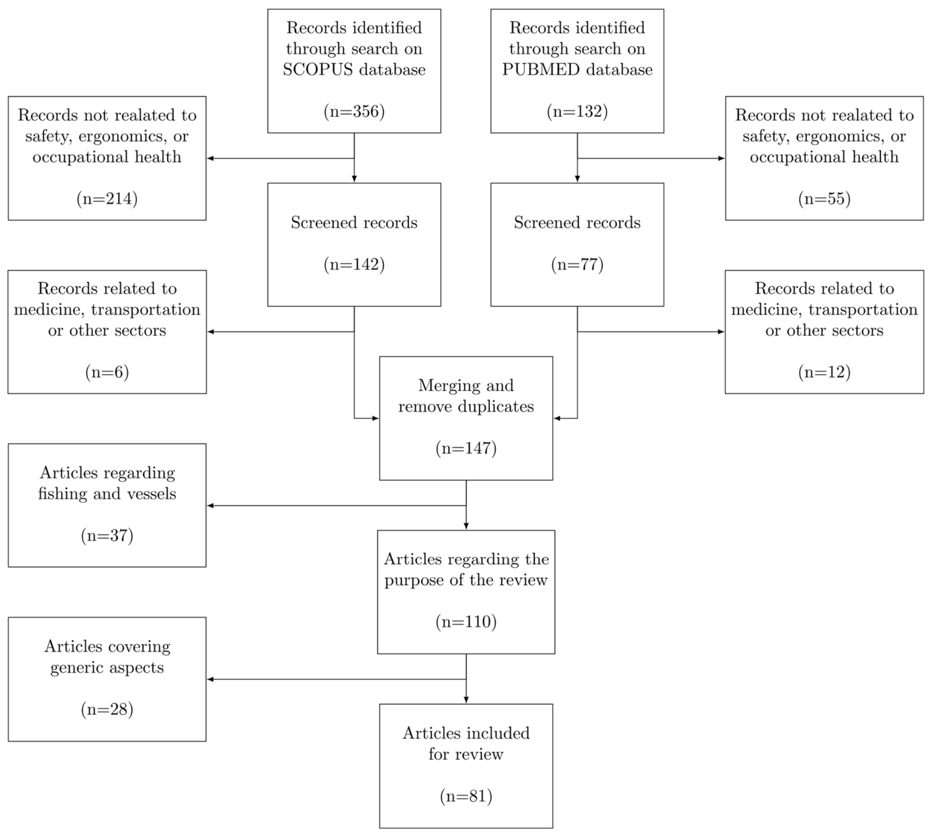

Figure 1.. Process of source gathering and selection.

The remaining 81 articles have been further organised for better presentation and comparison of their results. A taxonomy analysis indicated that, apart from a set of 19 articles that were useful to describe previous state-of-the-art analyses and that can properly introduce the subject, such works could be subdivided into (a) background information and risk assessment, (b) noise exposure assessments, (c) noise-induced hearing loss effects, (d) prevention and protection strategies.

The research works have been divided into three main categories, which can be listed as:

- Noise exposure levels in agricultural activities, forestry, and animal husbandry tasks (33 articles);
- Noise-induced hearing loss (NIHL) in agriculture and forestry (14 articles);
- Noise risk prevention and control (15 articles).

These categories have been analysed and divided into subsections for better understanding of the data and to highlight the findings, providing the possibility of comparing the results and findings from research activities. A summary of each section's findings is also provided, including the most important aspects of each study.

3.1. Noise Emission Levels in Agricultural and Forestry Activities

The most important aspect of noise prevention and control for many regulatory frameworks is noise emission measurements, which are used to determine peak exposures, as well as daily and weekly exposures over 8 h working shifts. In addition, agriculture and forestry workers might be required to work shifts longer than 8 h. In some contexts, agricultural vehicles are designed to significantly reduce driver's exposure to dust, vibration, and noise, but they might fail to provide this protection for nearby workers on-foot. In the following subsections, data and findings are reported from 33 scientific sources which focused on determining noise emissions from tractors (14 articles), farming activities (10 articles), and forestry or animal husbandry tasks (9 articles). Despite differences in samples sizes, the number of analysed tasks, and the geographic reference of the research studies, a general benchmark among activities, periods, and environments can provide useful information for understanding past and future trends in agricultural noise emissions.

3.1.1. Noise Level Related to Agricultural Tractors

Agricultural tractors represent a significant source of noise that can be difficult to prevent given their power, and research activities often focus on a small number of variables that influence their noise emissions. Given the wide number of parameters that affect tractor noise emission levels, comparisons must consider working conditions that have been observed by all of the studies. Data regarding such observations is reported in Table 3, including important details for each one, along with their research findings.

Table 3. Noise levels associated with tractors, obtained from the literature review.

Title	Year	Research Findings	Sample Data
Effects of noise and vibration on farm workers [22]	1991	Exposure exceeded 85 dB(A) for 30 of 31 tractors at full throttle, while 6 produced levels at 95 dB(A).	A total of 31 tractors, effects evaluated with a 5 dB exchange factor
Tractor noise exposure levels for bean-bar riders [23]	1993	Noise exposure levels at the bean-bar position were, on average, 10 dB(A) higher (92 dB(A)) than those at the bystander position.	One bean-bar tractor
Farm noise emissions during common agricultural activities [24]	2005	Noise levels were 76 dB(A) for cabbed tractors, 92 dB(A) for tractors without cabs; 106 dB(A) for chainsaws, 73 dB(A) for dairies.	A total of 38 tractors with cabs, 26 tractors without cabs; exchange factor: 3 dB
Safety and health of workers: Exposure to dust, noise, and vibrations [25]	2009	Daily exposure between 86,9 and 95 dB(A) for tractors and self-propelled machines.	A total of 15 hazelnut harvesters
Noise test of two manufactured power tillers during transport on different local road conditions [26]	2010	The maximum overall noise measured at driver ear's position at different gear ratios were between 92 and 98.2 dB(A).	Two power tillers; effects evaluated with an exchange factor of 3 dB
Exposure to audible and infrasonic noise by modern agricultural tractors operators [27]	2013	Analysed tractors emit considerable infrasonic noise levels that tend to exceed the occupational exposure limits.	A total of 32 modern tractors
Noise levels of a track-laying tractor during field operations in the vineyard [28]	2013	Sound levels exceeded the limits, in almost all the test conditions, by up to 92.8 dB(A).	One tractor, tested in four different activities
Harmful factors in the workplaces of tractor drivers [29,30]	2016	The noise levels were 90 dB(A) for tractors manufactured in the 1980s, 73 dB(A) for newer tractors.	A total of 30 tractors

Risk exposure to vibration and noise in the use of agricultural track-laying tractors [31]	2016	The daily noise exposure levels always exceeded 87 dB(A).	A total of 6 track-laying tractors
Tractor age effects on occupational noise level exposures inside agricultural tractor cabs [32]	2016	The data showed a positive correlation of 0.308 between tractor hours and the increase in noise level; no tractors exceeded 85 dB(A).	A total of 19 tractors of different models, ages, and engine hours
The hearing abilities of rural workers exposed to noise and pesticides [33]	2018	The motor's noise ranged from 88.3 to 93.4 dB(A).	One tractor, with concurrent exposure to pesticides
Assessment of tractor noise level during spraying operation while using a tractor-mounted aero blast sprayer [34]	2018	Noise at a tractor operator's ear level during spraying operation can reach up to 93 dB(A) at 2000 rpm.	One tractor
Noise exposure and its impact on psychological health of agricultural tractor operators [35]	2021	Value of 81.9 dB(A) during operation of seed drill, 84.9 dB(A) with disk harrow, and 86.9 dB(A) with cultivator operation.	One tractor, tested in four different field activities

In many of the articles listed in Table 3, the daily averaged noise emissions exceeded the 85 dB(A) threshold. Despite design improvements, which must have had a positive impact on reducing tractor emissions, it should also be noted that the type of farming activity also influenced their sound emissions by requiring the tractors to work at a wide range of engine speeds, torques, and terrain slopes [24]. It has been noted, for example, that an increase of 3 dB(A) was to be expected when passing from 1200 to 1500 rev/min or from 1500 to 2000 rev/min [23]. Data collection regarding tractor noise emissions has been performed on a large variety of samples, which differ in regards to:

- The number of vehicles in the sample, which range from just 1 tractor to 64 different models;
- The age of the vehicles, collected as the operational age or as year of manufacture;
- The design, which, in some cases, was simply divided into tractors with or without cabs;
- The power, ranging from power tillers to narrow-track tractors and large harvesters;
- The monitored activities, that have often been investigated singularly;
- The terrain and field conditions, including the slope.

The research often focused on just one or two of the previously listed variables, without considering any other of the aforementioned working conditions.

3.1.2. Noise Level Related to Farming Activities

Farming activities include a large number of different agricultural vehicles, and noise levels measured in research almost always resulted in values beyond the 85 dB(A) threshold, even up to 99 dB(A) for common farming activities and 102 dB(A) for certain specific tasks. A list of findings of noise levels related to farming activities is reported in Table 4.

Table 4. Noise level associated with farming activities.

Title	Sample Size	Year	Research Findings
Noise Exposure and Hearing Loss in Agriculture: A Survey of Farmers and Farm Workers in the Southland Region of New Zealand [36]	28 farms	2003	Noise levels for the subsample of 60 farms lay between 84.8 to 86.8 dB(A).
Noise Exposure and Hearing Conservation for Farmers of Rural Japanese Communities [37]	1538 farmers	2004	Daily noise exposure ranged from 81.5 to 99.1 dB(A) for tea harvesting, and from 83.2 to 97.6 for sugar cane harvesting.

Characteristics of Annual Exposure to Noise among Private Farmers on Family Farms of Mixed-Production Profile [38]	A total of 16 family farms.	2006	Noise levels equivalent to a mean exposure level equal to 91.3 dB(A).
Dust and Noise Exposures among Farmers in Southland, New Zealand [39]	A total of 60 farms.	2006	Total daily noise exposure levels were 86.8 dB(A) for sheep farmers, and 85.7 dB(A) for mixed farmers.
Occupational Noise Exposures among Three Farm Families in Northwest Ohio [40]	The family members of nine farmers.	2008	Occupational noise exposure for the children ranged from 15.4 to 81.2 dB(A), using the OSHA action level.
Task-Based Noise Exposures for Farmers Involved in Grain Production [41]	A total of 35 farmers or farm workers.	2013	Noise levels ranged from 78.6 to 99.9 dB(A) for 23 tasks and 18 pieces of equipment analysed.
Farmers' Work-Day Noise Exposure [42]	A total of 105 farmers.	2015	The average daily noise exposure was 85.3 dB(A).
Patterns and Trends in OSHA Occupational Noise Exposure Measurements from 1979 to 2013 [43]	A total of 493 samples between 1979 and 2013.	2019	Mean noise levels of 93.1 ± 6.8 dB(A) were found among the agriculture, forestry, and hunting industries.
Noise Exposure on Mixed Grain and Livestock Farms in Western Australia [44]	A total of 28 farm owners and workers.	2019	Up to 101 dB(A), mostly from seeding activities, but generally above 85 dB(A) for all farming activities.
Sound Power Determination for Centrifugal Pumps used for Local Agricultural Irrigation in Romania [45]	One farm, evaluating specific equipment.	2020	Noise level observed in all working conditions exceeded 85 dB(A), with a peak of 102 dB(A) at maximum pumping height.

Farm owners, farm workers, and family members are often affected by a large variety of noise sources, as shown in the research findings in Table 4. Apart from tractor noise emissions reported in the previous subsection, many other sources can produce additive effects and increase noise levels at any stage of involvement in farming activities, and as shown by Warwick et al. [42], several significant noise sources can be present at any time of the day—not just during work hours—on a farm. The same research noted a new trend in working models represented by a farming workload, often shared between male and female family members, on family-based farms, a key aspect that the authors highlighted for future research in NIHL among farm workers. In measurements performed by Miyakita et al. [38] in Japan, noise exposure was beyond 85 dB(A) for 8 h shifts in 82% of cases, while Firth et al. [39] assessed the incidence at 35% for New Zealand's farmers and indicated that 20% had a pattern of hearing loss; similar outcomes were also found in the United States of America by Sayler et al. [43], also indicating an apparent increase in occupational noise levels over time in agricultural industries. Despite several countries being included in studies focusing on agricultural noise levels, there is not enough information to state that similar outcomes could be generalised, but the research often indicated that technological progress in mechanisation in the past has led to a change in the agricultural working environment that occurred too quickly to be properly handled by occupational health and safety institutions.

Research findings also showed that several factors affect farm noise and as a result, control measures should consider the bigger picture including all possible hazardous noise sources. As pointed out by Humann [41], who analysed a large variety of farming activities, interventions that only focus on the noisiest tasks would diminish farmers' noise exposure, but given that high noise measurements have been observed in nearly every task examined in the study, exposure to noise levels that fall beyond the hazardous threshold would still be possible.

3.1.3. Noise Level Related to Forestry and Animal Husbandry

Forestry and animal husbandry noise measurements have also been examined in relatively new research works. In Table 5, such levels are listed, along with the research findings. Some of the articles that cover forestry might also cover tractor or farming measurements, while most of the specific works on forestry cover chainsaw or logging work. Animal husbandry activities, despite not showing particular noise issues in certain cases, in other cases, reported the highest noise measurement of the whole scoping review, with values that reached up to 108 dB(A).

Table 5. Noise level associated with forestry and animal husbandry activities.

Title	Year	Research Findings	Sample Size
Farm Noise Emissions During Common Agricultural Activities [24]	2005	Levels of 106 dB(A) for chainsaws, 73 dB(A) for dairies.	A total of 32 agricultural activities
Occupational Noise Exposure Assessment in Intensive Swine Farrowing Systems: Dosimetry, Octave Band, and Specific Task Analysis [46]	2005	Exposures exceeded 90 dB(A), up to 96.6 dB(A) in farrowing areas.	A total of 11 activities in a swine confinement facility
A Task-Based Assessment of Noise Levels at a Swine Confinement [47]	2007	None of the workers' noise levels exceeded 85 dB(A), but HPDs are needed for snaring and power washing activities.	A farrow-to-finish swine confinement center
Exposure to Noise in Wood Chipping Operations under the Conditions of Agro-Forestry [48]	2015	Exposure did not exceed 80 dB(A) at low level utilizations. It may exceed the lower action values for utilization above 64%.	One agroforestry chipper
Operators' Exposure to Noise and Vibration in the Grass Cut Tasks: Comparison between Private and Public Yards [49]	2016	Exposures exceeded limit values within a range of 79.4 to 92.6 dB(A).	A total of 6 operators in public and private yards
Workload, Exposure to Noise, and Risk of Musculoskeletal Disorders: A Case Study of Motor-Manual Tree Felling and Processing in Poplar Clear Cuts [50]	2018	Exposure exceeding the acceptable limits, of 97.15 dB(A) and the daily exposure of 96.18 dB(A).	One feller
Noise Exposure on Mixed Grain and Livestock Farms in Western Australia [44]	2019	Up to 108 dB(A), with the highest values for the chaser bin, shearing, and seeding.	A total of 28 agricultural workers
Noise Exposures and Hearing Protector Use at Small Logging Operations [51]	2021	Use of PPE reduced exposure below 80.7 dB(A), excluding bulldozer operations (93.5 dB(A)).	A total of 31 loggers in 7 different sites
Evaluation of Occupational Noise Exposure among Forest Machine Operators: A Study on the Harvest of Pinus Taeda Trees[52]	2022	Operators were exposed to noise levels above the exposure limit of 85 dB(A) during timber extraction.	A total of 4 operators of self-propelled forestry machines

3.1.4. Evaluation of Noise Emissions in Agricultural and Forestry Activities

Exposures in dB(A) from papers cited in the previous subsections are reported in Figure 2, reported for the corresponding year of observation, showing sources separated by type of activity: tractors, farming activities, animal husbandry, and forestry. Most of the observations fall beyond the threshold level of 85 dB(A), and a change can be observed only for tractor activities as the only category showing a small decrease over time. It should be noted that technical advances in tractors, such as improved cabs and mufflers, have influenced this trend, given that tractors manufactured from the year 2000 on presented noise levels of73 dB(A), which are significantly lower than those of tractors built in previous decades [29]. Research findings indicate, however, that noise issues can still be present for tractor activities involving workers on foot nearby the tractor or if the vehicle lacks proper maintenance [32].

Regarding noise in forestry activities, it is clear that the duration of the activity can highly influence the effects of noise exposure. This can be seen as a possible area for improvement, if equipment is designed to perform faster, but might also cause concern under heavier working conditions confirmed by some of the measurements, which yielded noise levels at 106 dB(A) for chainsaws, indicating that the most effective margin for improvement would be obtained by best-practices that minimise the exposure.

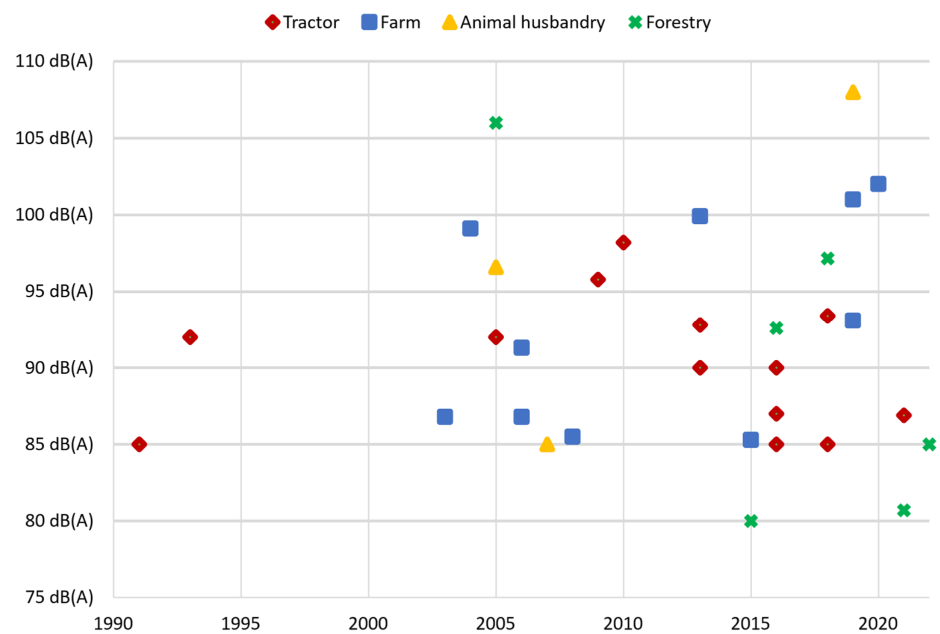

Figure 2. Distribution of noise emissions among agricultural, farming, and animal husbandry activities over time, as examined in Section 3.1 . Given the large number of parameters affecting noise measurements and the lack of protocols, the slight decrease in tractor noise emissions reported in various research findings cannot be taken as a function of time. Further studies are necessary to determine the impact of regulations and the effects of machinery electrification.

3.2. *Noise-Induced Hearing Loss (NIHL) in Agriculture and Forestry*

The effects of excessive noise exposures have been analysed since the mid-1990s. A research article [53] from 1996, based on a large sample of two thousand interviews with farmers, found that field crop farm operators were exposed noisy jobs, which made up as much as 30% of their work, while the lowest exposure levels (median noise 1%) was found among nursery farmers. In addition, smaller farms reported higher exposure levels compared to larger farms, given that operators of the latter were more likely to wear hearing protection devices. These results, however, are based on national data and self-reported information provided by farmers. Another activity which involves high noise levels is tractor driving, regarding which previous studies [54] showed that the correlation between hearing loss and noise emission exposure was stronger than that between hearing loss and the period of employment. Screening programs implemented among farm family members [55] between 1996 and 1998 showed that of the more than 1418 hearing tests, 31% of audiograms showed an early hearing loss, and 39% of the results were classified as abnormal. In fact, hearing loss among farmers can be even greater, with an up to 72% prevalence [56].

3.2.1. NIHL in Tractor Drivers

Tractor drivers, given the higher levels of noise generated in their activities, are expected to show a higher prevalence of hearing loss after 30 years of employment in agriculture. A study including drivers of medium and high-power tractors, performed in 2001 [57], assessed the chance of hearing impairment after 30 years of occupational exposure to noise from medium and high-power tractors to be between 13% and 37.9%. The risk of hearing impairment due to occupational exposure to noise that may cause an acoustic trauma was 37.9% for medium-power tractors and 13.0% for high-power tractors. Cross-sectional studies [58] also reported a higher prevalence of NIHL among tractor drivers compared to non-tractor driving farmers, which was determined to be present after only 5–10 years of employment, and the prevalence is much higher for tractor drivers with 20 or more years of employment in the industry, given the ratio of abnormalities noted in high frequency audiometry.

3.2.2. Risk-Related Effects and Occupational Injuries

Hearing loss represents a health issue among farmers. Farmers also experience an increased risk of hearing asymmetry [59], and the rate of injuries was higher for those exhibiting occasional use of hearing protection devices compared to workers that did not use them at all, suggesting that an irregular use of hearing protections could negatively affect safety. It must be also noted that such effects might trigger stress and fatigue in workers, affecting their sensibility to detect any early onset issues related to hearing loss. Further evidence of the impact of NIHL in occupational health [60] shows that workers exposed to noise had a 52% increased risk of injury compared to unexposed workers, while these risks were far higher for workers with mild and moderate hearing loss, where chances increased by 7.87-fold and 4.48-fold, respectively. Such results indicate that a reduction in occupational noise exposure might improve safety in the workplace. Given the seasonal cadence of many agricultural activities, it has been found that summer and autumn posed higher noise risks among farmers [61].

3.2.3. Exposures by Groups and Activities

Farmers do not represent the only group exposed to NIHL in agriculture: family members and children are, in fact, often unrecognized exposed groups which should be included in prevention and protection programmes. Hearing loss in farmers may begin during childhood, where it can result from both noise, as well as ototoxic exposure that might be due to specific solvents and pesticides [62], and this hearing loss increases with age. A high prevalence of NIHL, as indicated by Ref. [63], is not the result of presbycusis, and this highlights the need to begin to prevent hearing loss among farmers at a young age. Another study [64] showed that for 25 adolescents from rural areas, 44% of the mean daily noise exposures were higher than the NIOSH recommended exposure levels (REL) of 85 dB(A), while 18% of the 71 daily noise exposure measurements exceeded 90 dB(A). Another study from Humann et al. [65], conducted separately for men and women in a large sample of more than 1500 participants, reported that short-term exposures from hunting and pneumatic tools should also be considered and assessed along with long-term common activities, given that exposure to noise from such activities was common between both farmers and rural residents; at the same time, the study showed the need for more precise analysis of NIHL in women, since performing the same activity might differ in duration. Specific research has also been performed on particular agricultural activities. For cotton gins, it has been estimated that 7 to 8 weeks of acute noise exposure with 10 months of respite from exposure can lead to NIHL during a working lifetime [66]. Another recent study [67] focused on the effects of both noise and pesticide exposure, finding that insecticides and noise exposure could separately affect hearing thresholds for high frequency sound bands or may have an additive effect, causing an increase in the risk of NIHL. A summary of these research outcomes is show in Table 6.

Table 6. Summary of noise-induced hearing loss research findings included in review.

Title	Year	Findings
Exposure to Dust, Noise, and Pesticides, Their Determinants, and the Use of Protective Rquipment among California Farm Operators [53]	1996	Tendency of higher exposures to noise in small farms compared to large farms.
The Effect of Occupational Exposure to Noise among Tractor Drivers: Assessment Based on Noise Threshold [54]	1998	Higher correlation between hearing loss and noise emission dose than between hearing loss and duration
Hearing Conservation Program for Farm Families: An Evaluation [55]	1999	Audiograms in hearing tests showed 31% of early hearing loss in farm family members
Hearing Conservation for Farmers: Source Apportionment of Occupational and Environmental Factors Contributing to Hearing Loss [56]	2000	Estimated prevalence for NIHL in farmers can be up to 72%
Risk of Noise-Induced Hearing Loss in Farm Tractor Operators [57]	2001	Risk of hearing impairment for occupational exposure to noise from medium and high-power tractor spans between 13% and 37.9%
Effect of Tractor Driving on Hearing Loss in Farmers in India [58]	2005	Pure tone and hight frequency audiometry showed higher prevalence of hearing loss in tractor drivers after 5–10 years of employment
Hearing Loss as a Risk Factor for Agricultural Injuries [59]	2005	Hearing asymmetry can be identified as a risk factor, irregular use of HPDs can result in higher injury rates
Relationship Between the Level of Total Exposure to Noise among Private Farmers and the Degree of Hearing Loss [61]	2008	High noise risk during the summer-autumn period
Noise Exposures of Rural Adolescents [64]	2011	Children mean daily noise exposures for exceeded NIOSH REL in 44% of cases (exchange factor: 3 dB)
Effects of Common Agricultural Tasks on Measures of Hearing Loss [65]	2012	Associations between hearing loss and hunting, use of chain saws or pneumatic tools and living in a farm were observed
Effect of Noise Exposure on Occupational Injuries: A Cross-Sectional Study [60]	2012	Workers exposed to noise had a 52% increased risk of injury (exchange factor: 5 dB)
OSHA Noise Regulations and Agriculture, Including Cotton Gins [66]	2017	7 to 8 weeks of acute noise exposure with 10 months of respite from exposure can lead to NIHL during a working lifetime
Hearing Loss in Agricultural Workers Exposed to Pesticides and Noise [67]	2019	Exposure to pesticides and noise might produce additive effects in risk of NIHL
Hearing Impairment among Korean Farmers, Based on a 3-Year Audiometry Examination [63]	2019	Prevalence of hearing impairment in farmers is higher than that of general population

3.3. Noise Risk Prevention and Control

Analyses on noise exposures and effects provide a well-defined background for better risk prevention and control. Given the context, hazard elimination is not a viable solution: actions can aim to optimize vehicle engines and openings in cabs [68] or reduce noise emissions in cabins [69,70]. Regarding self-propelled harvesters [71] it should also be noted that noise issue related to pressurised air or vacuum systems also need to be tacked at design stage. In some cases, like in tasks involving chainsaws, short breaks and better equipment that provide enough protection to the harvesting operators are required [72]. Better designs can also lead to an easier identification of noise sources and thus reduce workers' exposure, especially by models that allow the definition of noise source indices [73] or by studying suppression effects for workers exposed to noise [74] since transient

Evoked Otoacoustic Emissions (EOAE) and Distortion Product Otoacoustic Emissions (DPOAE) examinations can be used as early identification of hearing damage.

Specific measures for mitigating noise risks also rely on HPDs and health programs or screenings. These aspects will be analysed in the following subsections.

3.3.1. HPD, Sensors and Other Detection Devices

Workers' behaviours are an important aspect in agricultural noise management, since proper education and training that aim to list the benefits provided by HPD can increase workers' willingness in wearing them: this approach can lead to better results, compared to mandatory requirements requested by laws or employers [75] and can also be promoted in schools or by adding training on farm noise for rural youth to other training courses that involve noise protections such as firearm training sessions. Randomized trials about the use of HPD and their effects [76] have also been proposed through the definition of test protocols, and the feasibility of hearing health education embedded in other already-existing and all-inclusive safety education programs has also been demonstrated to work out well as a booster intervention since it increased the chances of behaviour changes in wearing HPDs [77].

From medical point of view, sensors can be deployed to analyse in real time the difference in cardiovascular performances while workers are exposed to tractor noise at various engine speeds [78] or, for instance, evaluate how the operating conditions of different agricultural activities affect the main psychoacoustic parameters, namely loudness, sharpness, roughness, and fluctuation strength [79].

3.3.2. Screening and Health Programs

Another well-known approach is based on exposure levels, but healthcare institutions play a key role in that sector since rural areas often have limited access to hearing healthcare facilities. In addition, some categories have different perceptions related to noise effects and hearing loss since they might tend to consider it as a consequence of their job that cannot be avoided. Low-cost hearing screening [80] that could rely on community-based organizations, surveys regarding farmers' beliefs on hearing loss mixed with noise assessments and educational sessions [81] and methods to predict hearing loss by assessing the expected number of hours of hazardous noise exposure [82] can be a valuable resource especially if they lead to a better description of the effect of particular activities especially in older people and in workers with a family history of hearing loss [83].

As a result, a summary of these findings is reported in the following Table 7.

Table 7. Summary of noise prevention and control strategies.

Noise Prevention or Control Strategies	Focus	Findings
General design improvements	Tractor design and cabs	To reduce noise, cabs should be selected with as few openings as possible and follow preventive maintenance procedures on sealings. [68]
		Cabbed tractor's noise emissions increased significantly, even after a small increase in engine speed, and could be reduced at the driver's seat only if openings were closed [69].
		Use of laminated windows and proper absorbing and dampening materials on the transmission paths into the cabin can reduce tractor's overall noise by more than 6 dB [70].
	Equipment	Aerodynamic flow design should also be analysed in machines that operate by compressing air or by generating a vacuum [71].

		The necessity of work breaks for tasks involving chainsaws are extremely necessary because noise emissions might still be higher than recommended [72].
	Noise emission model	Definition of a formula that allows for the estimatation of a dominant noise source index [73].
Hearing Protection Devices	Education and training	A lack of basic knowledge about noise exposure hazards and protection strategies in rural adolescents could be promoted through social media and schools, while education regarding the use of hearing protection for noisy farm task could be reinforced in training for firearm safety [75].
		Development of an ad hoc test protocol that aims to test hearing conservation interventions for farm operators or farm youth; safety education programs increase the chances of behaviour changes in regards to the wearing HPDs [76,77].
	Monitoring	Possibility of real-time health monitoring of the effects of noise on farmers' cardiovascular systems [78].
		Possibility of correlating loudness, sharpness, roughness, and fluctuation strength of noise to specific farming tasks [79].
Prevention strategies	Hearing screening	Low-cost hearing screenings, together with awareness-building activities, despite a general underestimation of hearing health issues, could be a feasible solution for rural farming communities. [80]
	Hearing loss prevention	The mix of surveys regarding farmers' beliefs on hearing loss, noise assessments, and educational sessions increased the use of HPD 2–3 months after the implementation of the program, regardless of the farmer's age. [81].
	Hearing loss prediction	A hearing protection-corrected index, measured as an assessment of hours of lifetime exposure to hazardous noise, was defined based on phone interviews with a large sample of people [82].
	Efficiency of hearing conservation strategies	Reduced efficiency of hearing conservation strategies with age and by farmers with a family history of hearing loss [83].

4. Discussion

4.1. Summary of Evidence

Results show that general interest in occupational noise hazards in agriculture and forestry has increased significantly over the years, especially in those rural areas that are particularly exposed to mechanised agricultural activities. A total of 14 research topics out of 81 papers covered in this review (17%) deal with noise issues that are typical of certain countries, and considering only the 47 works included in the noise emission and exposure sections, the statistic increases to the 30% of research subjects. To date, research has focused on several aspects, in particular, the assessment of noise emissions in agricultural activities, the resulting exposure and risk of hearing loss, methods to reduce exposure such as the use of personal protective equipment, screening programs, and improved worker training.

Noise emissions from agricultural machinery showed a decrease over time, as new designs come on the market. Despite these efforts, however, noise still represents a major cause of occupational disease in agriculture, and given the existence of the large number of small farmland holders, noise also affects the farm owners' families, and not just the farmers themselves. Research has shown that farmers often deal with up to 18 different types of equipment, with daily noise exposures above 85 dB(A) and in some cases, exposures close to 100 dB(A).

4.2. Limitations

Research on noise emissions in agriculture has been carried out over the last decades by focusing on specific aspects separately; by doing so, despite the large amount of useful information produced on the subject, research showing the bigger picture regarding the impact from and to the agricultural environment is still missing. In addition, differences in research methods have been noted regarding parameters that affect noise emissions, but which were seldom excluded. As previously reported, factors such as a reasonable sample size, the identification of task types, context analysis, along with equipment information, such as operational age, design aspects, and work modes, should be considered. Another limitation is represented by different exchange factors (or rates) for balancing sound power levels and exposure times, which, for United States' Occupational Safety and Health Administration (OSHA), is 5 dB, while NIOSH recommends an exchange factor of 3 dB. Moreover, some research studies did not provide enough information regarding this critical parameter, indicating that a research standard for assessing noise exposure levels—particularly NIHL—is necessary.

4.3. Conclusions

The research results prove that current efforts are not only still insufficient, but also that noise exposure estimations can fail to paint a comprehensive picture of agricultural noise: the risks are higher for smaller farms, while research showed a correlation between excessive noise exposure and higher injury rates, generally attributed to stress and fatigue. The use of HPD should also be employed consistently, given that irregular utilisation can also result in higher injury rates. Since completely eliminating the noise risk would be unrealistic, it should be noted that improvements in agricultural machinery, like better cabs and mufflers, had a positive impact on emission trends, indicating that both newer vehicles and aftermarket upgrades can play an important role in noise prevention. On the other hand, however, tractor designs should better fit the contexts and socio-technical aspects of the specific agricultural activities, i.e., by employing new technological advances in power transmissions to reduce the noise exposure of nearby workers on foot, by emphasising the importance of regular maintenance as an action that can have a beneficial impact on workers' health, apart from having an obviously positive effect on machinery performance, and lastly, by testing the noise emission levels of tractors during various activities on different terrain conditions. Technological advances can also have a positive impact on screening measures, but most research regarding prevention programmes showed that raising the farmers' awareness of the problem is essential.

Future research could focus on the widespread use of electrical equipment, which has progressed over the last few years as an effect of better equipment design. Regarding protections, smart devices and hearing protection devices should also be investigated, while screening programmes could increase their domain to include seasonal operators and farm owners' family members, evaluating the additive effect of common rural activities. Regarding screenings and health programmes, the feasibility of low-cost audiometric screenings should encourage authorities to provide such services to rural and agricultural workers with sufficient frequency, while geographical correlations might be investigated in further research activities.

Author Contributions: Conceptualization, P.R. and M.C.; methodology, M.C.; validation, S.R. and D.M; resources, P.R.; data curation, P.R. and L.A.; writing—original draft preparation, P.R.; writing—review and editing, P.R. and L.A.; visualization, S.R.; supervision, M.C.; project administration, D.M.; funding acquisition, D.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article. Any supplementary material, such as postprocessing of bibliometric data, is available on request.

Acknowledgments: Authors are thankful to Rome Technopole tech hub, which is part of the Next Generation EU programme (ECS 0000024), Italy's "Piano Nazionale di Ripresa e Resilienza (PNRR)", mission 4, component 2, investment no. 1.5.

Conflicts of Interest: The authors declare no conflicts of interest.

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