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Systematic Review

Studies on Air Pollution and Air Quality in Rural and Agricultural Environments: A Systematic Review

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Abstract: Studies on air quality in rural environments are fundamental to obtain first-hand data for the determination of base emissions of air pollutants, to assess the impact of rural-specific airborne pollutants, to model pollutant dispersion, and to develop proper pollution mitigation technologies. The literature lacks a systematic review based on the evaluation of the techniques and methods used for the sampling/monitoring (S/M) of atmospheric pollutants in rural and agricultural settings, which highlights the shortcomings in this field and the need for future studies. This work aims to review the study design applied for on-field monitoring campaigns of airborne pollutants in rural environments and discuss the possible needs and future developments in this field. The results of this literature review, based on the revision of 23 scientific papers, allowed us to determine (i) the basic characteristics related to the study design that should always be reported; (ii) the main techniques and analyses used in exposure assessment studies conducted in this type of setting; and (iii) contextual parameters and descriptors of the S/M site that should be considered to best support the results obtained from the different studies. Future studies carried out to monitor the airborne pollution in rural/agriculture areas should (i) include the use of multiparametric monitors for the contextual measurement of different atmospheric pollutants (as well as meteorological parameters) and (ii) consider the most important boundary information, to better characterize the S/M site.

Keywords: airborne pollution; sensors; monitors; analysis; rural emissions; rural environment

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Citation: Borghi, F.; Spinazzè, A.; De Nardis, N.; Straccini, S.; Rovelli, S.; Fanti, G.; Oxoli, D.; Cattaneo, A.; Cavallo, D.M.; Brovelli, M.A. Studies on Air Pollution and Air Quality in Rural and Agricultural Environments: A Systematic Review. *Environments* **2023**, *10*, 208. https://doi.org/10.3390/environments10120208

Academic Editors: Yonghang Lai and Peter Brimblecombe

Received: 18 October 2023
Revised: 23 November 2023
Accepted: 27 November 2023
Published: 30 November 2023

1. Introduction

Studies on air pollution and air quality in rural and agricultural environments are fundamental to (i) obtain first-hand data for the determination of base emissions, (ii) assess the impact of rural-specific airborne pollutants, (iii) model the pollutant dispersion, and (iv) develop mitigation technologies [1]. In fact, rural emissions are considered one of the major contributors to atmospheric pollution worldwide which, as well known, can cause severe adverse effects on human health and on the environment [2]. Agricultural activities (i.e., plowing, harrowing, cultivating, sowing, harvesting, threshing, and grain handling) are related to the emission of airborne pollutants [3], especially of particulate matter (PM) and ammonia (NH_3) (often used as a proxy for all the pollutants produced by intensive agricultural activities) [4]. Moreover, agricultural burning, deemed as a cost-effective system of cleaning and preparing the field for the succeeding growth season [5], emits different airborne pollutants, including PM, nitrogen dioxide (NO_2), carbon monoxide (CO), volatile organic compounds (VOCs), and polycyclic aromatic hydrocarbons (PAHs) [6–11].

In this context, agricultural workers are an occupational group that should be given priority in terms of public health [12]. Exposure in agricultural contexts could be indeed related to different pollutants, such as (i) inorganic dust, (ii) organic dust (containing microorganisms, mycotoxins, or allergens), (iii) decomposition gases, and (iv) pesticides [13]. For these reasons, agriculture workers may experience health problems related to their potential exposure to the aforementioned airborne pollutants [12,14]. In particular, the respiratory system is greatly affected by this kind of exposure; indeed, as reported by Babaoglu and collaborators [13], different on-field studies showed increased respiratory problems among agricultural workers, such as (i) asthma, (ii) chronic bronchitis, and (iii) other respiratory dysfunctions [15–18]. For the reasons reported above, the evaluation of rural-related airborne pollutants and occupational exposure to airborne pollutants in agricultural settings is of particular interest in terms of risk assessment for human health.

Even though the first studies conducted in agricultural contexts were characterized by a limited number of samples and collected data, in recent years growing technological innovations in sensors and monitors for air quality assessment have allowed the realization of studies characterized by a more complex and broad study design in this type of context. In fact, as already reported by Ni in 2010 [1], remarkable developments in the field of monitors and sensors have allowed improvements in terms of (i) temporal and spatial sampling/monitoring scales and (ii) pollutants investigated. Potentially, new-generation sensors and monitors could be easily adopted in exposure assessment evaluations, as they are able to adapt to several types of study design and/or to noticeably improve the spatial and temporal resolution [19]. In addition, improved exposure assessment methods could provide substantial progress and increase the potential and level of detail and depth of air quality studies [20].

By way of example, different literature reviews based in the agricultural context have been recently published. Abdurrahman and collaborators [2] published a review in 2020 of the literature regarding the current state of stubble burning in India. In their work, the authors focused (i) on the generation and combustion of stubble crops; (ii) on the composition of emissions from the combustion of stubble; (iii) on the transport and dispersion of emissions into the atmosphere; and (iv) on the effects of stubble combustion. Moreover, they also considered (i) stubble combustion legislation and policies and (ii) alternative techniques for crop stubble management. In addition to reviewing the literature based on specific activities, as in the latter case, some authors have focused on specific contaminants. For example, Švajlenka [21] presented the need to address indoor environmental monitoring in the agricultural context, summarizing the most used methods for monitoring biological agents and characterizing their negative effects on exposed humans and animals in the context of agricultural hygiene. Tudi and collaborators [22] presented, in addition to a historical perspective of pesticide usage, the general types of pesticides in use and their role in agriculture, the effect of pesticides on the environment, and climate-change-related factors in pesticide use and the adverse effects on the natural environment. Pesticide exposure was also evaluated by Amoatey [23]. The authors focused on the assessment of exposure in greenhouse farms by (i) discussing pesticide exposure levels and toxicity; (ii) identifying common routes of exposure; and (iii) exploring the health effects on greenhouse workers.

Nevertheless, to the knowledge of the authors, the scientific literature lacks a systematic review based on the evaluation of the techniques and methods used for the sampling/monitoring (S/M) of atmospheric pollutants in agriculture, which highlights the needs and shortcomings of future studies in this field. The aim of this review is therefore to present (i) a description of the selected papers (in terms of period and season of S/M, area of interest, and main investigated pollutants; Section 3.1) and especially the (ii) main techniques of S/M and (iii) the analytical methods used in the agricultural context (Section 3.2). Finally, some additional information that is useful to better contextualize the S/M site will be presented in detail (i.e., type of cultivation, type of activity performed, presence of livestock and farms near the S/M site, and use of pesticides and/or fertilizers; Sections 3.2.3 and 3.2.4).

2. Materials and Methods

This systematic review was conducted considering outcomes from three different databases (PubMed, Scopus, and ISI Web of Knowledge). Papers were detected and then selected through the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) criteria guidelines [24]. For each database, keywords referring to (i) agricultural activities (agriculture, farming, tillage, cultivation, harvest, agronomy, agronomics, agriculture crop, and agriculture burning); (ii) the rural/agricultural environment (rural, country, agriculture community, and agricultural setting); (iii) the atmospheric pollution (airborne pollutants, particulate matter, PM, $PM_{2.5}$, PM_{10}, gaseous pollutants, ammonia, NH_3, sulfur dioxide, SO_2, marker, biomarker, air quality, air pollution, emissions, models, agricultural pollution, and farm pollution); and (iv) human exposure (exposure or human health) were used in a search query.

As reported in Figure 1, 1045 papers in Web of Science, 247 papers in PubMed, and 1330 papers in Scopus (last search: 24 January 2022) were found. Papers were investigated and selected following specified inclusion and exclusion criteria. Only (i) scientific articles (ii) written in English and concerning the (iii) exposure to airborne pollutants in (iv) rural/agricultural settings via (v) different monitoring or sampling techniques were considered for the purpose of this review. For these reasons, literature reviews, congress proceedings, and any articles not written in the English language were not included in this work. Moreover, papers focused solely on the evaluation of exposure to pesticides were not considered. After the elimination of the duplicates, the authors double-selected (to reduce operator error) the potentially suitable articles after reading the title, the abstract, and the complete manuscript. After this process, 23 articles were deemed valid and included in this review (Figure 1). The results of the eligible studies are described in the following sections.

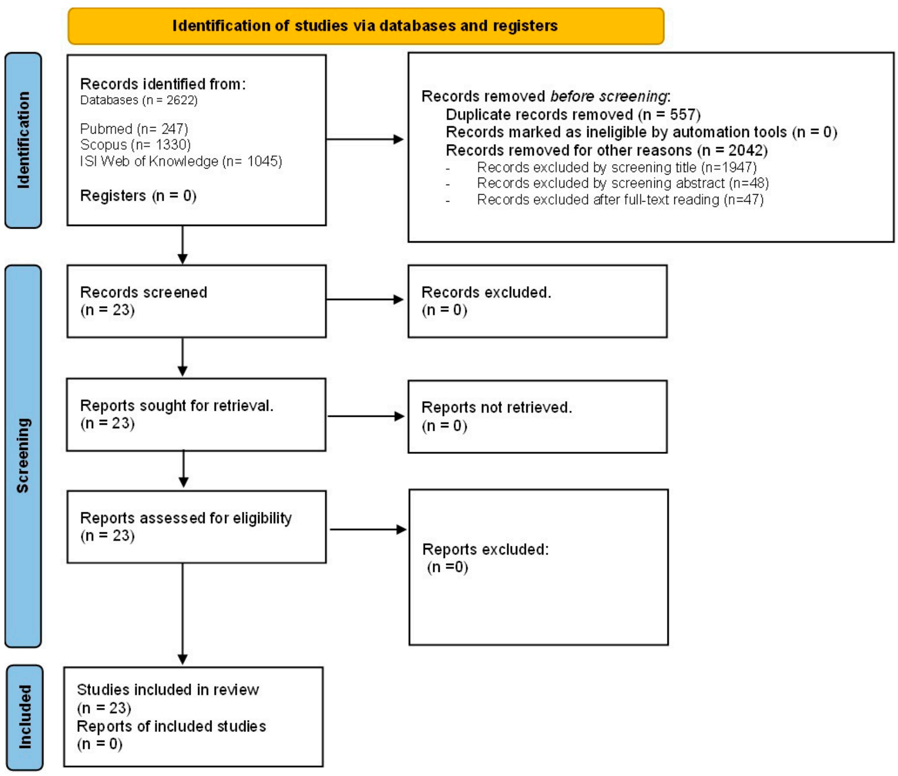

Figure 1. Flowchart of searched and reviewed literature (modified from [24]). Italics refers to the number of excluded articles; bold refers to the number of maintained articles.

3. Results and Discussion

3.1. Description of the Investigated Studies

The studies considered in this systematic review were principally (n = 8) conducted between 2005 and 2010 [25–32]. Four studies were performed before 2000 [33–36], while three studies were conducted in the period 2000–2005 [37–39], in the period 2010–2015 [40–42], and after 2015 [43–45] (Table S1; Supplementary Materials).

Most of the study designs (n = 9) considered a single-season evaluation [31,34,38,39,42–46]. On the contrary, five and seven works were respectively based on a two-season campaign [27,30,33,36,40] and on four seasons, respectively [25,26,32,35,37,41,47] (Table S1; Supplementary Materials). Overall, 16 studies conducted an S/M campaign during the summer season [25–27,30,32–35,37,39,41–43,45,47], 11 during autumn [25–27,30,32,35,37,38, 41,44,47], 10 during winter [25,26,31,32,35–37,40,41,46,47], and 10 in spring [25,26,32,33,35–37,40,41,47]. It should be noted that considering the season during which S/M is carried out can be of fundamental importance in the agricultural context. In this field, the contribution of the various sources and activities can be different. By way of example, Campos-Ramos and collaborators [25], showed that during the summer period, sampled particles are characterized by a greater contribution of the mineral phase, whose presence is correlated to the re-suspension of volcanic ash deposited from old volcanic events coming from the northeast sector on the prevailing winds. On the contrary, during spring, the greatest contribution is that of sodium chloride and calcium-rich particles, the presence of which is caused by the transport of air masses from the Pacific Ocean. The authors also showed how the particles sampled during autumn and winter are related to the burning of cane crops, an activity carried out during these seasons; in this case, the particles are therefore rich in organic carbon. Similarly, Sevimoglu and collaborators [35] reported that the total measured level for 18 investigated PAH compounds was 15 times higher during winter (i.e., the sugarcane harvesting and processing season) than during the summer (i.e., when agricultural activities around sugarcane fields are limited). These results clearly indicated how activities related to sugarcane harvesting and processing can cause elevated PAH levels. In addition to these examples, it is necessary to consider that the various activities performed in the agricultural context (i.e., ploughing, harrowing, cultivating, sowing, harvesting, threshing, and grain handling) are characterized by a specific seasonal cycle and as a function of the type of crop considered.

In terms of geographical distribution, most of the studies (n = 7) were conducted in North America [29,31,33,35,37,38,41] and Europe (n = 6) [32,40,41,45–47]. Five studies were conducted in Asia [28,39,42–44], whereas four studies were performed in South America [25,27,30,34] and only one in Africa [26] (Figure S1 and Table S1; Supplementary Materials). The details of the investigated areas, at a local level, are reported in Table S1 (Supplementary Materials). Identifying the region investigated by this type of exposure assessment study could be of interest. The regional distribution of agricultural land use is indeed a combination of local (i) agricultural, (ii) climatic, (iii) edaphic, and (iv) soil conditions as well as (v) socio-economic drivers [31]. Data for the period 2007–2016 report that the largest share of agricultural land was in Asia (34%), followed by America (25%) and Africa (24%). Finally, Europe and Oceania represent approximately 9 and 10% of the total, respectively [31]. Moreover, as will be further explained, even the typical kind of cultivation of a region will have effects on the atmospheric pollution concentrations because of edaphic and soil conditions as well as the type of activity required (e.g., mechanical or manual).

Regarding the type of studied pollutants, the most investigated pollutants were $PM_{2.5}$ [29,31,38–40,42–45] and PM_{10} [25,27,29,35,38–40,45], analyzed in nine and eight studies, respectively. The coarser PM fractions were analyzed in five studies [33–35,40,46], the finer fractions in two papers [26,40], and Ultra Fine Particles (UFPs) in a single work [40]. Elemental and organic carbon (EC and OC) were investigated in only one study [38] as well. As regards the gaseous pollutants, two studies and one work respectively analyzed the atmospheric concentrations of CO [34,42] and carbon dioxide (CO_2) [38]. Several nitrogen oxides (NOx) were investigated in four studies [36,38,41,42]. Nitric acid (HNO_3) [41], NH_3 [41,47], sulfur dioxide (SO_2) [42], and ozone (O_3) [42] were analyzed as well. Inorganic anions (NO_3^-, SO42−, Cl−) and cations (NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}) were examined by Wei and collaborators [42]. Moreover, two studies [37,40] analyzed different families of VOCs in the atmosphere, benzene (C_6H_6) and formaldehyde (HCHO) were measured in another study [34], and different PAHs were considered in three studies [30,35,43]. Moreover, in addition to the pollutants reported above, the presence of endotoxin [29,46], levoglucosan [38], acrolein [34], quartz [26], and asbestos fibers [32] were considered as well (Tables S1 and S2; Supplementary Materials). As reported, one of the most investigated pollutants was PM which, together with NOx, is the most present pollutant in agricultural contexts. As one of the major sources of atmospheric PM, soil PM emissions make up 5–20% of the mass concentration of ambient atmospheric PM_{10} and contribute significantly to PM_{10} air pollution under certain weather conditions and/or topography [48]. Specifically, the main agricultural activities responsible for the generation and release of PM from soil emissions are the following: (i) tillage, (ii) land management practices, and (iii) harvesting. PM emissions from this type of activity could therefore have a regional (and not only local) air pollution effect, especially in particular conditions (i.e., in the presence of intensive agricultural activities or in arid or semi-arid regions [49]). Indeed, in addition to rural activities, the wind erosion of soil in agricultural areas can significantly contribute to the formation of PM. Wind erosion in farmland occurs mainly because of (i) naturally windy conditions, (ii) field cultivation and harvesting, where the soil particles disintegrate, and (iii) where the PM becomes entrained in the air by mechanical action, especially in the case of PM10 [50,51]. Another aspect to be considered in the agricultural sector is the use of non-road mobile machinery. For example, in Europe, PM and NOx emissions of non-road machinery (agricultural and construction equipment) account for 25% and 15% of the total PM and NO_x emissions of Chinese mobile machinery, respectively [52,53]. In detail, according to the China Mobile Source Environmental Management Annual Report (2020) [54], non-road mobile sources can emit tons of hydrocarbons, NOx, and PM (in reference to 2019 data). Furthermore, as is well known, $PM_{2.5}$ is formed through different processes and interactions between primary particles, various precursors (e.g., NO_x, SO_x, VOCs, and NH_3), photochemical reactions, and meteorological processes. For these reasons, the composition of $PM_{2.5}$ may vary and may include diverse types of chemicals, both from primary and secondary origins (e.g., ionic species such as chloride, nitrates, sulphates, and ammonium; EC/OC—elemental and organic carbon), as well as elemental species [55]. In detail, some studies have suggested that ammonia plays a critical role in the PM2.5 formation, as a precursor of secondary inorganic aerosols, including ammonium sulphate ($(NH_4)_2SO_4$) and ammonium nitrate (NH_4NO_3). This may play a key role in agricultural settings, due to the high amount of ammonia released from agricultural sources (e.g., animal husbandry, fertilizer use, and crop residue combustion) [55]. Furthermore, the production of NO_x from soils is controlled by microbial processes, including nitrification (i.e., oxidizing process in which aerobic bacteria oxidize ammonium to nitrite and nitrate) and denitrification (i.e., a series of processes that reduce nitrite or nitrate to nitric oxide (NO), nitrous oxide (N_2O), and dinitrogen (N_2) in anaerobic conditions). Different soil characteristics and microenvironmental variables, such as (i) soil texture, (ii) inorganic availability, (iii) soil pH, (iii) temperature, (iv) oxygen content, and (v) water-filled pore space play a critical role in the processes of NOx production and diffusion out to the atmosphere. As reported in the literature [56], these factors are influenced by different agricultural management practices, such as irrigation and fertilization [56,57]. Also, as reported by Yang and collaborators [58], agricultural activities dominated by chemical nitrogen fertilizers and livestock production may contribute to NH_3 emissions which, as an important alkaline gas, can subsequently react with acidic substances (i.e., SO_2 and NO_x), forming ammonium salts (NH_4^+), with a consequent contribution to fine PM pollution and affecting human health.

3.2. Monitoring, Sampling, and Analytical Techniques

3.2.1. Instrumentation

The articles reviewed in this study mostly relied on environmental (i.e., fixed-site) S/M; this type of S/M was encountered in 18 studies [25,29–45]. One study combined the use of environmental techniques with the use of modelling methods [47], while two studies [27,46] performed both environmental and personal S/M. A single study involved the use of S/M only on a personal level [26] (Table S2, Supplementary Materials) Other useful information (e.g., sampling substrate and acquisition rate/collection time) related to the methods used in the investigated studies are reported in Table S2 (Supplementary Materials). As shown, (Table S2; Supplementary Materials) gaseous pollutant (i.e., CO, CO_2, NO, NO_2, NOx, and O_3) concentrations were evaluated via direct reading monitors. In only two cases [34,41] were CO and NO_2 respectively sampled with an inert gas sampling bag and via a Willems badge passive sampler. Regarding the different PM fractions (UFPs–TSPs (Total Suspended Particles)), a small number of studies (n = 7) used direct-reading techniques to measure PM concentrations. On the contrary, different studies (n = 14) used filter-based techniques for the measurement of PM concentrations (especially for PM_{10} and $PM_{2.5}$): in this case, the authors associated the gravimetric determination with a posteriori analysis performed on the sampled filter (further described in Section 3.2.2). It is worth noting that indirect active sampling techniques on a collection substrate and direct-reading monitoring techniques present, as is well known, different characteristics and opportunities for further investigation. The choice of one or the other depends on the overall needs of the study [59–61].

3.2.2. Analytical Methods

Most of the studies that analyzed $PM_{2.5}$ applied filter-based techniques, as these studies often included, in addition to the gravimetric determination of $PM_{2.5}$ concentrations, a posteriori analyses on filters, such as (i) Scanning Electron Microscopy with Energy Dispersive X-ray spectroscopy (SEM-EDX) and Scanning Transmission Electron Microscopy (STEM) analysis, to determine the particles' aspect ratio, characterize the particles in terms of elemental components, and identify the fibrous morphology of the sampled powder [25,27,33,39,44]; (ii) X-Ray Diffraction (XRD) analysis, for both the qualitative and semi-quantitative determination of mineral phases; (iii) infrared absorption spectrophotometry (IR), for the analysis of quartz particles; (iv) Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES), Inductively Coupled Plasma-Mass Spectrometry (ICP-MS), or Atomic Emission Spectroscopy (AES), to quantify and analyze the concentration of trace elements in particle samples; (v) High Performance Liquid Chromatography (HPLC) and Ion Chromatography (IC), as well as AES and ICP-MS for the characterization of PM chemical composition [39]; (vi) thermal optical transmittance (TOT), to determine EC and OC; (vii) Gas Chromatography-Mass Spectrometry (GC-MS), for PAH and VOC analysis; and (viii) extraction of endotoxins (Table S2; Supplementary Materials).

As reported in the literature [62], the gravimetric analysis is a well-standardized regulatory procedure, exhaustively described in the EN 12341 reference technical standards. This filter-based technique is based on a time-integrated approach, and for this reason, the information obtained (both in terms of PM mass concentration and from the analyses performed a posteriori) cannot provide data on (i) temporal trends and variability, (ii) peak levels, and (iii) short-term emissions. In any case, this technique, as mentioned, is often associated with more complex off-line analyses, which can be particularly useful for several reasons. For example, from an elemental and morphological characterization of the sampled particles, it is possible to trace the emission sources of the pollutants investigated, as performed by Campos-Ramos and collaborators [25]. In their study, the authors were indeed able to identify the major contributions to the particles' emissions during the different seasons considered. In particular, the authors verified how, during the autumn and winter seasons, the greatest % fraction came from carbon-rich particles (46 and 48%, respectively), whose presence was linked to burning cane crops, an activity conducted during these seasons. Analyses of this type are also useful for evaluating the exposure levels measured during activities, for example, during pre-harvest agricultural burning of sugarcane, as in the study performed by Le Blond et al. [27]. Moreover, in addition to the chemical composition of particles (mostly characterized by carbonaceous matter and silicates), the authors also analyzed their size distribution: this allowed them to define how airborne PM samples captured during burning and harvesting were found to be within the ultra-fine and fine range and how mineral particles present in the respirable size fraction could contribute to respiratory illness. As previously mentioned, (and as reported in Table S2; Supplementary Materials), filter-based techniques usually require a prolonged sampling time, mainly because of the need to obtain sufficient amounts of particulate material for the subsequent chemical analyses, if further off-line investigations are planned (which is a basic requirement, for example, for substances or components present at trace or ultra-trace levels). Obviously, and as already stated above, this choice can also lead to some disadvantages in the study design, preventing, for example, the possibility of identifying day-to-day or daytime-to-nighttime variability, as reported by Rovelli and collaborators [63].

3.2.3. Supporting Information

Thirteen articles considered in this review [25,27,29,31,34,35,38,39,41–45], together with the evaluation of atmospheric pollutant concentrations, acquired meteorological information, including the following, in order of representativeness: (i) relative humidity; (ii) temperature; (iii) wind intensity; (iv) precipitation; (v) wind direction; (vi) atmospheric visibility; and (vii) barometric pressure. In addition to these, single studies evaluated various other parameters, useful for the characterization of the S/M site (i.e., grain size [26] and activities related to forest fires and volcanic emissions [25]). Despite it being recognized that (i) high wind intensities, (ii) low precipitation, (iii) poorly aggregated soils, and (iv) high-intensity agricultural activities often promote wind erosion in agricultural fields [64], as highlighted by Avecilla and collaborators [48], many studies in the literature underline the relationship between the surface conditions and the dust emission, especially in desert areas and dry lakes or playas. On the contrary, little is known about the influence of meteorological variables on PM (i.e., PM_{10}) emissions from agricultural soils. Different laboratory tests have been conducted with the aim of testing this hypothesis: these studies showed how threshold wind speed, which initiates the process of wind erosion, principally depends on the air humidity, as this affects the moisture content of the soil surface and consequently the cohesion strength between particles [65–67]. Similarly, other authors showed how both wind speed and air temperatures were the most important influence factors in the determination of high PM concentrations in the investigated environment [68]. For the above reasons, acquiring all the information (e.g., meteorological data) relating to the boundary conditions of the S/M point is of particular importance in studies conducted in an agricultural context.

In addition to the data reported above, some authors also used questionnaires to acquire more detailed information with respect to the activities carried out at the S/M sites. In particular, four authors relied on this method, obtaining information about (i) the type of farm (i.e., modern or non-modern); (ii) the method of storage of hay (i.e., round bales, in bulk, or other types); (iii) the distance between the farm buildings and the house [46]; (iv) the degree of perceived annoyance and season(s) of highest perceived annoyance, as well as the origin of odor [47]; and (v) agricultural operations [29]. In addition to the questionnaires, inspections were sometimes conducted by certified hygienists, to acquire detailed information on the tasks performed by farmers, as well as the duration of these tasks and the type of process (i.e., manual or mechanical) [26]. Time–location–activity information was also gathered by Jimenez and collaborators [38]. As will be reported below (Section 3.2.4), the analysis of the activities performed by the subjects under examination, or during the S/M period, as well as other information more easily acquired from questionnaires/interviews (e.g., type of farm present near the S/M point), are of fundamental importance in studies conducted in the agricultural context, as the concentrations of atmospheric pollutants are often correlated to the activities carried out during the S/M period.

3.2.4. Additional Information to Consider

Eleven studies considered in this review specifically reported the type of cultivation present in the area under consideration. In particular, two studies were conducted in fields producing grass/hay or forage [33,36], while single studies were conducted in potato [33], sunflower [26], cotton [45], canola, and oat fields [33], as well as in tree orchards [31]. Maize [26,36], wheat [33,42], and barley [33,39] were analyzed in two studies. Finally, four studies conducted work in sugarcane fields [25,27,30,35]. As can be highlighted, most of the studies (n = 13) do not explicitly report the type of cultivation present during the S/M period (Table S3; Supplementary Materials). This aspect can be of particular importance, as different crops can behave differently, requiring different cropping techniques, which in turn can involve the presence and possible emission of different pollutants in the atmosphere [69]. In addition, the environmental conditions necessary for a particular crop can affect the environmental concentrations of pollutants. For example, Green and collaborators [33] highlighted in their study how the organic content measured in breathable dust can be influenced by several factors, such as the type of cultivation. The authors reported how the type of cultivation can influence the granulometric distribution, due to the type of irrigation necessary for the different crops; the periodic flooding of the soil causes a differential sedimentation of the soil suspensions based on the size of the particles. In this case, the finest particles will remain deposited on the surface of the ground, and they can be easily suspended in the air, due to natural or anthropogenic phenomena (e.g., windy movements or agricultural activities). In addition, it is necessary to consider another aspect related to crop residue burning. The amount of crop residue burned in fields is characterized by large regional variations and depends on the crop type. As mentioned, this activity can lead to the emission of different airborne pollutants (e.g., PM, CO, CO_2, SO_2, NO_x, NH_3, methane (CH_4), EC, OC, VOCs, and PAHs), whose dispersion in air may vary as a function of the season and meteorology and also according to the type of agricultural residue [6–11,70–72]

Eleven studies considered in this review do not specify the type of activity carried out in the fields during the pollutant monitoring or sampling. On the contrary, seven articles evaluated a typical activity performed in this environment, namely agricultural burning [30,34,35,38,39,42,44]. Only three studies [26,27,33] were performed during harvesting activities, while individual studies were conducted during planting [26], silages [36], and pesticide application [45] (Table S3; Supplementary Materials). Also in this case, as reported in the literature [26], specifying the type of activity carried out and the manner in which the task is performed (e.g., mechanical or manual) may be an important determinant of exposure, even if the contribution of open field activities is particularly difficult to estimate because of the wide variety of field operations and crops as well as other parameters (e.g., climatic factors and pollutant emission sources) [73]. As reported in the literature review conducted by Maffia and collaborators [73] and focused on PM sources in the agricultural environment, agricultural workers can produce and emit different pollutants, depending on the different activities carried out throughout the year. Those emissions are mainly due to (i) the raising of soil particles due to the passage of heavy machinery and (ii) the pulverization of biomass, such as crop residues and animal waste. In any case, it must be emphasized that PM emissions associated with particular crop activities usually occur in periods of only days to weeks. However, the quantity of atmospheric PM emitted during these activities is likely to be several times that of wind erosion emissions, for example [49]. In their review, Maffia and collaborators [73] reported that the main agricultural operations during which PM is released into the atmosphere are the following:

i. Soil tillage: activity associated with a significant amount of primary PM emissions, which can vary according to environmental conditions (e.g., soil moisture) and to the specific tilling implement used. Tillage can also lead to the emission of pesticide particles previously deposited onto the soil through pesticide spraying or sowing of coated seeds.

ii. Harvesting: one of the major sources of PM in agriculture, together with post-harvest activities (e.g., yield transport, storage, and drying).
iii. Burning of crop residues: recognized to generate high emissions of greenhouse gasses and PM.
iv. Sowing: this activity, due to using seed drilling machines, produces PM emissions. The emitted particles are generated mainly from the soil, but a small portion may also come from the seeds, which are abraded during sowing activity.
v. Manure and fertilizer distribution: one of the contributors to primary PM emissions in the agricultural sector. In this case, the importance of PM emission from this activity is strongly linked to the composition of the generated particles, which includes bioaerosol emissions.
vi. Spraying operations: both through the primary drift of droplets and secondary drift of evaporating compounds.

In addition to the intrinsic characteristics of agricultural activity reported above (i.e., cultivation type and type of activities performed), some contextual parameters present in these environments should be carefully observed and analyzed, as they are potentially able to influence the concentrations of airborne pollutants. Among these is the presence and type of animal farms near the S/M point; in this review, most of the studies (n = 19) did not explicitly report this aspect, unlike three and two studies that reported the presence of cattle [31,37,47] and swine [46,47], respectively (Table S3; Supplementary Materials). As reported by Cambra-Lopez and collaborators in their interesting review of the literature [74], indeed, PM concentrations are not only important within livestock housing but also in the surrounding space as, through exhaust ventilation, air pollution generated indoors is released into the external environment [75]. In addition, the particles emitted by livestock can be a carrier of (i) gas and odors, (ii) microorganisms and their components, and (iii) other bioactive components that may have effects on the health of the subjects living in the vicinity of the farms. For the reasons mentioned above, the evaluation of livestock presence/characteristics could be of interest in studies conducted in the agricultural field. Several factors control the formation and concentrations of PM in farms, including (i) the housing system, (ii) type of feeding, (iii) type of animal, (iv) animal activity, (v) animal density, and (vi) humidity conditions [74].

Another aspect of potential importance is the application and use of pesticides and/or fertilizers during monitoring and sampling, an issue analyzed in five studies in this review [28,33,37,39,45] (Table S3). Although this literature review is not focused on pesticide exposure, their assessment is of fundamental importance in agricultural settings and has already been deepened in different literature review papers [23,76–79]. Many commonly used pesticides indeed have a high potential toxicity, and even low-dose exposures can lead to adverse effects on human health, resulting, for example, in (i) increased risk of cancer; (ii) neurodegenerative diseases; (iii) impaired neurological development in children; and (iv) adverse respiratory outcomes (e.g., asthma morbidity, chronic obstructive pulmonary disease, and reduced lung function) [80]. As reported in the literature [81], humans are exposed to pesticides through three routes: (i) dermal contact; (ii) ingestion of food/dust/soil; and (iii) inhalation. Although ingestion seems to be the major contributor to human exposure [82], the other exposure routes are also important to evaluate, as pesticides can diffuse and reach other outdoor or indoor environments in diverse ways [83]:

i. Spray drift: After the application of pesticides, they may not fully reach the target point, and up to 30% of the applied pesticides can spread through the surrounding environment.
ii. Secondary drift: Several weeks after the application of pesticides, these can evaporate from the soil and plants into the air.

iii. Take-home exposure pathway: Farm workers may introduce pesticides indoors (e.g., via (i) shoes, (ii) clothing, (iii) skin, and (iv) hair).
iv. Insects: Pesticides can enter the indoor environment through insects.
v. Volatilization from indoor products: Pesticides can volatilize from indoor products, such as wooden furniture, fabrics, and carpets containing pesticides.

Several studies have been conducted on the evaluation of pesticide concentrations in indoor dust, affected by (i) indoor emissions; (ii) transport from outdoor soil; (iii) removal rates by ventilation and cleaning; (iv) indoor activities; (v) rates of degradation indoors; and (vi) infiltration from outdoors. In addition to the actual pesticide exposure, it is necessary to consider how many solvents are applied during the use (and production) of pesticides [84] and how the emission of VOCs caused by these activities should be evaluated. As an example, pesticide production and application contributed approximately 5.5% of total VOC emissions to the San Joaquin Valley in 2019, as reported in the literature [85]. In addition, some VOCs emitted by pesticides, such as methanol and xylenes, actively participate in oxidative chemical reactions in the air and, under solar ultraviolet radiation, contribute to the formation of ozone [86] as well as secondary organic aerosols [87]. In addition to evaluating the use of pesticides, as mentioned, during studies conducted in the agricultural field, it could be useful to evaluate the application of fertilizers before or during the S/M period, as (i) bioaerosols are emitted during and following manure application to land and (ii) enteric microorganisms and pathogenic bacteria from application sites can aerosolize [88].

4. Conclusions

The results obtained from this literature review, based on the revision of 23 scientific papers, allowed the authors to report, in addition to (i) some basic characteristics related to the study design that should always be considered, the (ii) main techniques and analyses used in exposure assessment studies conducted in agricultural settings. This review also highlights some boundary parameters and descriptors of the S/M site that should be considered as, in addition to being easily obtainable, they allow comparison with the results obtained from different studies. The following information should always be acquired during studies of this type, in the opinion of the authors.

i. Season: Considering the season during which S/M is performed could be of fundamental importance in the agricultural context, because the contribution of the various sources and activities can be different.
ii. Region: The typical kind of cultivation of a region will have effects on atmospheric pollution concentrations because of edaphic and soil conditions as well as the type of activity required (e.g., mechanical or manual).
iii. Cultivation type present at the S/M point: This aspect can be of particular importance, as different crops can behave differently, requiring different cropping techniques, which involve the presence of different pollutants. In addition, the environmental conditions necessary for a particular crop can affect the environmental concentrations of pollutants.
iv. Activities performed before/during the S/M: Specifying the type of activity carried out and the manner in which the task is performed (e.g., mechanical or manual) may be an important determinant of exposure, even if the contribution of open field activities is particularly difficult to estimate because of the wide variety of field operations and crops as well as other parameters (e.g., climatic factors and pollutant emission sources).
v. Presence and type of animal farms near the S/M point: PM concentrations are not only important within livestock housing but also in the surrounding space as, through the exhaust ventilation, air pollution generated indoors is released into the external environment. In addition, the particles emitted by livestock can be a carrier of (i) gas and odors, (ii) microorganisms and their components, and (iii) other bioac-

tive components that may have effects on the health of the subjects living in the immediate vicinity.

vi. Application and use of pesticides and/or fertilizers before/during S/M: due to the chemical products emitted, respectively, VOCs and bioaerosols.

vii. Meteorological parameters: because of the recognized relationship between (i) high wind intensities, (ii) low precipitation, (iii) poorly aggregated soils, (iv) high-intensity agricultural activities and wind erosion in agricultural fields, which in turn can cause the resuspension of particles.

Much of the information presented above (and other more detailed data) could be easily acquired through the administration of questionnaires, a practice that is not fully exploited in the studies analyzed in this review. Similarly, the use of an activity diary could be essential for acquiring detailed information on the activities carried out by farmers during the S/M period.

From the studies analyzed, it also emerged that the instrumentation used is situated in a fixed location and that the S/M is not conducted at a personal/individual level. This can lead to a reduced spatial variability of the obtained measurements. In addition, most of the studies used time-integrated techniques, characterized by a reduced temporal resolution. It should be noted that an adequate spatial and temporal resolution is fundamental in heterogeneous environments, characterized by different emission sources and by a high variability in terms of point pollutant concentrations. On the contrary, it is equally true that, when direct-reading instruments are used, data obtained through these techniques should be treated carefully, given their worse performance in terms of accuracy than standard techniques that are commonly adopted. Regarding the analyses performed a posteriori on the sampled filters, these can be extremely useful to better characterize the acquired samples through, for example, chemical and morphological analysis, which in turn can allow the identification of the emission sources that impact the S/M site. Despite this, filter-based techniques, on which off-line analyses are performed, usually require a prolonged sampling time, which can lead to a misidentification of the daily variability. In conclusion, considering the main results reported above, future studies conducted with the aim of an exposure assessment in the rural/agricultural environment should evaluate the most important boundary information in order to better characterize the S/M site. In addition, the study designs should provide for the use of multiparametric monitors for the contextual measurement of different atmospheric pollutants (as well as meteorological parameters), because of the complex environment in which the S/M is performed.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/environments10120208/s1, Table S1. Summary of the characteristics of the experimental design adopted in the different studies considered in this review (aim of the study; pollutants investigated; year and period of monitoring/sampling; country; area). Table S2. Summary of the instruments and analyses adopted in the different studies considered in this review. Table S3. Summary of the additional information acquired by the authors (cultivation type; activity performed; presence and type of farms; use of pesticides and fertilizers). Figure S1. Spatial distribution of the evaluated papers. The number of studies is given by the grayscale. References [25–47] are cited in the Supplementary Materials.

Author Contributions: Conceptualization, F.B. and A.S.; methodology, F.B. and A.S.; formal analysis, F.B.; data curation, F.B., A.S., N.D.N., S.S., S.R. and G.F.; writing—original draft preparation, F.B.; writing—review and editing, A.S., N.D.N., S.S., S.R., G.F., D.O., A.C., D.M.C. and M.A.B.; supervision, A.C. and D.M.C.; project administration, A.S., D.O. and M.A.B.; funding acquisition, A.S., D.O. and M.A.B. All authors have read and agreed to the published version of the manuscript.

Funding: This study was performed within the framework of the D-DUST project (Data-driven moDelling of particUlate with Satellite Technology aid). This work was supported by Fondazione Cariplo, grant No. 2020–4022.

Data Availability Statement: The data presented in this study are available in this published article and its supplementary materials.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the study's design, the collection, analyses, or interpretation of data, the writing of the manuscript, or the decision to publish the results.

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