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Particulate Matter Exposure in Agriculture

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1. Introduction

World Health Organization (WHO) defines agriculture as all kinds of activity concerning growing, harvesting, and primarily processing of all kinds of crops; with breeding, raising and caring for animals; and with tending gardens and nurseries (Jager, 2005). Agriculture is estimated to have the greatest labor force in the world with over one billion people and employs about 450 million waged woman and men workers (FAO-ILO-IUF, 2005). Agriculture requires a wide variety of operations in order to meet the food, feed, and fiber demands of mankind, requiring specific tasks in the fields, orchards, greenhouses, animal production facilities, and in the agriculture based industry. The methods of production, mechanization levels and labor needs differ significantly in each work setting. Post-harvest operations including grain processing, fruit and vegetable sorting, packaging, and meat processing add different types of operations to the conventional agricultural production practices. In agri-industry, feed mills, flour mills, cotton ginneries, textile industry, etc have different nature in processes involved.

Particulates are generated during the agricultural operations and processes. The “particulates” (or particles) is a term referring to fine solid matter dispersed and spread by air movement (Förstner, 1998). Particulate matter (PM) may be either primary or secondary in origin and is generated naturally (pollen, spores, salt spray, and soil erosion) and by human activities (soot, fly ash, and cement dust) occurring in a wide range of particle sizes (Krupa, 1997). The human health is affected as the PM penetrates into the respiratory system. Size of particulates may range from less than 0.01 to 1000 microns and are generally smaller than 50 microns. As a principle, PM can be characterized as discrete particles spanning several orders of magnitude in size and the inhalable particles fall into the following general size fractions (EPA, 2012a):

- PM₁₀ (generally defined as all particles equal to and less than 10 microns in aerodynamic diameter; particles larger than 10 microns are not generally deposited in the lung);

- PM_{2.5}, also known as fine fraction particles (generally defined as those particles with an aerodynamic diameter of 2.5 microns or less)
- PM_{10-2.5}, also known as coarse fraction particles (generally defined as those particles with an aerodynamic diameter greater than 2.5 microns, but equal to or less than a nominal 10 microns); and
- Ultrafine particles generally defined as the particles less than 0.1 microns.

The fresh air at sea level is composed of a variety of gases, including nitrogen (70.09%), oxygen (20.94%), argon (0.93%) and more than ten other gases at small proportions (Salvato et al., 2003). But natural events and human activities change the composition slightly across the world. Additionally, industrial production, forest fires, dust storms, acid rains, agricultural operations, etc. pollute the fresh air with gases and solid particulate matter. Pollution may be described as “the undesirable change in the physical, chemical, or biological characteristics of air, land, and water” or “the presence of solids, liquids, or gases in the outdoor air in amounts that are injurious or detrimental to humans, animals, plants, or property or that unreasonably interfere with the comfortable enjoyment of life and property” (Salvato et al., 2003). The humans, animals, and plants are exposed to different concentrations of PM (or dust) due to polluted air depending on the environment and PM exposure has health implications of living organisms, including humans (Salvato et al., 2003). Therefore, it is of utmost importance to deal with issues associated with air pollution. Agricultural field operations, animal production, and agri-industry are the sources of indoor or outdoor air pollution, resulting in personal exposure to different concentrations of dusts from different sources at different size fractions described above.

Although agriculture is thought of as a single sector, it is extremely diverse with substantial respiratory hazards resulting from organic and inorganic particulates, chemicals, gases, and infectious agents (Jager, 2005). In some industries there may be one or two predominant respiratory hazards or categories of hazards. The nature of agricultural practice, however, also varies with climate, season, geographic location, moisture content and other properties related to growing practices, and with the degree of industrialisation of the region. The contents of particulates also depend on where, when and how the dust is produced (The Swedish National Board of Occupational Safety and Health, 1994). Consequently, the permutations of potential exposures in agricultural work environments are virtually infinite (Jager, 2005).

The sources of air pollution either as a single source or as combination can be field and orchard operations, unpaved roads, farm equipment exhaust, agricultural burning, processing and handling facilities, pesticides, livestock, and windblown dust (HSE, 2007). In the work environment mineral dusts, such as those containing free crystalline silica (e.g., as quartz); organic and vegetable dusts, such as flour, wood, cotton and tea dusts, and pollens may be found (WHO, 1999). Grain dust is the dust caused by harvesting, drying, handling, storage or processing of barley, wheat, oats, maize and rye. And this definition includes any contaminants or additives within the dust (HSE, 1998). The grain dust includes bacteria, fungi, insects and possibly pesticide residues as well as dry plant particles. Organic dust may contain not only the grain and hay contents but pollen, fungal spores, fungal hyphae, mycotoxins, bacteria and endotoxins and dust from livestock pens may contain skin, hair,

feathers and excrement particles (The Swedish National Board of Occupational Safety and Health, 1994).

As cited by Jager (2005), the University of Iowa's Environmental Health Sciences Research Centre exclaims that it is organic dust that accounts for the most widely exposure leading to agricultural respiratory diseases and that virtually everyone working in agriculture is exposed to some level of organic dust. It was also noted that, in general, the studies of respiratory hazards in agriculture lags the investigation of hazards in mining and other heavy industries.

2. PM exposure in agriculture

Agricultural field operations causing dust production in conventional crop production includes soil tillage and seed bed preparation, planting, fertilizer and pesticide application, harvesting and post-harvest processes. In most countries, awareness in sustainability has been increasing so as to accomplish soil and water conservation. Minimum soil tillage reduces tillage operations resulting in less soil manipulation and direct or zero planting methods eliminate tillage operations that are conventionally applied before planting. These differences in soil tillage, seedbed preparation and planting methods create significant variations in the level of soil perturbation. Thus the amount of mineral dust generated as a result of soil tillage and planting are likely to vary significantly not just due to the differences in these field operations but to different soil types and climate variations. Determining personal PM exposure is important during these operations because of the health hazards to be explained in sub-section 2.6. Another important task is to determine the total amount of dust generated during agricultural operations because the impact of agriculture on air quality is not well-known. Some information on the air pollution in agriculture might be useful before introducing the topic of personal exposure.

An eight-year extensive field study conducted at University of California, along with previous research results obtained in the same university, allowed development of PM₁₀ fugitive dust emission factors for discing, ripping, planing, and weeding, and harvesting of cotton, almonds, and wheat (Gaffney and Yu, 2003). As a result of more than ten-year of studies the researchers developed activity specific and crop specific emission estimates for all agricultural land preparation and harvesting activities within California. In the San Joaquin Valley, PM₁₀ emissions estimates for land preparation and all harvest operations were 13 000 tons year⁻¹ and 13 300 tons year⁻¹, respectively. The researchers considered this step as a critical one since they can seek cost-effective means to reduce fugitive dust emissions from agricultural field operations, and determine future research needs associated with air quality.

Since air pollution is known to be the result of industrialization and mechanization, agriculture is not considered a major cause of air pollution. The emission trends (Figure 1) estimated from all sources and from agriculture in European Union shows that agriculture is a major source of emission and should be studied further to increase the health and welfare of rural community. PM_{2.5} and PM₁₀ contribute to emissions by 5% and 25% in

Europe, respectively, however recent studies imply that agricultural PM emissions in intensive emission areas might be more (Erisman et al., 2007).

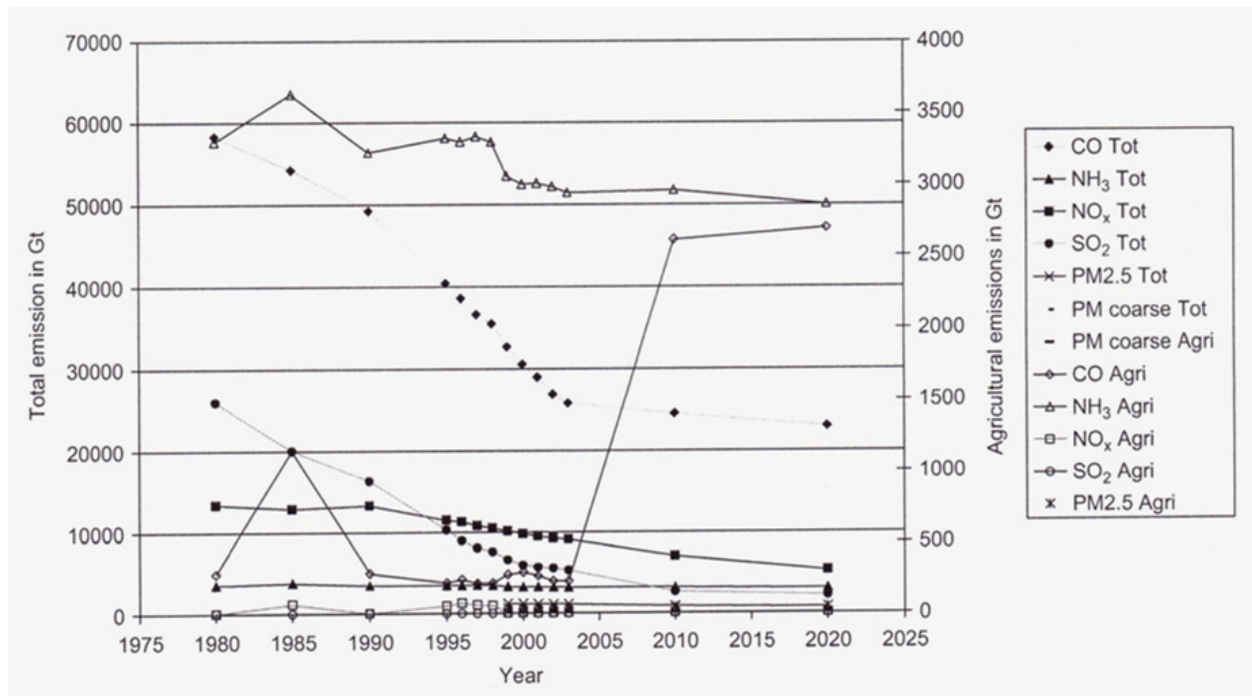


Figure 1. Trend in best estimate emissions from all sources and from agriculture in EU-15 (Erisman et al., 2007)

Bogman et al. (2007) assessed the particle emission from farming operations in Belgium and depending on the conversion factor used, they assessed 10.1 kton or 7.5 kg ha⁻¹ total suspended particle (TSP) emission per year, 2.0 to 3.1 kton PM₁₀, or 1.5 to 2.3 kg ha⁻¹, respectively. It was estimated that agriculture generates 35% of total TSP emission and 24% of total PM₁₀ emission. In a study conducted over one year they also found that mineral dust was approximately 8 times higher than organic dust. Particles smaller than 20 µm made up of more than 50% and the particles smaller than 40 µm were more than 80%, suggesting that harmful PM₁₀ is not negligible within the total suspended particles. These findings are informative in that the agriculture is one of the major sectors polluting the air.

Air quality standards were violated at certain times of the year, particularly during row crop agricultural operations, implying that row crop agriculture could be a major contributor to PM₁₀ (Madden et al., 2008).

The stubble burning is a common practice in agriculture in many parts of the world. It is often preferred to remove the harvest leftovers from the field to reduce the draft force needed in soil tillage equipment, to prevent tillage and planting machines from being clogged by the stubble, to achieve a smoother seed bed, etc. In areas where second crop production is a practice, stubble burning saves time before planting because the time available for planting is limited after the first crop is harvested. Smoke from field burning, however, may be disruptive or hazardous to the people in the rural and neighboring urban

areas. Rural communities living in eastern Washington and northern Idaho in the United States were worried about health hazards posed by smoke exposure resulting from stubble burning, but research showed that air quality standards were not violated by pollution from field burning (Jimenes, 2006). The contributions of PM_{2.5} from soil, vegetative burning, and sulfate aerosol, vehicles and cooking were 38%, 35%, 20%, 2%, and 1%, respectively in the Pullman airshed.

2.1. Agricultural field operations

Conservation tillage accomplished approximately 85% and 52% reduction in PM₁₀ emissions on two different farms (Madden et al., 2008). In this study conservation tillage systems required zero or one operation whereas conventional tillage required six operations. Furthermore, conservation tillage could be done at higher soil moisture contents resulting in even less dust compared to dry soil conditions. Other studies also found significantly less amount of dust in conservation tillage compared to standard tillage applications because of decreased number of field operations (Baker et al., 2005). In a two-year study, the cumulative dust production in no-till was one third of traditional tillage. The reduction in dust production was due to the elimination of the two dustiest operations, which were disking and rotary tilling (Baker et al., 2005). However, Schenker (2000) discusses that in conservation tillage, some benefits of reduced dust may be offset to some extent by an increased organic fraction resulting from the cover crop treatment. In the cover crop treatments high organic constituent was found in the respirable dust, suggesting that there may be the potential for increased allergic responses in agricultural workers due to organic dust, but the potential health effect of increased organic matter is not known (Schenker, 2000).

The exposure of tractor operators to dust depends on the availability of a cabin on the tractor and the ventilation system. Early studies found dust exposure levels to be much higher than the ACGIH's threshold limit value (10 mg m⁻³) for inhalable dust, however the exposure levels were considerably lower in the case of a tractor with an enclosed cabin (Nieuwenhuijsen et al., 1998). The tractor operators were subjected to personal respirable quartz concentrations of 2 mg m⁻³ in an open cabin and 0.05 mg m⁻³ in a closed cabin. Pull type soil tillage equipment may generate great amount of dust clouds but the scientific data is not sufficient to determine to what extent quartz exposure creates a risk in agriculture (Swanopoel et al., 2010). This is probably due to the difficulties in exposure assessment posed by varied and cyclic nature of the farmers' work and the diverse locations of the farms (Nieuwenhuijsen et al., 1998).

The field work may require different durations to be completed, resulting in exposure times more or less than 8 hours. It is important to correct measurements and assess the exposure based on actual working time for a task since the threshold limits for occupational exposure are based on 8 h working duration. For instance, dust levels would have been found well below the ACGIH's TLV of respirable nuisance dust (3 mg m⁻³), but well above the TLV of inhalable dust (10 mg m⁻³) if the exposure had lasted for an 8-hour period for many operations (Nieuwenhuijsen et al., 1998).

Mean dust concentrations in field operations, transportation and conveying of materials, and indoor tasks showed that dust concentrations were higher than 10 mg m^{-3} in soil tillage, plant harvesting, and confinements, as shown in Figure 2 (Moloczniak and Zagorski, 1998). Annual work cycle of operators and farmers show that the dust exposure vary significantly during the year depending on the tasks in different seasons (Figure 3). The dust levels were more variable for the tractor/harvester operators considering the work cycle throughout the year while both drivers and farmers were subjected to high dust levels from July to October.

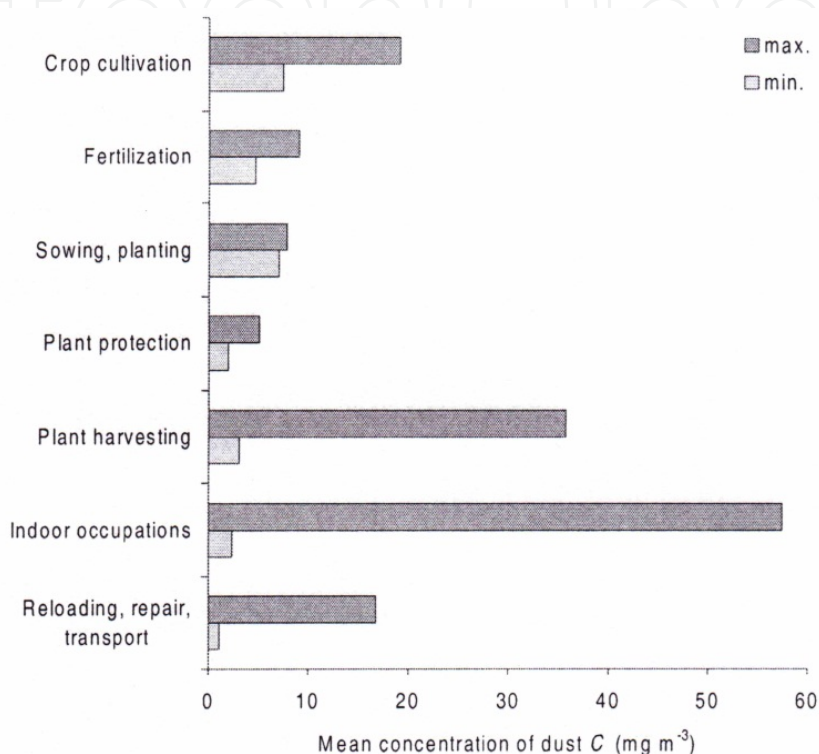


Figure 2. Dust levels in individual groups of farming activities (Moloczniak and Zagorski, 1998)

The soil tilling with rotary tiller, disc harrow, soil packer, fertilizer and the planter predominantly generate inorganic dusts (Figure 4) while harvesting wheat and corn, hay making and baling produce predominantly organic dusts (Figure 5). PM₁₀ concentrations measured gravimetrically were greater than the OSHA threshold ($15000 \mu\text{g m}^{-3}$) in rotary tilling ($25770 \mu\text{g m}^{-3}$), wheat harvesting ($29300 \mu\text{g m}^{-3}$), and hay making ($24640 \mu\text{g m}^{-3}$).

Also, PM_{2.5} concentration levels were higher than the TLV ($5000 \mu\text{g m}^{-3}$) in these operations, respectively with 5888, 10560, 8470 $\mu\text{g m}^{-3}$. PM_{1.0} concentration was too high particularly during wheat harvest ($3130 \mu\text{g m}^{-3}$) and hay making ($6026 \mu\text{g m}^{-3}$). It may be striking that PM_{1.0} concentrations measured during hay making were higher than the TLV set for PM_{2.5}. PM₁₀ and PM_{2.5} concentrations were below the threshold limits in all other field applications (Arslan et al., 2010).

Smokers (63% of operators) had complains about coughing with 60% and phlegm with 83% (Arslan et al., 2010). The operators' complaints about chest tightness were 31% and breathlessness about 29%. But, coughing rate decreased to 47% and chest tightness reduced

to 13% when smokers and non-smokers were evaluated separately (Figure 6). The operators should use personal preventions to avoid adverse health effects when operating tractors and combine harvesters without cabins.

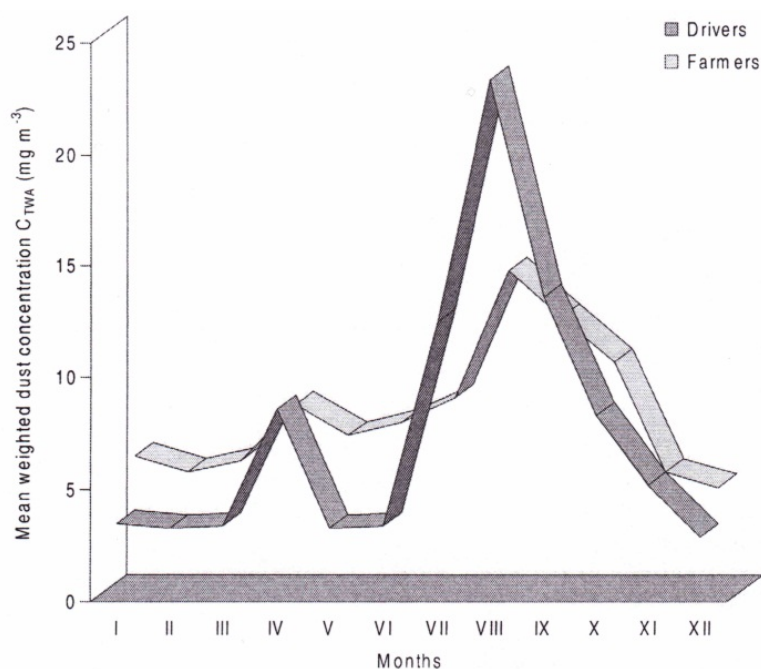


Figure 3. Distribution of exposure to dust in annual work cycle among drivers and farmers (Moloczniak and Zagorski, 1998)

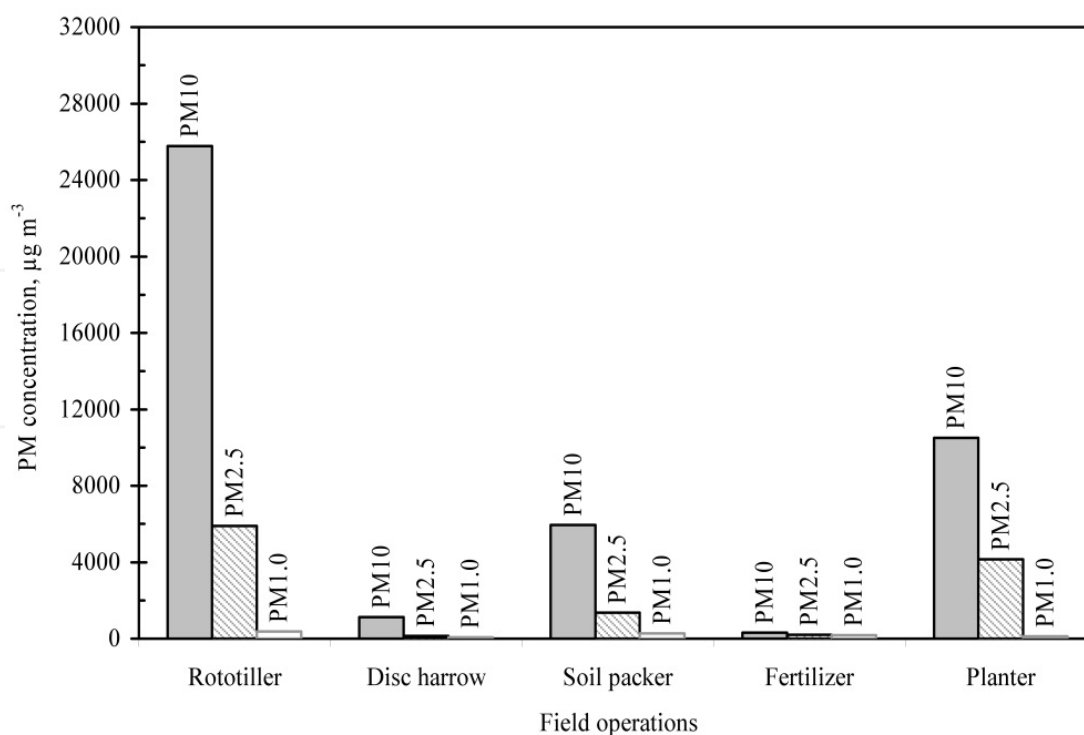


Figure 4. Particulate matter exposure in agricultural operations – predominantly inorganic PM sources (Arslan et al., 2010)

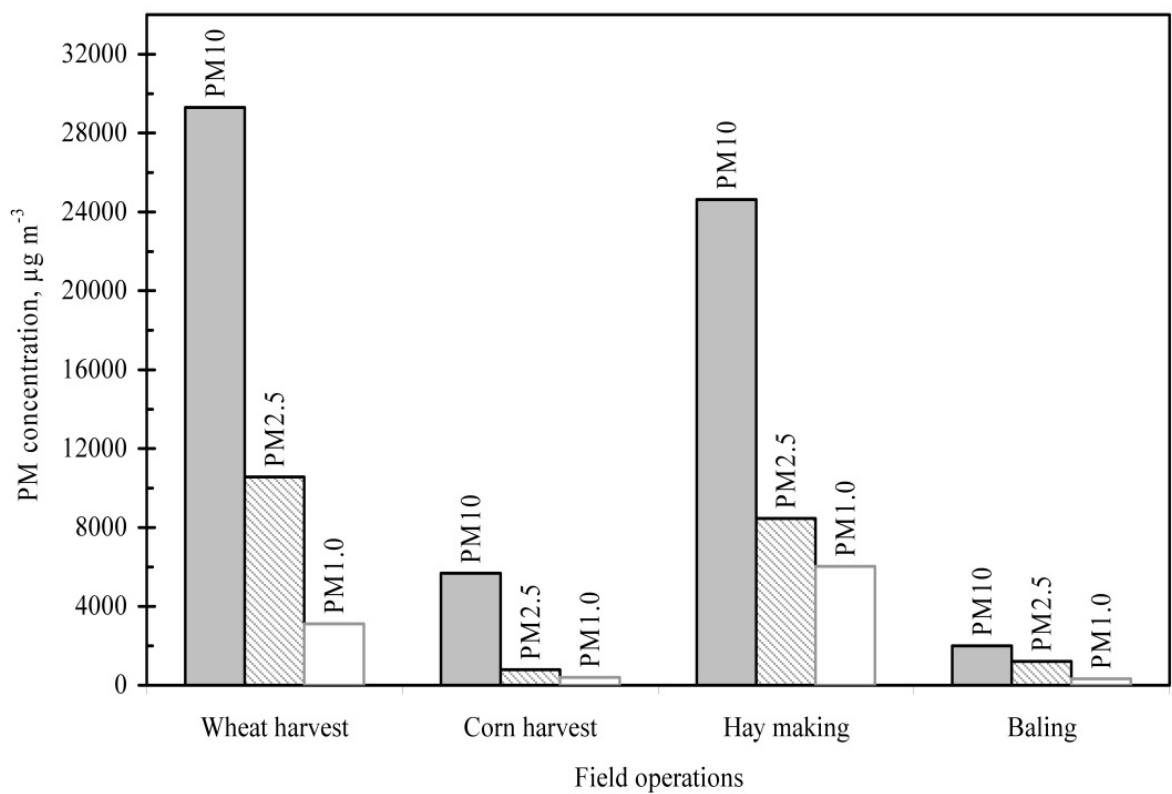


Figure 5. Particulate matter exposure in agricultural operations – predominantly organic PM sources (Arslan et al., 2010)

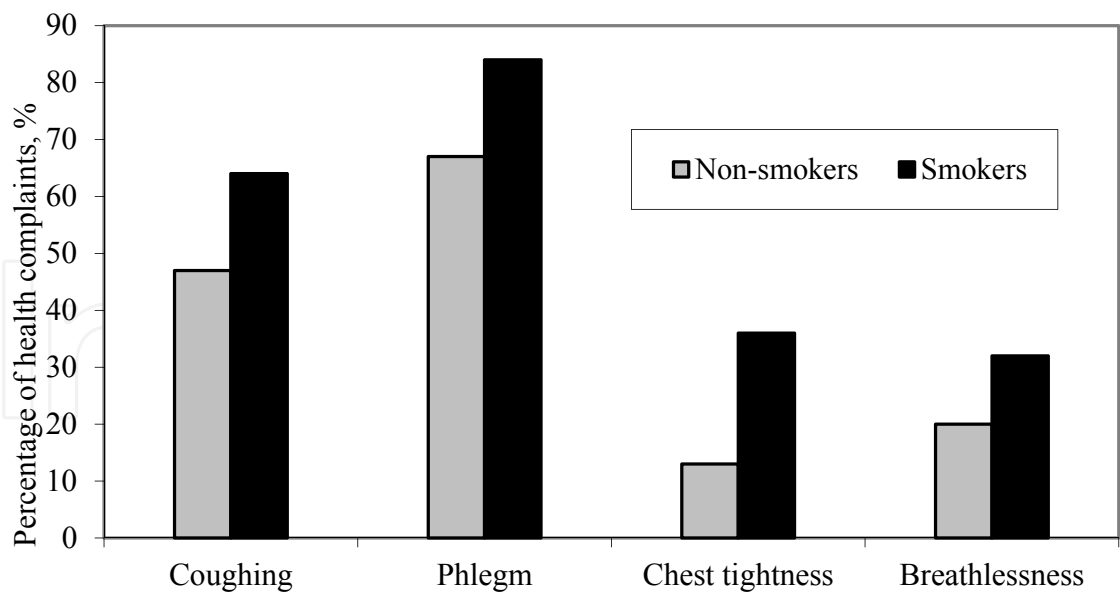


Figure 6. Effect of smoking on health complaints of operators (Arslan et al., 2010)

Literature review and South African Survey was conducted on quartz exposure and quartz related diseases in order to conduct a comprehensive exposure assessment of respirable dust and quartz during farming on a central South African farm (Swanepoel et al., 2010).

Respirable quartz was measured to be not detectable to $626 \mu\text{g m}^{-3}$. The maximum time weighted average concentration was found during wheat planting. They found that twelve of 138 respirable dust measurements (9%) and 18 of 138 respirable quartz measurements (13%) were greater than the occupational exposure limits of 2 mg m^{-3} and $100 \mu\text{g m}^{-3}$, respectively.

The ACGIH threshold limit value ($25 \mu\text{g m}^{-3}$) was exceeded in 57% of respirable quartz measurements and quartz percentages of the fine dust were between 0.3 and 94.4% with a median value of 13.4%. Swanepoel et al. (2010) concluded that the published literature regarding quartz exposure in agriculture is not sufficient and that the quartz risk in agriculture should be quantified systematically and further discussed that the public health could be seriously threatened especially in poor and middle-income countries since tuberculosis and HIV rates might be high in these countries employing large numbers of people in agriculture.

The dust concentration at operator's breathing zone ranged in a wide interval during grain harvesting and handling (HSE, 2007). On the other hand, the measured concentration range was very small in combine harvesters equipped with cabins or with filtration (Table 1). The dust concentrations were above the workplace exposure limit (WEL) of 10 mg m^{-3} for grain dust in combining without the cabins, grain carting work, and grain drying. The harvesters without cabins had extremely higher concentrations than the permissible level. Thus HSE (2007) emphasized that dust exposure needs to be reduced below the WEL and should be kept as low as possible in practice.

Process	Dust level measurement averaged over 8 hours	Comments
Combining (no cabin)	$18 \text{ to } 41 \text{ mg m}^{-3}$	2.4 times daily legal amount
Combining (with cabin and air filtration)	$0.2 \text{ to } 2.5 \text{ mg m}^{-3}$	$1/4^{\text{th}}$ of daily legal amount
Grain carting work	$1 \text{ to } 40 \text{ mg m}^{-3}$	Up to 4 times daily legal amount
Grain drying	$4 \text{ to } 57 \text{ mg m}^{-3}$	Almost 6 times daily legal amount
Milling and mixing	$0.1 \text{ to } 11 \text{ mg m}^{-3}$	Can exceed daily legal amount

Table 1. Dust concentration levels in an operator's breathing zone during grain harvesting and handling equipment (HSE, 2007)

Spankie and Cherrie (2012) exclaimed that employers should be aware of both short-term peaks in exposure and longer term time-weighted averages. They explained that the grain workers were often exposed to high levels of inhalable dust concentration in Britain. The exposed levels in 1990s were usually about 20 mg m^{-3} and were greater than the general guidance level of inhalable dust (10 mg m^{-3}) especially at import and export grain terminals. Therefore the authors conducted a small survey of industry representatives to determine updated exposure levels. According to the newer data, long-term average exposure to

inhalable dust was generally estimated to be less than 3 mg m^{-3} (Figure 7). It was also calculated that 15–20% of personal exposures was greater than 10 mg m^{-3} . The British experience clearly shows that improved engineering systems are very effective in reducing dust concentrations and dust exposure. Improved technologies to reduce dust exposure enable the governments and institutions to set newer and stricter limits to protect public and worker health. For instance, The Dutch Expert Committee on Occupational Safety (DECOS) has set a long-term limit of 1.5 mg m^{-3} for inhalable grain dust (DECOS, 2012). This exposure limit, based on Dutch experiences, shows that there is a need to lower the dust concentrations as much as possible in the work environments, also as recommended by HSE (2007).

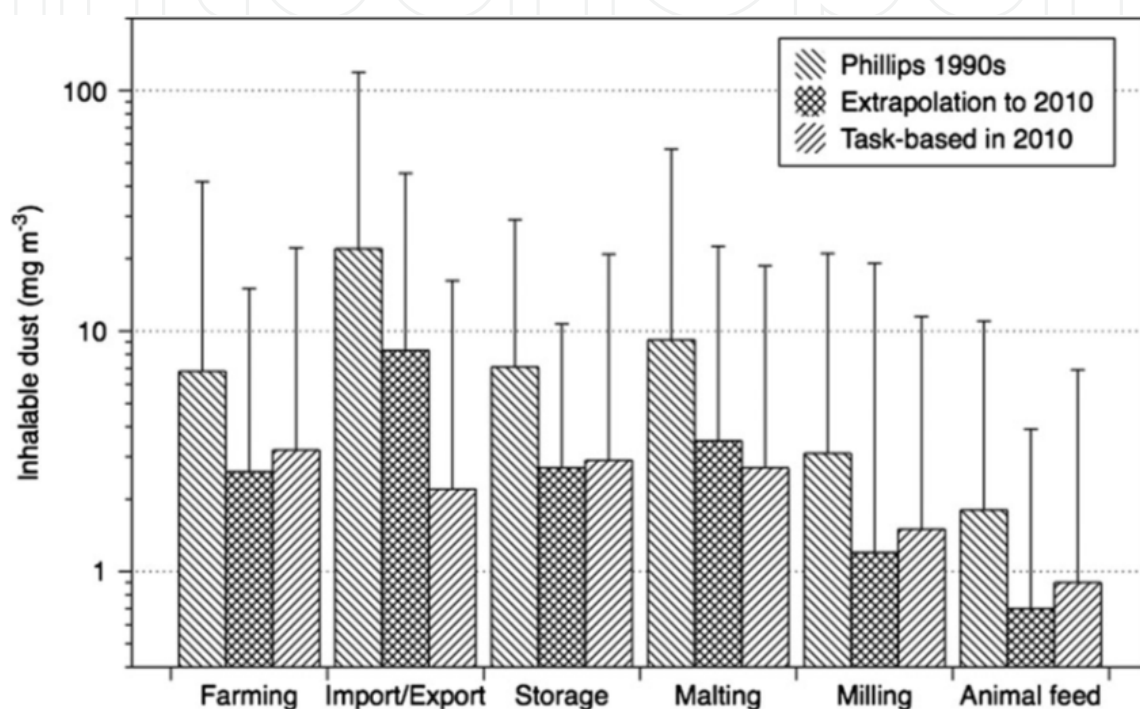


Figure 7. Inhalable dust levels measured in the British grain industry in the early 1990s and estimated levels in 2010—long-term (8 h) average data (Spankie and Cherrie, 2012)

Based on previous research on dust emission and exposure in crop production in agriculture, several conclusions may be drawn. First, the dust generated in agriculture should not be underestimated since the contribution of agricultural activities to air pollution is not negligible. Second, the soil perturbation mostly causes mineral dusts whereas harvesting, hay making, and conveying grain mostly generate organic dusts. Third, the personal exposure is more likely to be a problem for operators when tractor and combine harvesters are used without an enclosed cabin. The operator exposure depends heavily on the presence of an enclosed cabin with a proper filtering system, rather than the PM concentration in the air caused by field applications. Similarly, the farm worker exposure to size fractionated PM particles depends on the personal preventions taken, but farm workers rarely use personal preventions. Forth, the mineral dust generation can be significantly reduced through conservation agriculture, but the potential in organic dust increase due to cover crops during all applications should be monitored through scientific studies.

2.2. Orchards and vegetable growing

In one of the earliest comprehensive studies 103 cascade impactor measurements and 108 cyclone measurements were done to determine personal dust exposure and particle size distribution during field crop, fruit and nut farming, and dairy operations at three farms in California (Nieuwenhuijsen et al., 1998). Personal dust exposure levels were high, especially during land planing with 57.3 mg m^{-3} , and disking with 98.6 mg m^{-3} . The great majority of the collected dust particles were large and belonged to the extrathoracic fraction. Measured exposure levels were significantly lower when the tractor was equipped with a closed cabin, resulting in sixtyfold reduction in large particles and more than fourfold reduction for the respirable dust fraction. In peach harvesting total and respirable dust levels were 13 mg m^{-3} and 0.50 mg m^{-3} , respectively during hand harvesting (Poppendorf et al., 1982).

Among other agricultural machines, tractors are also used to operate sprayers that apply agro-chemicals. When applied in open spaces pesticide droplets smaller than 100 microns (according to CIGR Handbook of Agricultural Engineering (1999), 100-200 micron range is considered fine particles in agricultural spraying) are more susceptible to drift and relatively small droplets are preferred for a better coverage and biological efficiency in spraying. Average droplet diameter, for instance, may be 200-300 microns (medium size droplets in spraying) when herbicides are applied and smaller mean diameter is needed for fungicides and insecticides. However, the ratio of particles smaller than 100 microns could be substantial if the pressure settings are not appropriate resulting in excess drift due to smaller particles. Larger droplets would settle with or without drift if they cannot reach the target. Kline et al. (2003) determined the surface levels of pesticides and herbicides at different interior and exterior locations using five tractors, one of which was without a cabin and four with cabin using carbon-bed air-filtering systems and three commercial spray rigs. The equipment was used during fruit and vegetable growing. They found the greatest chemical concentrations on steering wheels and gauges, and in the dust obtained from the fabric seats. It was suggested that the contamination observed in the steering wheel and seat might cause pesticide exposure if the operator uses the tractor without personal protection in other field applications. It was also noted that the outlet louvers of the air filtering systems on the enclosed cabins frequently had more compounds at higher levels compared to the samples taken from the inlet louvers. Thus the carbon-bed may release the chemical compounds back into the cabin later on. While the efficiency of enclosed cabins in protecting against pollutants is known, the efficiency of carbon-bed systems in removing chemicals may be an important topic to study in the future. And the operators should be careful in thorough and regular cleaning of the tractors (Kline et al., 2003).

The researchers found that the workers were exposed to a complex mixture of organic and inorganic particles during manual harvest of citrus and table grapes (Lee et al., 2004). Geometric means for inhalable dust and respirable dust were 39.7 mg m^{-3} and 1.14 mg m^{-3} , respectively during citrus harvest, which were significantly higher compared to the levels that were determined for table grape operations and exceeded the TLVs for inhalable dust and respirable quartz. The exposure levels did not exceed the TLVs in table grape operations with the exception of inhalable dust exposure during leaf pulling. It was

determined that the degree of contact with foliage was significant in determining exposure factors. It was concluded that inhalable dust and respirable quartz exposures may be sufficiently high to result in respiratory health effects.

During mechanical harvest of almonds, dust levels in the dust plume were 26513 mg m^{-3} and 154 mg m^{-3} , respectively for inhalable dust and respirable dust (Lee et al., 2004). Mechanical harvesting of tree crops caused average personal exposure of 52.7 mg m^{-3} of inhalable dust and 4.5 mg m^{-3} of respirable dust. During manual harvest the workers are closer to the plant compared to mechanical harvest, but emissions are less and the plume size is smaller during manual harvest. Mean dust exposures was 1.82 mg m^{-3} during manual tree crops harvest and 0.73 mg m^{-3} during vegetable harvest whereas during peach harvest the respirable dust exposure was 0.5 mg m^{-3} .

2.3. Animal production

Class of animal, animal activity levels, type of bedding material, cleanliness of the buildings, temperature, relative humidity, ventilation rate, stocking density, and feeding method are among the factors affecting the dust concentrations in animal production (Jager, 2005). The components of the particulate matter found in concentrated animal production systems may include soil particles, bedding materials, fecal matter, litter, and feed, as well as bacteria, fungi, and viruses (EPA, 2004; Guarino et al., 2007).

Compared to non farmers, pig, poultry or cattle farmers have greater prevalence of work related and chronic respiratory symptoms and these farmers may have non specific respiratory symptoms or specific syndromes including organic dust toxic syndrome (ODTS) (Reed et al., 2006). Early studies showed excess amount of PM concentrations from all sources in animal production buildings (Mitloehner and Calvo, 2008). Although the dust generated from soil or crops may tend to have large particles, the particles found in animal confinement facilities belong to respirable fraction (Lee et al., 2006).

Exposure levels were 0.02 and 81 mg m^{-3} for inhalable dust and between 0.01 and 6.5 mg m^{-3} for respirable dust for poultry houses (Jager, 2005). On the other hand, heavy endotoxin concentrations were observed in poultry houses and swine confinement buildings in Sweden. Relatively low amount of endotoxin ($0.1 \text{ } \mu\text{g m}^{-3}$ air) can cause acute feverish reaction and airways inflammation while concentrations were as high as $1.5 \text{ } \mu\text{g endotoxin m}^{-3}$ air in poultry houses (The Swedish National Board of Occupational Safety and Health, 1994).

Both composition and distribution of feed in a barn are important key factors affecting the release of dust from animal feed (Guarino et al., 2007). Thus researchers have studied the effect of adding different oils to the feed in order to reduce the feed dust. An early study by Xiwei et al. (1993) showed that the fine fraction of the airborne dust could be reduced as much as 85% through pelleting and coating the feed. The effect of adding food grade soybean oil or two commercial feed additives to animal feed at 1% or 3% levels was studied under laboratory conditions (Guarino et al., 2007). Reductions of 80% to 95% was achieved in inhalable fraction using soybean oil and were much higher than either of the two

commercial additives whereas commercial additives were better in reducing fine particles (<4 μ m in diameter), particularly with 1% oil treatment. The respirable dust reductions (70% to 90%) were noticeable but the Guarino et al. (2007) notes that feed additives would not affect pig skin or dander and in actual pig growing conditions the dust reductions could be less. The respirable dust concentrations in poultry barns were found to be much higher during winter than during summer in Canada, making it difficult to keep respirable dust to an acceptable level in the winter months (Jager, 2005). According to the latter study, high animal activity propels dust into the air causing dust concentration fluctuations and peaks and at such rates that the ventilation usually fails to remove the dusts whereas in the summer respirable dusts are generally lower because of high ventilation rates.

No occupational hazard was found in terms of lung function for the workers in poultry farms in the Potchefstroom district, South Africa due to exposure to ammonia, particulate matter and microorganisms in the short term, but the long term effects are not known (Jager, 2005). The measured concentrations did not exceed the limits of OSHA, NIOSH and the Regulations for Hazardous Chemical Substances of 1995. It was concluded that the current legal limits provide sufficient protection in the short term for poultry farm workers.

The European Farmers' Project showed that animal farmers had significantly lower prevalence of allergic diseases while they had higher prevalence of chronic phlegm than the general population (Radon et al., 2003). A major predictor of chronic bronchitis was the ODS indicating that the allergens could be carried to the living environment of the farmer. Additionally, the ventilation was poor and the temperatures were high inside the animal buildings, causing a negative impact on respiratory symptoms and lung function parameters. Radon et al. (2003) concluded that animal producers were at high risk of chronic bronchitis and ODS and should be studied.

The accurate determination of personal dust exposure depends on time schedule of a worker. A farmer or a worker may be involved in a variety of tasks daily, seasonally or annually. Based on the duration of each task, the worker may be exposed to different environments consisting of a variety of biological or other pollutants that might affect health. The duration of farmers' exposure to various factors were studied on 30 farms by grouping farmers based on their major interests, which were Group A-plant production, Group B-animal production and Group C-mixed production (Moloznik, 2004). Working time ranged from 106–163% of the legal working time in plant production, 75–147% in animal production, and 136–167% in mixed production. Thus working time on private farms usually exceeded the legal working time in all types of operations. Other conclusions from the work cycle study were as follows (Moloznik, 2004): 1) Agricultural tasks are frequently accompanied by a variety of hazards simultaneously, 2) Among the factors most frequently occurring and creating risks are dusts, thermal elements, and biological agents, 3) Sixty percent of farming operations are accompanied by biological agents, 4) Workers were exposed to biological agents 51% of the total time in plant production, 80% in animal production, and 77% in mixed production systems, 5) Work cycle data constitutes a basis for biasing prophylactic actions.

Animal feeding operations (AFOs) are “agricultural enterprises where animals are kept and raised in confined situations” (EPA, 2012b). Information on PM_{2.5} concentrations and the spatio-temporal variations of PM_{2.5} in AFOs is insufficient (Li et al., 2011). In a high-rise layer egg production house the ambient PM_{2.5} levels were greater than 35 $\mu\text{g m}^{-3}$ (24 h) and 15 $\mu\text{g m}^{-3}$ (annual) PM_{2.5} National Ambient Air Quality Standards (NAAQS). The ambient and in-house measurements showed the effect of season on PM_{2.5} concentrations. Highest levels in ambient PM_{2.5} occurred in the summer whereas the greatest in-house concentration levels were measured in winter (Li et al., 2011). Also, PM_{2.5} levels were negatively correlated with ambient relative humidity, egg production, and ventilation rate.

Lee et al. (2006) discussed that more information is needed on the combined effect of organic and inorganic dust exposures considering size fractions of sampled particulates on different types of farming operations since the effect of biological dust in the total dust exposure is not well known in agriculture. Therefore they collected data on six farms (three types of animal confinements (swine, poultry, and dairy), and three grain farms) on personal exposure to dust and bioaerosols in size range of 0.7 to 10 μm to cover the range of most bacteria and fungi. The number concentrations of small particles (0.7 μm to 3 μm) were greater than those of large particles (3 μm to 10 μm) in all animal confinements. Particle concentrations were higher on the swine farm in winter. The concentrations at the workers' breathing zone were 1.7×10^6 to 2.9×10^7 particles m^{-3} for total dust in animal confinements and 4.4×10^6 to 5.8×10^7 particles m^{-3} during grain harvesting (Lee et al., 2006). The total particles were composed mainly of large particles (3–10 μm) during grain harvesting whereas in animal confinement facilities the total dust was composed mostly of smaller particles (<3 μm). It was noted that about 37% of the particles were fungal spores in the size of 2–10 μm , implying that predominantly large particles during grain harvesting were partly due to the increased fungal spores. However, the overall combined effect of dust and microorganism exposure was more severe in harvesting compared to confined animal production.

Organic dust and endotoxin exposures are widely described for agricultural industries, however a detailed overview of concentration levels of airborne exposure to endotoxins and a systematic comparison using the same exposure measurement methods to compare different sub sectors of agriculture are needed (Spaan et al., 2006). Therefore the researchers collected 601 personal inhalable dust samples in 46 companies of three agricultural industrial sectors: grains, seeds and legumes sector (GSL), horticulture sector (HC) and animal production sector (AP), with 350 participating employees. Figure 8 shows the means and the variations in measured average concentrations. The greatest dust and endotoxin levels were found in the GSL sector while smallest levels were observed in HC sector. The exposure was higher in the primary production section compared to the parts of all sectors. Occupational exposure limit (50 EU m^{-3}) and the temporary legal limit (200 EU m^{-3}) of the Dutch for endotoxin were exceeded frequently. Spaan et al. (2006) concluded that a 10–1000 fold reduction is required in endotoxin exposure to accomplish reduction in health related hazards. The authors also noted that the wet processes resulted in reduced exposure to endotoxin and less dusty environment.

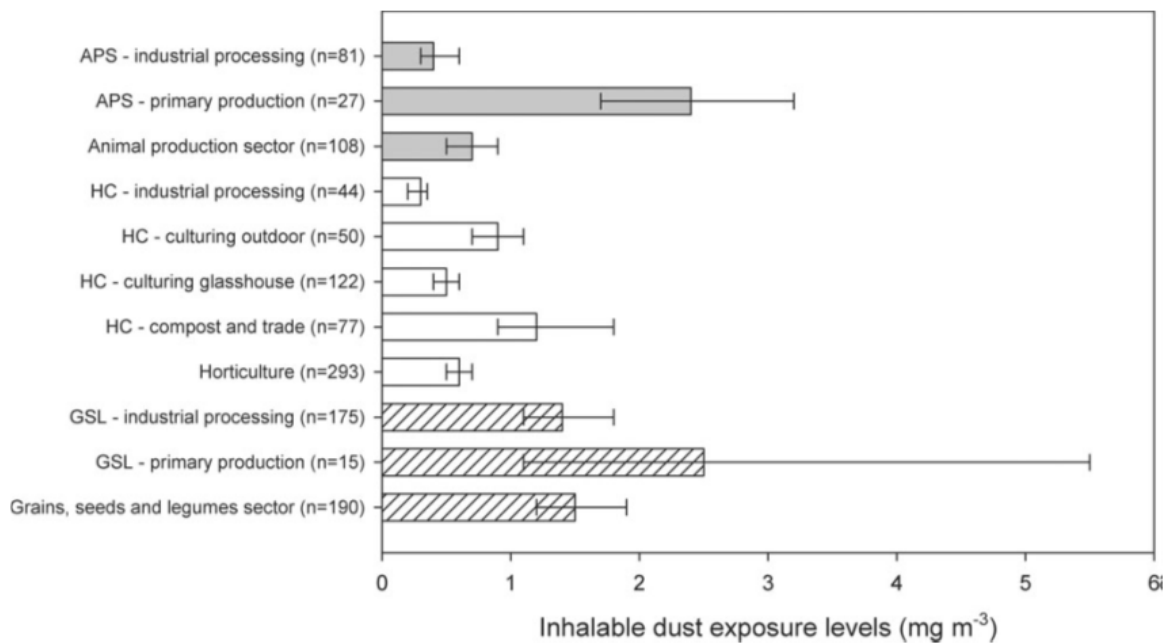


Figure 8. Inhalable dust exposure (Geometrik Mean and 95% CI) levels in three sectors and subsectors of the agricultural industry (Spaan et al., 2006)

2.4. Agriculture based industry

Another important area of interest in occupational exposure to dusts is the agri-industry where agricultural products are processed to be consumed by humans, animals or plants. Agriculture based industry may include a variety of different facilities, including storages, feed mills, flour mills, cotton ginner, hullers and shellers of nuts, etc.

Respirable dust (PM_{2.5}) and very fine particle (PM_{1.0}) concentrations in Turkey were higher than the OSHA TLV (1000 $\mu\text{g m}^{-3}$) in the ginner, press, and storage areas of two cotton ginner, except for PM_{1.0} in the storages (Arslan and Aybek, 2011). There is no threshold limit value for very fine particles generated from raw cotton, but the concentrations of PM_{1.0} were even greater than the TLV set for PM_{2.5} (Figure 9). The range of coefficient of variation was 0.33-0.54 for PM₁₀ and was the narrowest range among the three fractions, implying large variations in measured quantities for all PM fractions. The technology used is not advanced and engineering controls are very weak in these facilities, resulting in excess amount of dust in all fractions. Therefore, the workers should use personal preventions to minimize the potential adverse health effects of personal PM exposure (Arslan and Aybek, 2011).

Most ginner are in operation for only several months following the cotton harvest in autumn in eastern Mediterranean, Turkey. Thus the workers in cotton ginner are usually exposed to cotton dust seasonally. The workers are employed in other agricultural and non agricultural jobs for the rest of the year or may be unemployed for some time. Thus it may be difficult to assess the long-term health effects of personal exposure with such a work cycle.

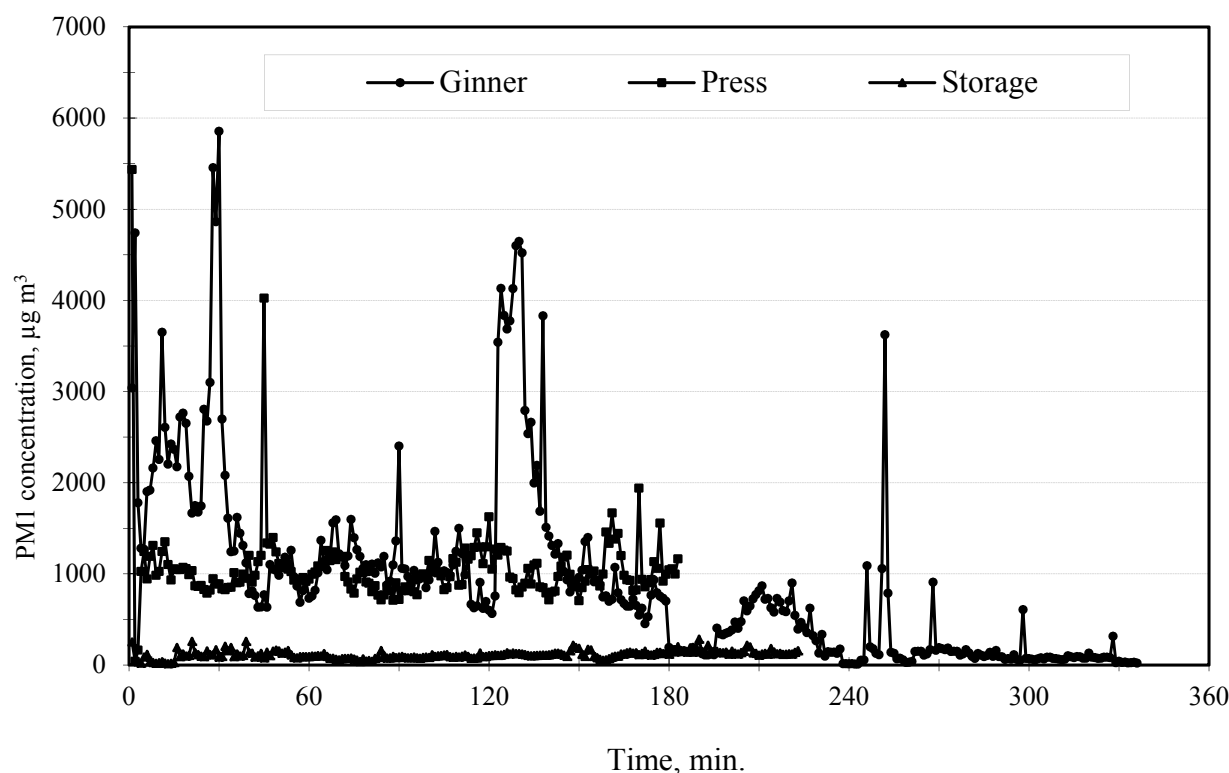


Figure 9. Continuous PM1.0 concentration measurements in three different working areas of ginners (Arslan and Aybek, 2011)

Pure endotoxin causing adverse pulmonary effect can be as low as 9 ng m^{-3} if the subjects are sensitive to cotton dust (Omeland, 2002). However, in the cotton industry, healthy subjects may experience a cross shift decline in forced expiratory volume FEV1 when exposed to concentration levels of about $100\text{--}200 \text{ ng m}^{-3}$, chest tightness with $300\text{--}500 \text{ ng m}^{-3}$ and fever with $500\text{--}1000 \text{ ng m}^{-3}$ (Rylander, 1987). Therefore the latter study concluded that exposure to endotoxin pose a possible risk for workers and also endotoxin content in cotton dust may have a different effect compared to the effect of endotoxin in dust from various farming operations. According to personal PM2.5 exposures measured gravimetrically in four different working areas of three feed mills (bulk storage, dosing, mill, and bagging units) in Turkey, the highest PM2.5 concentration was in the mill section (3033 µg m^{-3}), and the smallest in weighing section (782 µg m^{-3}) (Aybek et al., 2009). The measured concentrations were lower than OSHA TLV for PM2.5. A health survey administered on the workers revealed that the workers did not have serious health complaints, including coughing, phlegm, chest tightness, and breathlessness. However, smokers had more complaints about coughing and phlegm.

Textile industry may employ large numbers of workers depending on the capacity and the level of technology used. The workers in spinning factories were exposed to concentration levels greater than the occupational TLV (200 µg m^{-3}) for respirable dust (PM2.5) in eastern Mediterranean, Turkey (Aybek et al., 2010). In the textile industry, weaving caused higher PM concentrations compared to spinning. TLV for PM2.5 (750 µg m^{-3}) was exceeded in weaving with rapier weaving machines. Air jet weaving machines generated finer dusts due

to agitation around the machine caused by the air stream. PM_{2.5} concentration was higher when air jet weaving machines were used whereas rapier types caused more coarse particles.

Organic dusts are generated in hemp processing plants and the measured dust concentrations were usually ten times more or higher than that of cotton processing (spinning) with 1580, 3730 ve 360 $\mu\text{g m}^{-3}$ in spinning, as cited from other studies (Fishwick et al., 2001).

2.5. Standards and threshold limit values

The regulations and related terminologies to improve air quality may differ in different countries. For instance, national standards in the USA (NAAQS) were set for a variety of air pollutants “to protect public health and welfare”, Canada uses air-quality objectives, in Germany air-quality guidelines are effective and World Health Organization recommends desirable air-quality levels (Krupa, 1997). EU has established directives to reduce gas and particle pollution in the air (EU Council Directive, 1999). These regulations are aimed at improving public health and try to limit concentration levels of a specified pollutant in the air. Air Quality Index (EPA, 2009) classifies air quality into several categories within certain limits such as good (0-50 $\mu\text{g m}^{-3}$), moderate (51-100 $\mu\text{g m}^{-3}$), unhealthy for sensitive groups (101-150 $\mu\text{g m}^{-3}$), unhealthy (151-200), very unhealthy (201-300 $\mu\text{g m}^{-3}$), and hazardous (301-500 $\mu\text{g m}^{-3}$). Occupational exposures require different regulations to limit PM in specific work related environments. Threshold Limit Value (TLV) is the average 8-hr occupational exposure limit and is calculated to be safe exposure for a working lifetime (Salvato et al., 2003). Occupational Safety and Health Organization (OSHA) in the United States determined the threshold limit values for several agricultural sources (Table 2).

Feature	Limit values ($\mu\text{g m}^{-3}$)	Particle size
Lower respiratory system nuisance limit	5000	PM _{2.5}
Total nuisance limit	15000	PM ₁₀
Grain dust (wheat, barley, rye)	15000	PM ₁₀
	5000	PM _{2.5}
Raw cotton	1000	PM ₁₀
Spinning	200	PM _{2.5}
Weaving	750	PM _{2.5}

Table 2. TLVs for some agricultural pollutants for PM₁₀ and PM_{2.5} (OSHA, 2010)

The criteria to evaluate occupational environment have been established by national institutions in different countries. The National Institute for Occupational Safety and Health (NIOSH) in the United States uses recommended exposure limits (RELs); the American Conference of Governmental Industrial Hygienists (ACGIH) uses threshold limit values (TLVs); American Thoracic Society uses permissible exposure limits (PELs); and Occupational Exposure Limits (OELs) are used in some European countries. Table 3 shows the current permissible exposure levels currently set by organizations in the United States.

Hazard	OSHA PEL	NIOSH REL	ACGIH TLV	Animal Confinement Research
Nuisance total dust	15 mg m ⁻³	NE	10 mg m ⁻³	
Nuisance hazard respirable dust	5 mg m ⁻³	NE	3 mg m ⁻³	
Grain dust	10 mg m ⁻³	4 mg m ⁻³	4 mg m ⁻³	
Organic dust	NE	NE	NE	2.4-2.5 mg m ⁻³
Respirable organic	NE	NE	NE	0.16-0.23 mg m ⁻³
Endotoxin	NE	NE	NE	640-1000 ng m ⁻³
Ammonia	50 ppm	25 ppm	25 ppm	7.5 ppm

Table 3. Recommended maximum exposures in agriculture (Kirkhorn and Garry, 2000)

As far as quartz exposure is considered, reference values of respirable dust and quartz concentrations are 2 mg m⁻³ for respirable dust and 100 µg m⁻³ (South African Occupational Exposure Limit), 50 µg m⁻³ (NIOSH REL), and 25 µg m⁻³ (ACGIH TLV) (Swanepoel et al., 2010).

Grain dust, as defined by HSE (1998), has been assigned a maximum exposure limit (MEL) of 10 mg m⁻³, 8-hour time-weighted average (TWA). Also the exposure should not exceed 30 mg m⁻³ over any 15-minute period. Even then, exposures should still be kept as low as reasonably practicable. Additionally, grain dust has been given a workplace exposure limit (WEL) by Control of Substances Hazardous to Health Regulations (COSHH, 2002). It was noted that WEL is a maximum concentration value, not a target limit. The exposures should be reduced far below the WEL if possible (HSE, 1998). In order to advise on indicative limits in EU, The Health and Safety Directorate of the Directorate-General of Employment, Industrial Relations, and Social Affairs of the Commission of the European Union formed a Scientific Expert Group. PELs are legal standards, but they do not apply to farms and most agricultural field operations. But TLVs are consensus exposure guidelines.

Scientific data have not been accumulated enough to set threshold limit values for some specific particulate matters. General nuisance levels are known (Table 2) and may vary depending on the institution that sets the standard. Threshold limits for mineral or organic PM concentrations do not exist due to the difficulties to characterize the PMs found in the soil and in agricultural products since they are made up of different sources. Because of such complexities exposure limits for soil-implement interactions for PM₁₀ and PM_{2.5} are not known yet. Another important difficulty in determining threshold limits for coarse and fine dust exposure comes from the fact that the combined effects of dusts with toxic gases and other microorganisms are not known.

Literature has dealt more with PM₁₀ while PM_{2.5} exposure studies are gaining more attraction. On the other hand threshold levels for very fine particles (PM_{1.0}) have rarely been published in agriculture.

2.6. PM health effects in agriculture

Exposure to PM has been related to a series of respiratory and cardiovascular health problems (EPA, 2012a): “The key effects associated with exposure to ambient particulate matter include: premature mortality, aggravation of respiratory and cardiovascular disease, aggravated asthma, acute respiratory symptoms, chronic bronchitis, decreased lung function, and increased risk of myocardial infarction. Recent epidemiologic studies estimate that exposures to PM may result in tens of thousands of excess deaths per year, and many more cases of illness among the US population.” The exposure to dust in agriculture is a combination of occupational and environmental exposures with widely varying work practices. The specific respiratory hazards related to different commodities and related work practices are given in Table 4 (Kirkhorn and Gary, 2000) and a list of respiratory hazards by American Thoracic Society is given in Table 5 (Schenker, 1998).

Categories	Sources	Environment	Conditions
Organic dusts	Grain, hay, endotoxin, silage, cotton, animal feed, animal byproducts, microorganisms	Animal confinement operations, barns, silos, harvesting and processing operations	Asthma, asthmalike syndrome, ODS, chronic bronchitis, hypersensitivity pneumonitis (Farmer's Lung)
Inorganic dusts	Silicates	Harvesting/tilling	Pulmonary fibrosis, chronic bronchitis
Gases	Ammonia, hydrogen sulfide, nitrous oxides, methane, CO	Animal confinement facilities, silos, fertilizers	Asthmalike syndrome, tracheobronchitis, silo-filler's disease, pulmonary edema
Chemicals Pesticides Fertilizers Disinfectants	Paraquat, organophosphates, fumigants Anhydrous ammonia Chlorine, quaternary compounds	Applicators, field workers Application in fields, storage containers Dairy barns, hog confinement	Pulmonary fibrosis, pulmonary edema, bronchospasm Mucous membrane irritation, tracheobronchitis Respiratory irritant, bronchospasm
Others Solvents Welding fumes Zoonotic infections	Diesel fuel, pesticide solutions Nitrous oxides, ozone, metals Microorganisms	Storage containers Welding operations Animal husbandry, veterinary services	Mucous membrane irritation Bronchitis, metal-fume fever, emphysema Anthrax, Q fever, psittacosis

Table 4. Agricultural respiratory hazards and diseases (Kirkhorn and Garry, 2000)

Maximum levels of indoor air contaminant levels, including total dust, ammonia, respirable dust, and total microbes were determined for workers in swine buildings (Donham, 1995). The levels given in the last column in Table 3 are for animal confinement research while Table 6 relates maximum indoor levels for swine building, explaining the slight differences in the two tables.

Maynard and Howard (1999) cited several literatures regarding PM effect on human health: “PM₁₀ is currently regarded as the size fraction best representing those particles most likely to cause ill health (DoE, 1995). PM₁₀ is not as long-lived as PM_{2.5}, with a life-time of some 7±3 days, as the latter is less subject to efficient removal by gravitational settling or scavenging by rain (DoE, 1993). However, particles have to be < 2.5 µm in order to penetrate into the gas exchange regions of the lungs. Numerous epidemiological studies have found a relationship between particulate air pollution and increased cardiorespiratory morbidity and mortality (Pope et al., 1995), and hospital admissions for asthma and chronic obstructive pulmonary disease (Schwartz, 1994; Schwartz et al., 1993)”.

Respiratory Region	Principal Exposures	Diseases/Syndromes
Nose and nasopharynx	Vegetable dusts Aeroallergens Mites Endotoxins Ammonia	Allergic and nonallergic rhinitis Organic dust toxid syndrome (ODTS)
Conducting airways	Vegetable dusts Endotoxins Mites Insect antigens Aeroallergens Ammonia Oxides of nitrogen Hydrogen sulfides	Bronchitis Asthma Asthma-like syndrome ODTS
Terminal bronchioles and alveoli	Vegetable dusts Endotoxins Mycotoxins Bacteria and fungi Hydrogen sulfide Oxides of nitrogen Paraquat Inorganic dusts (silica, silicates)	ODTS Pulmonary edema/adult respiratory distress syndrome Bronchiolitis obliterans Hypersensitivity pneumonitis Interstitial fibrosis

Table 5. Agricultural respiratory disease common exposures and effects (Schenker, 1998)

Air contaminant	Recommended 8-hour TWA for human health
Total dust (mg m^{-3})	2.40
Respirable dust (mg m^{-3})	0.23
Endotoxin (g m^{-3})	0.08
Ammonia (ppm)	7.00
Total microbes (cfu m^{-3})	4.3×10^5

Table 6. Maximum air contaminant levels for humans in swine buildings (Donham, 1995)

Air pollution has been thought of as an urban phenomenon, but it has been understood better that urban–rural differences in PM₁₀ are small or even absent in many regions of Europe, implying that PM exposure is widespread (WHO, 2000). Although most studies provided data on PM₁₀ exposure, the data on fine particulate matter (PM_{2.5}) has been increasing and the recent studies show that PM_{2.5} is a better predictor of health effects compared to PM₁₀ (WHO, 2000).

Agricultural and food industries introduce various dangers because organic dust in these sectors is frequently associated with endotoxins, mycotoxins and microorganisms (Zock et al., 1995). Granular products generate high quantities of particles during conveying, loading and unloading from hoppers, trailers, and grain silos. Grain dust may also contain mould spores and if inhaled they can cause a fatal disease called farmer's lung (HSE, 2006). Farmer's lung caused by intoxicant dusts in the lower respiratory tract may result in labor loss, increased health costs, and even death in severe cases (Sabancı, 1999). The wide variety of different exposures may result in numerous respiratory diseases including bronchitis or asthma that may result from or exacerbated by organic dust (grain dusts, animal dander, plant dusts), toxic gases, and infectious agents whereas inorganic dusts and other irritants may exacerbate, if not cause, asthma (Schenker, 2000). Early studies explained that dust exposure might cause inflammation of the eyes, lungs, and the skin (Matthews and Knight, 1971), poisoning and allergy in the respiratory system (Witney, 1988), and grain fever (HSE, 2007). While allergic responses, such as asthma, are generally linked with exposure to organic dust, nonallergic responses, such as bronchitis and chronic obstructive airways disease, are usually associated with exposure to inorganic dust from agricultural origins (Baker et al., 2005). Fine particles can pollute the blood by reaching air packets in the lung or might start various disturbances and diseases. The disease called byssinosis is due to chronic PM inhalation of high levels of microbial products such as endotoxin from cotton processing (Lane et al., 2004).

Jimenes (2006) reports detrimental health effects due to both chronic and acute exposures to biomass smoke (EPA, 2004), which includes both vapor and mostly particulate phase material with PM_{2.5} fraction. Reduced lung function, depressed immune system and increased risk of respiratory diseases were listed as the effects of chronic exposure to biomass smoke, as cited from Sutherland (2004), Sutherland and Martin (2003), and acute health effects in susceptible people, including chronic obstructive pulmonary disease (COPD) patients, and asthmatic children, as cited from Romieu et al. (1996); Pekkanen et al. (1997); Peters et al. (1997). It was stated that coughing, wheezing, chest tightness and

shortness of breath were among the health effects. Long et al. (1998) conducted a survey in Winnipeg, Canada and reported that straw burning had more effect on individuals with asthma or chronic bronchitis. In another study on children, a relationship was found between PM₁₀ from rice straw burning and increased asthma attacks in Niigata, Japan (Torigoe et al., 2000). Another effect of PM₁₀ emissions is the visibility impairment (e.g., Brown Cloud) (Arizona Air Quality Division, 2008).

According to numerous researchers, as cited by Baker et al. (2005), diseases such as asthma, pulmonary fibrosis, and lung cancer are associated with dust inhalation. Additionally, organic PM exposure is related with allergic responses, including asthma. Inorganic PM is generally generated during agricultural field applications and causes non-allergic diseases such as bronchitis and chronic obstructive airways disease. Fume and dust exposures are predominant in animal buildings and barns and the main elements related to respiratory health are dust, bacteria, moulds, endotoxin and ammonia (Omland, 2002).

Farming characteristics were determined through a questionnaire study in 1468 cattle farmers in Schleswig-Holstein, showing a high correlation between the ventilation systems in the cattle house and respiratory symptoms (Radon et al., 2002). Other important factors affecting the symptoms were climatic factors and the size of the animal house. In their study, the pig farmers were found to be at the highest risk for developing respiratory symptoms associated with asthma-like syndrome whereas an increased risk of wheezing was found in poultry farmers. The dose-response relationship was significant between daily hours inside the animal buildings and symptoms. The study also found that the sheep producers had excess cough with phlegm.

Schenker (2000), by citing numerous research papers, summarized the types of hazards arising from agricultural dust as follows: Scientific work generally dealt with dust exposure as it relates to respiratory diseases in terms of allergic diseases resulting from inorganic dusts, namely occupational asthma and hypersensitivity pneumonitis. However, inorganic (mineral) dust exposure may be substantial in the agricultural work force. The frequency of exposure to mineral dust may be more in dry-climate regions. Soil tillage operations such as plowing, chiseling, and harrowing disturb the soil, causing operators to be exposed to 1-5 mg m⁻³ respirable dust and >20 mg m⁻³ total dust in dry regions. The soil composition is usually reflected by the inorganic dust in the soil. For instance, 20% of particles in the soil are made up of crystalline silica and 80% is of silicates. Such high levels of inorganic concentrations possibly explain some of the increase in chronic bronchitis reported in farmers' studies. A disease called pulmonary fibrosis (mixed dust pneumoconiosis) was found in agricultural workers. Chronic obstructive pulmonary disease morbidity and mortality have also been observed in farmers living in different geographies. It is likely that inorganic dust exposure is to some extent related with chronic bronchitis, interstitial fibrosis, and chronic obstructive pulmonary disease however the individual effect of mineral dusts beyond the effects of organic dusts is unknown. Some cross-sectional surveys showed increased prevalence rates of chronic bronchitis among swine confinement farmers and poultry workers independent of the effects of cigarette smoking. Workers in animal production are predominantly exposed to organic dusts compared to field workers. In

addition to the the physical, chemical and biological properties of particles, the factors affecting worker's health as a result of PM exposure include concentration level, duration of exposure, gender, age, weight, smoking habits, etc.

A cross sectional study called the European Farmers' Project was conducted in two stages to determine the prevalence and risk factors of respiratory diseases in farmers in seven centers across the Europe (Radon et al., 2003). About 8000 farmers in Denmark, Germany, Switzerland, the UK, and Spain were administered a standardized questionnaire to determine the characteristics and respiratory symptoms of the farmers in the first stage while the second stage studied the exposure assessment and lung function determination in four of the seven centers. Among animal production farmers, pig farmers were found to be at high risk of asthma-like syndrome compared to others. When plant production was considered, greenhouse workers were found to be at higher risk of asthma-like symptoms. According to the European Community Respiratory Health Survey, animal farmers had lower prevalence of allergy symptoms while the prevalence of chronic bronchitis symptoms was significantly higher in animal farmers. It was found that the ventilation in the animal production facilities and greenhouses was the major risk factor for respiratory symptoms. It was shown that the highest median total dust (7.01 mg m^{-3}) and endotoxin (257.58 ng m^{-3}) concentrations occurred in poultry houses in Switzerland. Also, growing vegetables, tomatoes, fruits or flowers in greenhouses was a secondary risk factor for asthma.

Elci et al. (2002) did not observe any dose-response relationship with asbestos, grain, or wood dust exposure. They found 958 larynx cancer stories in 6731 patients diagnosed with cancer at Okmeydani Hospital, Istanbul. Patients exposed to silica and cotton dusts had more cancer rates but there was no correlation between larynx cancer and asbestos, wood or grain dusts. They found "an excess risk of laryngeal cancer among workers exposed to silica and cotton dust in a large study in Turkey".

Müller et al. (2006) determined sociodemographic and farming-production parameters of 1379 poultry farmers from Southern Brazil, and determined that workers were exposed to high levels of organic and mineral dusts. Their findings present the significance of income level, gender, age, and smoking habits. The low income farmers had higher prevalence of respiratory symptoms and chronic respiratory disease symptoms were more in poultry workers. Additionally, woman had significantly ($p < 0.01$) higher (15%) asthma symptoms compared to men (10%), but the difference was not statistically significant in chronic respiratory disease symptoms with 24% in women and 20% in men ($p = 0.09$). Müller et al. (2006) also found more prevalence among persons over 40 years of age and children under four years of age. Furthermore, smokers, particularly ex-smokers showed more chronic respiratory disease. Also, smokers consuming more than 182 packs per year had more respiratory symptoms.

3. Future research and perspectives

Dust emissions from agriculture and the personal exposure to generated particulates are two major issues to be addressed for both policy makers and researchers. Dust emission

results in outdoor and indoor air pollution threatening public health. Occupational exposure to dust, on the other hand, is associated with respiratory health in the work environments. The researchers and health organizations have focused on both aspects in order to reduce air pollution and occupational health hazards.

One of the most important and challenging issues is differentiating between the effect of dust components. The management choices in a feed operation, for instance, affect the compounds in the mixture of emissions and complex mixes of various particles create difficulties to regulation, given the lack of information on the effect of individual components (Mitloehner and Calvo, 2008). However, it would be difficult to separate the individual health effect of a component; also it may be somewhat artificial to separate inorganic mineral dusts from other respiratory toxins (Schenker, 2000). The combined health effects of dust components (both mineral and organic) and microorganisms such as endotoxins deserve to be further studied thoroughly in different sectors and subsectors of agriculture. The scientific studies regarding the relationships of gaseous and particulate mixtures in biosystems is still in its infancy (Mitloehner and Calvo, 2008), requiring more exploration in agricultural operations.

The emissions from agriculture may create local and regional problems in terms of air quality in Europe and such problems may include PM exposure, eutrophication and acidification, toxics and contribution to greenhouse gas emissions, causing numerous environmental impacts and hence PM emissions should be investigated not only for PM₁₀ but PM_{2.5} with NH₃ as precursor (Erisman et al., 2007).

Spatial distribution of contaminants is of importance when sampling locations are to be determined in confined buildings in agriculture and the same should apply for sampling to assess the emissions during field operations. The researchers tend to make the sampling near the center of buildings or at the breathing zone of workers or animals however the sampling location might be random only if the distribution of the pollutants is homogenous throughout the sampling volume; otherwise the spatial distribution across the building needs to be measured first to accurately determine the best sampling locations (Jerez et al., 2011).

It was suggested that, in Australia, each major animal production industry (pigs, poultry, dairy, horses and sheep) should be investigated in a range of climate and seasonal conditions to determine worker exposure to a range of contaminants. Other issues to deal with are changes in respiratory function before and after exposure, respiratory symptoms for at least a week after exposure, both exposure and respiratory function and symptoms over time, long term changes in respiratory function and symptoms, species of bacteria and fungi to which workers are exposed in the different animal industries, the toxicity, and if needed developing appropriate approaches to occupational hygiene (Reed et al., 2006). Further studies were recommended to explore the independent effects on symptoms of smoking, gender and farm characteristics in Australia and was concluded that the relatively high prevalence of asthma in Australian pig and poultry farmers compared with overseas farmers also requires further investigation.

Dust exposure in and near farm fields is of increasing concern for human health and may soon be facing new emission regulations. Dust plumes have rarely been documented due to the unpredictable nature of the dust plumes and the difficulties of accurate sampling of the plumes, requiring further research on dust dispersion measurements and simulations to better assess the dust emissions (Wang et al., 2008). Also more focus should be put on the air quality during agricultural burning and related health effects because few studies have been conducted on air quality during stubble burning and even fewer studies on characterization of exposure (Jimenes, 2006).

Kline et al. (2003) discussed that thoroughness and frequency of cleaning enclosed cabins, the work practices, training, and behavior of operators are important variables in future studies because these factors have direct effects on the sources of chemical contamination. The authors emphasized that further studies were needed in carbon bed air filtration systems in cabin to assess efficiency and specificity of chemical removal, particularly in relation to bed size and chemical breakthrough trends.

Crystalline silica may make up to 20% of the soil composition, representing a risk for interstitial fibrosis and other silicates up to 80% may also result in or contribute to mixed-dust pneumoconiosis (pulmonary fibrosis) (Schenker, 2000). Since the prevalence and clinical severity of pulmonary fibrosis is unknown, more research is needed in this area (Schenker, 2000).

It is emphasized that worker exposure studies should be conducted with a link to health outcomes and similarly health studies should be associated with personal exposure measurements (Reed et al., 2006). Additionally, when occupational exposure studies are conducted, personal sampling should be preferred because stationary sampling estimates of airborne allergens are lower (Lee et al., 2006).

Since poultry workers are exposed to high dust concentrations resulting in increased risk of occupational respiratory symptoms, respiratory protection programs should be implemented and should include poultry production workers (Müller et al., 2006).

As previously discussed, different institutions have set different threshold or permissible exposure levels for the same particulates. For instance, ACGIH limits the personal exposure concentration for PM₁₀ and PM_{2.5} to be 10000 $\mu\text{m m}^{-3}$ and 3000 $\mu\text{m m}^{-3}$, respectively whereas NIOSH recommends 4000 $\mu\text{m m}^{-3}$ concentration for granular dust. However, health effects might be seen at concentrations just above 2400-2500 $\mu\text{m m}^{-3}$ in pig production whereas health effects may be observed in poultry at concentrations as low as 1600 $\mu\text{m m}^{-3}$ (Kirkhorn and Garry, 2000). The composition of dust may vary substantially along with accompanying microorganisms in animal production compared to crop production or agro-industry since more toxic gaseous particles might be generated in animal confinements. This could result in adverse health effects in animal production with less concentration compared to other subsectors in agriculture. Therefore research should continue until health organizations set more practicable limits for a wide variety of compounds in order to protect workers from both short term and long term health hazards of occupational dust exposure. The differences in threshold levels determined by different organizations also imply the need for further research in organic and mineral dust exposure.

Much research is required to characterize the nature and pathogenicity of exposure to agricultural dust, particularly on inorganic dusts and actual dose (Schenker, 2000). Numerous questions raised by Schenker (2000) still seeking answers, to varying degrees in different countries/geographies/climates/subsectors of agriculture, are as follows: “What is the composition of mineral dusts to which agricultural workers are exposed? How do climatic conditions, agricultural operations, soil conditions, and personal characteristics affect dust exposure? What are average and extreme cumulative exposures to inorganic dust among agricultural workers, and where do they occur? What cumulative dust exposure occurs with agricultural work? What is the pulmonary response to inorganic dusts, and what is the mechanism of that response? What are the critical components and relative potency of different inorganic dusts? Does chronic exposure cause pulmonary fibrosis? Is airway inflammation a critical component of the response? If so, by what mediators? Is the response similar to that seen for organic dusts? How do personal characteristics such as age, gender, smoking atopy, and genetic factors affect the response to inorganic dusts? Is there a similar pattern of acute cross-shift change in pulmonary function, and is it predictive of long-term pulmonary function decline? What are effective measures to reduce exposure and other control methods suitable for the agricultural setting? This should include educational strategies, engineering controls, and regulatory interventions. Should the occupational silica standard be applied to the agricultural workplace? What is the role of the practicing physician in recognizing, treating, and preventing respiratory disease among agricultural workers?” The research in air quality and personal health seem to be advanced in industries such as mining, but more research in agriculture and related industries is needed to address all the questions above.

Previous research clearly shows that more scientific studies are needed to accumulate sufficient data to determine dose-response relationships so as to improve engineering control systems and personal protective devices or to increase awareness and implementation of prevention techniques in agriculture.

4. Policies and prevention

The implementation of air quality policies in rural areas usually lags urban settings, resulting in poor monitoring and weak inspection in agricultural work environments. The awareness in air quality issues, the effects of personal exposure to dusts, and personal protective measures hence is generally not strong among farmers and farm workers. An important cause should be related to the fact that the jobs requiring less than 11 people are not subjected to routine inspections by OSHA, resulting in poor awareness, lack of engineering controls and irregular personal protection among agricultural workers in the US (Kirkhorn and Garry, 2000) and the situation is probably similar in other countries.

Policies to reduce air pollution or work-related exposure to dust and microorganisms are of utmost importance. Different countries may impose different measures to improve air quality or may recommend methods to reduce exposure levels. For improved public health the emissions from all industries should be kept as low as possible but may not be

economical or practicable under given conditions. For instance, the contribution of particulate matter from agriculture was considered a pressing issue in emissions and to accomplish the objectives on acidification, eutrophication and PM concentrations, much greater reductions should be targeted in EU (Erisman et al., 2007).

Environmental Protection Agency (EPA) in the US redesignated the Moderate PM₁₀ Nonattainment Area to Serious in 1996 to include unregulated sources including unpaved roads, unpaved parking lots, vacant lots and agriculture, requiring emission reduction programs for these areas (Arizona Air Quality Division, 2008). Arizona Legislation required all farmers to comply with PM₁₀ program by the end of 2007, imposing that farmers with 4 ha of contiguous land located within the Maricopa PM₁₀ Nonattainment Area and Maricopa County Portion of Area A must comply with the agricultural PM₁₀ general permit. To aid farmers the Arizona Legislature defined Best Management Practices (BMPs) and farmers are required to implement at least one of BMPs for each of the three categories defined, including tillage and harvest, non-cropland and cropland (Arizona Air Quality Division, 2008).

The personal protection is not common in agriculture mainly due to the fact that they are hot and uncomfortable, but in dusty and mouldy conditions two-strap dust and mist respirators approved by NIOSH may be used (Arizona Air Quality Division, 2008).

The use of sixteen types of engineering controls and thirteen types of personal protective equipment (PPE) was studied using the information obtained from 702 certified pesticide applicators (Coffman et al., 2009). The results of this study showed that 8 engineering control devices were used out of 16 by more than 50% of the applicators. The adoption of engineering control was affected by the crop produced, field size, and type of pesticide application equipment. Engineering devices were usually adopted on large farms, when hydraulic sprayers are used. Most respondents used PPE with chemical-resistant gloves resulting in the highest level of compliance. Appropriate headgear use also increased in pesticide applicators.

Mitchell and Schenker (2008) surveyed 588 farmers longitudinally from 1993 to 2004 to determine respiratory protective behaviors and the personal characteristics of farmers. They identified some characteristics related to smoking and farm size, and found that about 75% of the farmers were not "very" concerned about respiratory health risks. Interestingly, the use of a dust mask or respirator decreased significantly from 54% in 1993 to 37% in 2004, whereas 20% was consistent in use of respiratory protection. From 1993 to 2004 closed-cabin useage increased slightly from 14% to 17%. Those who regularly used a dust mask or respirator were ex-smokers or the ones concerned about the health risks. Also, closed-cabin tractors were used in larger areas and were related to higher salary and the farmers preferred using personal protection in small areas. The researchers recommended that farmers be educated about the long term respiratory health risks.

Some practices in the field can be helpful in reducing dust emissions and hence personal exposure levels. Some of these practices include no tillage or soil preparation if wind speed exceeds 40 km h⁻¹ at 2 m height, adopting reduced tillage including minimum tillage system,

mulch tillage system, and reduced tillage system (Arizona Air Quality Division, 2008). These practices should also incorporate other preventions such as avoiding conditions in which soil is susceptible to produce PM₁₀, reducing vehicle speed, planting vegetative barriers to the wind (tree, shrub, or windbreak planting), managing residues to reduce soil erosion and maintain soil moisture (Arizona Air Quality Division, 2008).

Some of the technical preventive measures may include appropriate technology for drying, storage, conservation and handling of granular materials and hay; vacuum cleaning; water sprinkling; mist sprinkling; addition of vegetable oil to flour feed; sprinkling of fine oil aerosol over the animals; and design and ventilation of the premises however the materials should be carefully selected and the design of the equipment, process, and the work should be done properly to reduce dust generation (The Swedish National Board of Occupational Safety and Health, 1994).

When the dust concentrations are high enough respiratory protective equipment should be used to avoid upper and lower respiratory disturbances and diseases. HSE (2005) warns that the use of nuisance dust masks (NDMs) may prevent only from large particles during handling grain, and are inappropriate since they cannot prevent fine particles from reaching the lungs. Recommended RPSs are disposable filtering face piece respirator to BS EN 149 or a half mask respirator to BS EN 140 with particle filters to BS EN 143 (HSE, 2006). Nevertheless, oxygen sufficiency in the work environment may be an important factor to choose the best type of mask since the use of a mask could be hazardous when oxygen level is less than 17% (Hetzl, 2010). Powered filtering equipment (helmets or hoods) should be used when large quantities of dust are released during agricultural operations. Some examples of such operations include manual weighing of animals, the transfer of poultry to and from battery cages, the cleansing of grain hoppers from mouldy grain, and threshing with a cabinless threshing machine (The Swedish National Board of Occupational Safety and Health, 1994).

The cost effectiveness of engineering solutions might be important in implementing various methods to reduce emissions and work-related exposures. Technical solutions are usually poor in developing countries due to low level of technologies used such as cotton sawgins in Turkey (Aybek et al., 2010). Lahiri et al. (2005) estimated a cost of 5000-10000 \$ to eliminate the risks for silicosis in factories working in three shifts with 5 workers in each shift for stone grinders in construction sector. In other areas ventilation cost was only 650 \$. Lahiri et al. (2005) suggested that an annual cost of 106 \$ would be required to improve ventilation in these sectors both in developing and developed countries. It was noted that these estimates were based on reducing silicosis and did not account for the effect of smoking.

In crop production the most advanced technical solution is the use of enclosed cabin with appropriate filtering systems. An original cabin might sufficiently filter the air and reduce PM concentrations from 2000-20000 $\mu\text{g m}^{-3}$ to 100-1100 $\mu\text{g m}^{-3}$ (Kirkhorn and Garry, 2000). Thus an enclosed cabin is important especially in soil tillage operations generating silica. Concentration of grain dust may widely vary and can be as high as 72500 $\mu\text{m m}^{-3}$ in threshing and cleaning, implying the need for both technical and personal preventions. However, the masks could feel hot and uncomfortable and are not routinely used in agriculture (Kirkhorn and Garry, 2000).

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