Particulate matter emissions from arable production - a guide for UNECE emission inventories

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Abstract

Within arable production we distinguish the following subsequent stages: soil cultivation (includes all working steps treating the soil e.g. ploughing, harrowing, and seeding), harvesting and post harvest treatments at farm scale (like unloading, cleaning and drying crops).

For the arable crops wheat, rye, barley and oat, a first estimate of the emission factor is 3 – 5 kg PM10/ha. The actual and local emission factors are dependent on fixed parameters like soil properties (sand, loess, silt fraction) and variable parameters like dry or moist soil.

It is assumed that a part of the emitted PM10 is deposited in the field and will not leave the field. The part that leaves the field is considered to be inventory relevant. The in-field reduction percentage is dependent on atmospheric stability and wind speed.

Keywords: PM10, arable farming, tillage, emission rates, in-field deposition

Human health aspects

Thomas Jefferson's Declaration in 1776 states that 'Cultivators of the earth are the most valuable citizens. They are the most vigorous, the most independent, the most virtuous, and they are tied to their country and wedded to its liberty and interests by the most lasting bonds'. Unfortunately, the myth of the robust, reliably healthy farmer does not correspond with the realities of agricultural life. Respiratory diseases associated with agriculture were one of the first-recognized occupational hazards. As early as 1555 there was a warning about the dangers of inhaling grain dusts, but it has only been in the 20th century that respiratory hazards in agriculture were studied and documented (ATS, 1998).

Respiratory health hazards in agriculture are documented in full detail in a conference report of the American Thoracic Society, and in a review article (ATS, 1998; Eduard W. 1997). Both studies comprise animal agriculture as well as arable production. Recently a review article has been published devoted to soil as a source of dust and the associated human health aspects (Smith J. L. and Lee K. 2003).

Focus on arable production

This paper is concerned with the emission rates of particulate matter during arable production, storage and handling products while producing food and non food plants and fruits. Not included in the paper are emissions from movement on unpaved roads, from the consumption of fuels and emissions due to the input of pesticides. Also pollens which are mainly larger than the particle sizes concerned in this paper, are not included. Wind blown particles from cultivated soils not arising directly from field operations will be considered as natural emissions. These emissions, often called wind erosion, are very variable as well in size as in frequency.

Arable production in more detail

Different types of soil cultivation, harvesting, and the application of mineral fertilizer are responsible for particulate matter emissions from the fields. Soil cultivation includes all working steps treating the soil e.g. ploughing, harrowing, and seeding. Post harvest treatments like unloading,

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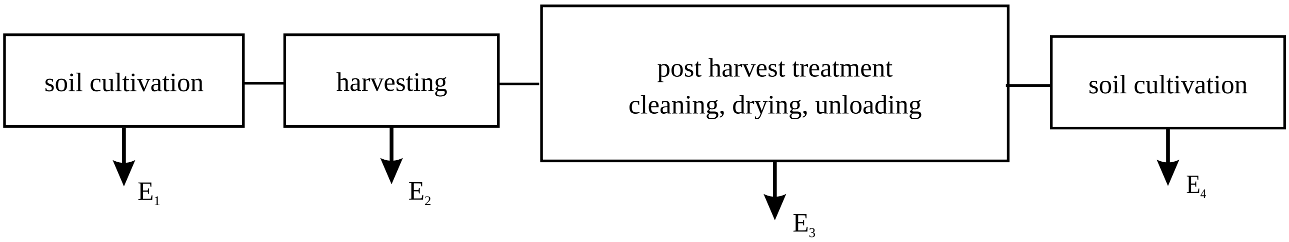
cleaning and drying crops are only taken into account if they take place on farm level. Farm level includes all operations on the farm until the produce leaves the farm.

The main sources of particulate matter emissions are caused by combine harvesting and soil cultivation and their magnitude is within the range of more than 80 % of total PM10 emissions from arable production.

Emission of particulate matter in arable production

Emissions of particulate matter in arable production occur from different sources and at different times. Sources are operations on the fields and the farms. In chronological order follow from spring to autumn soil cultivation, harvesting, post harvesting treatments and again soil cultivation (figure 1 and 2).

Figure 2:
Soil cultivation



area related emission: $\overset{n4}{\underset{j=1}{E}} = \Sigma E_j$

Figure 1:
Scheme of particulate matter sources in arable production

- Mass flows of emitted particles are governed by a large number of parameters:
- the produce, type of crop, fruit, vegetable
- the physical properties of the particles depending on their origin
- origin of the particles: soil, plant, machinery
- soil composition (sand, loess, silt fraction)
- meteorological conditions of soil and/or produce before and during the operation (wind speed, temperature, rain fall, humidity)
- type of operation (harrowing, discing, cultivating, ploughing)
- parameters of the machinery (working speed, working capacity, working surface).

Particle emissions from arable production may be related to the cultivated area of each produce.

$$E_{10} = \sum_{=1}^{n} EF_{10} \cdot A \cdot n$$

E_{10}	emission of PM10 in kg/year
EF_{10}	emission factor in kg/ha
A	annual treated area in ha
n	annual repetitions of treatment

The emission factors of post harvest operations are generally given related to the amount of handled mass. These emissions factors can be converted to area related factors by multiplying with the averaged annual yield:

$$EF_{10} = EF_{10m} * Y$$

EF_{10}	emission factor in kg/ha
EF_{10m}	emission factor in kg/ton
Y	averaged annual yield in ton/ha

The emissions during arable production follow the seasons and are given in table 1.

Table 1:
Time table for considerable working steps in arable production

	Working step, time table			
Crop	Soil cultivation/seeding	Harvesting	Cleaning	Drying
Wheat	March/October	July/August	July/August	July/August
Rye	March/October	August	August	August
Barley	March/September	June/July	June/July	June/July
Oat	March	August	August	August

Definitions of PM10, PM2.5 and TSP

There are different definitions for particle fractions, but all of them define penetration curves of virtual separators. PM10 and PM2.5 origin from US EPA defined for environmental purpose. ISO gives health related definitions which are considering the pathway into the human breathing apparatus.

Figure 3 shows these different curves. Differences are obvious for PM10 and the thoracic fraction which correspond with it by the same cut off at 10 µm. PM10 do not consider particles larger than 15 µm while thoracic reaches up to 40 µm. particulate matter. This must be considered for PM10 and thoracic fraction if the emissions include a high portion of particles with size between 15 µm and 40 µm. Practical measuring equipment will often follow the ISO definition. Definitions for PM2.5 and the respirable fraction (risk group) are consistent.

TSP means total suspended particles and it is mainly used in ambient air for sizes below 57 µm. From emission point of view TSP means more or less total dust considering all sizes up to the largest particles which size depends on the origin of the dust.

Dust particles should be limited to sizes not larger than 500 µm (aerodynamic diameter).

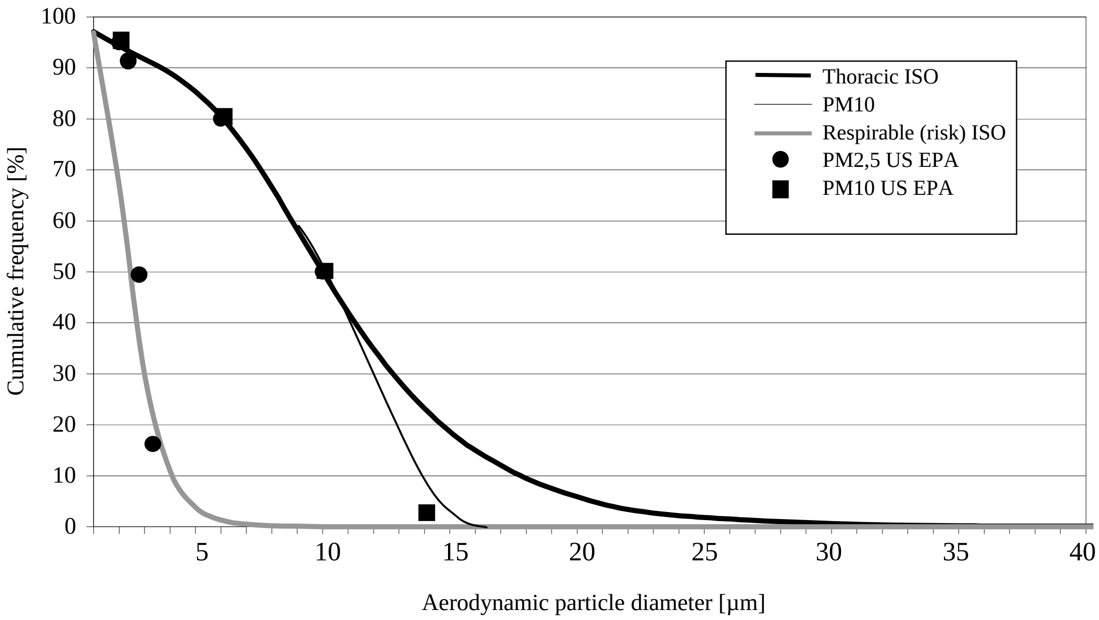


Figure 3:
Patterns of different particle fractions

The presented curves describe virtual particle separators simulating the corresponding parts of the breathing tract. They are characterized by their shape and by the 50 % value of separation and penetration the so called cut off diameter. Samplers with same cut off diameters but different shaped penetration curves will collect different fractions of

Compilation of emission factors

There are different methods for establishing emission factors for arable production.

- Direct measurements of the particulate matter emission flows of tractors and implements. From these machinery related data of the potential strength of a source, field related emission factors must be calculated.

- Indirect estimation of source strength using concentration measurements carried out machinery bound on the drivers place and models of a layer or a plume on the treated area to get the connection with a balance volume or a volume flow rate concerned.
- Measurements of particulate matter concentrations at the border of a field fitted to an inverse computing model of dispersion.

There is a lot of information on measurements available form California (Baker J. B. et al. 2005, Clausnitzer H. and Singer M. J. 1996, 1997, Holmén B. A. et al. 2000, 2001), Germany (Batel W. 1975, 1976, 1979, Goossens D. et al. 2001, Hinz T. and Funk R. 2007, Oettl D. et al. 2005) and Belgium (Bogman P. et al. 2007).

For soil cultivation the following PM10 emission factors are found:
0.1 kg/ha, RAINS (Klimont T. et al. 2002)
0.06 - 0.3 kg/ha (MAFF 2000, Wathes C. M. et al. 2002)
0.28 - 0.48 kg/ha (Hinz T. et al. 2002).

In table 3 an averaged field emission factor of 0.25 kg/ha is used.

Measurements in California are much higher, 4.2 - 5.2 kg/ha (WRAP, 2006). The reason is probably the climatic and soil conditions with higher temperature and lower humidity. This assumption is supported by measurements done in Brandenburg, Germany under the 2006 hot and dry conditions, resulting in a dry soil and emission values one order of magnitude higher than in former years (table 2).

Table 2:
Emission factors for soil operations (Oettl D. et al. 2005, Hinz T. and Funk R. 2007).

Emission factors for PM10, PM2.5 and PM1 for field operations			
	PM10 kg/ha	PM2.5 kg/ha	PM1 kg/ha
Harrowing	0.82	0.29	<1
Discing	1.37	0.12	0.03
Cultivating	1.86	0.06	0.02
Ploughing, dry soil	10.5	1.3	0.1
Idem, moist soil	1.2	0.05	0.01

For combine harvesting the following PM10 emission factors are found:
4.1 - 6.9 kg/ha, parameter cereal, cereals humidity during harvesting (Batel W. 1976)
3.3 - 5.8 kg/ha (WRAP, 2006).

PM10 emissions from arable production originate on the spots where the tractors and the machinery operate. We have to distinguish between these emissions and the emissions leaving the agricultural field. The latter emissions are much lower by self cleaning effects of the dust plumes by settling and by washing out of fine particles by large particles. This will be discussed in the next section.

Validation of emission factors

From recent US research it is known that regional air quality models overestimate the contribution of PM10 emissions from unpaved roads to the ambient PM10 concentration. A 'dividing by four of the emission' approach is often used as correction term. This overestimation is explained by rapid near source deposition resulting in a smaller transportable fraction to far-field places (Dong Y. et al. 2004). Important parameters for local deposition are land cover type, atmospheric stability and wind speed. Local deposition is reduced under unstable atmospheric conditions and high wind speeds (Etyemezian V. et al. 2003, Pace T. G. 2005, Hagen L. J. et al. 2007).

The same mechanisms hold for PM10 emissions from arable production. It is assumed that only a part of the emitted PM10 leaves the field. Only this part is considered to be inventory relevant. In table 3 two situations are presented: one with 50 % of the original PM10 emissions leaving the field and one with 10 % leaving the field.

Draft emission factors for the UNECE Emission Inventory Guidebook

Based on the cited literature in the section on compiled emission factors we constructed table 3. The PM10 emission factors are a first estimate and the final emission factors will be dependent on the following factors:

- Fixed parameters like soil properties (sand, loess, silt fraction)
- Variable parameters like dry or moist soil
- In-field reduction percentage (unstable/stable atmospheric conditions, wind speed).

Table 3:
Matrix of field emission factors for considerable working steps and totals for crops, as presented as draft in the expert group of the UNECE Emission Inventory Guidebook in Thessaloniki, 2006.
NB The working steps EF are measured on the spot; the amount of PM10 leaving the field is given for 2 situations: 50 % and 90 % reduction by settlement in the near-field.

	Working step EF_{10} kg/ha				EF_{10} kg/ha		
Crop	Soil cultivation	Harvesting	Cleaning	Drying	No reduction	50 % red	90 % red
Wheat	0.25	2.7	0.19	0.56	3.70	1.85	0.37
Rye	0.25	2.0	0.16	0.37	2.78	1.39	0.28
Barley	0.25	2.3	0.16	0.43	3.14	1.57	0.31
Oat	0.25	3.4	0.25	0.66	4.56	2.28	0.46

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