PM emission factors for farming activities by means of dispersion modeling

D. Öttl[1] and R. Funk[2]

Abstract

In this study emission factors for use in emission inventories are provided for different agricultural operations. These are plowing, harrowing, disking, and cultivating. Emission factors were derived for PM10, PM2.5, and PM1. Measurements were conducted by the Leibniz-Centre for Agricultural Landscape Research (ZALF) in Müncheberg, Germany, while the emission factors were obtained with the Lagrangian dispersion model GRAL (Graz Lagrangian Model). The latter has been developed by the Institute for Internal Combustion Engines and Thermodynamics, Graz University of Technology, Austria.

Keywords: agricultural operations, PM emission factors, Particle model, farming activities

Introduction

Fine particulate matter (PM) is nowadays being recognized as one of the most critical pollutants regarding the compliance with air quality standards. In many studies it became evident, that the major source for high PM-concentrations close to the ground is traffic. However, it is recognized that there are many other sources (anthropogenic and natural), which can also contribute significantly to the total pollutant burden. Air quality observations indicate that the so called background concentration of PM10 accounts for roughly 50 % of the total observed concentrations even within larger cities (Lenschow P. et al. 2001). In order to allow for a detailed source apportionment regarding the background concentration, comprehensive emission inventories are necessary. There exist only a few studies about PM emission factors from agricultural operations (Holmén B.A. et al. 2001), and hence, these are not accounted for in emission inventories. This study aims at providing emission factors for different kinds of agricultural operations namely: plowing, harrowing, disking, and cultivating.

Experimental set up

The experiments were all conducted by the Leibniz-Centre for Agricultural Landscape Research (ZALF) in Müncheberg, Germany. The observations consisted of

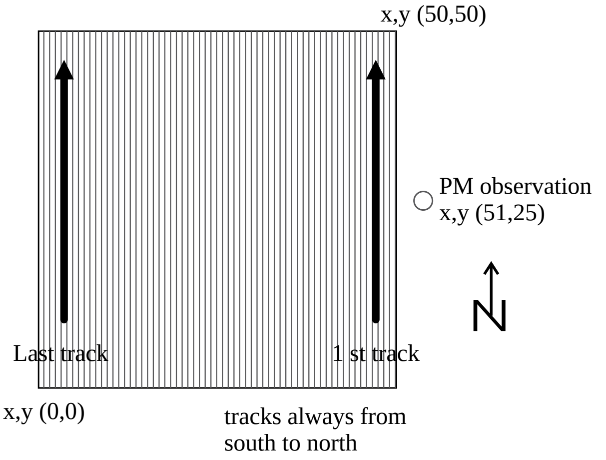

Figure 1:
Sketch of the test field for the different agricultural operations

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[1] Air Quality Department of Styria, Austria

[2] Leibniz-Centre for Agricultural Landscape Research (ZALF) Müncheberg, Germany

a wind vane and a cup anemometer 1 m above ground level, and a particle counter for PM10, PM2.5, and PM1 (GRIMM 107 PTFE ENVIRONcheck). PM observations took place at a height of 2 m above ground level close to a test field, which had an extension of 50 m x 50 m (figure 1). In all experiments the tractor drove from south to north.PM emission factors for farming activities by means of dispersion modeling

Figure 2 shows the investigated agricultural operations. The soil type of test field can be characterized as sandy cambisol. The soil texture is given in table 1. It can be seen, that PM10 accounts for about 6 % of the total volume. Figure 3 depicts a typical soil moisture distribution within the test field during the experiments. Little variation was found for the experiments, which took place between June and October 2004. It is clearly visible, that only the first few centimeters of the soil may significantly contribute to PM emissions, as the soil moisture is strongly increasing with depth up to a constant value of about 5.5 %. Tests in a wind tunnel revealed a critical value of about 2.5 % soil moisture above which practically no PM emission takes place.

Table 1:
Soil texture of the test field

Fraction	Diameter (µm)	Share (%)
Coarse sand	630 - 2000	5.0
Middle sand	200 - 600	37.9
Fine sand	63 - 200	40.4
Coarse silt	20 - 63	7.5
Middle silt	6 - 20	3.3
Fine silt	2 - 6	1.8
Clay	<2	4.2

Figure 2:
Investigated agricultural operations: plowing including a packer, harrowing, disking, and cultivating

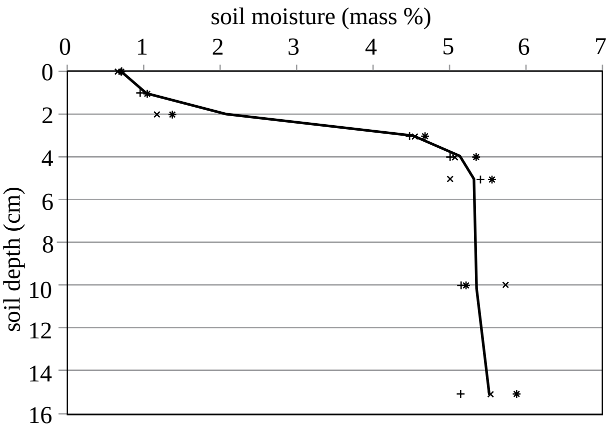

Figure 3:
Typical soil moisture distribution within the test field during the experiments

Modeling approach

In order to obtain PM emission factors the Lagrangian dispersion model GRAL (Graz Lagrangian Model) has been utilized. GRAL is a well-validated short range numerical model applicable for a wide range of wind speeds and atmospheric stabilities. In this study the following relationships were used to determine the turbulent velocities:

$$du = -(pu + qv)dt + \sigma_u \sqrt{2pdt}\, \xi_u \tag{1a}$$

$$dv = -(-qu + pv)dt + \sigma_v \sqrt{2pdt}\, \xi_v \tag{1b}$$

$$dw = a \cdot dt + \left[C_0 \cdot \varepsilon \ dt\right]^{0.5} \xi_w \tag{1c}$$

du, dv, and *dw* are the wind fluctuations in x, y, and z-direction. ξ_u, ξ_v, and ξ_w are increments of a Wiener process with zero mean, a standard deviation of one and a Gaussian probability density function. *dt* is the time step, ε the ensemble average rate of dissipation of turbulent kinetic energy, C_0 the universal constant set equal to 4 (Wilson J.D. et al. 1996, Degrazia G. A. et al. 1998, Anfossi D. et al. 2000), a is the deterministic acceleration term computed according to Franzese (Franzese P. et al. 1999), and $\sigma_{u,v}$.are the standard deviations of the horizontal wind fluctuations. The latter are determined in the surface layer by

$$\sigma_{u,v} = \mathrm{u}_* \cdot \left(1 + 1.8 \cdot \left|\frac{\mathrm{z}}{\mathrm{L}}\right|^{0.1}\right) \tag{2}$$

The ensemble average rate of dissipation of turbulent kinetic energy according to Kaimal and Finnigan (Kaimal J. C. et al. 1994) is:

$$\varepsilon = \frac{\mathrm{u}_*}{\kappa z}\left(1 + 0.5\left|\frac{z}{L}\right|^{0.67}\right)^{1.5} \tag{3}$$

In eq. (2) and (3) u_* denotes the friction velocity, κ the von Karman constant, and *L* is the Monin-Obukhov length. The friction velocity is determined according to Golder (Golder D. 1972) and the Monin-Obukhov length according to Venkatram (Venkatram A. 1996).

Equations (1a) and (1b) were derived by Oettl (Oettl D., et al. 2005) to account for horizontal meandering flows in low wind speed conditions. The parameters *p* and *q* control the shape of the modelled autocorrelation function, which usually shows oscillation behaviour in low wind speed conditions and an exponential shape in higher wind speed conditions (Anfossi D. et al. 2004, Hanna S. R. 1983). According to Anfossi (Anfossi D. et al. 2004) parameters *p* and *q* are defined as:

$$p = \frac{2}{(m^2 + 1) \cdot T_3} \tag{4a}$$

$$q = \frac{m}{(m^2 + 1) \cdot T_3} \tag{4b}$$

$$T_3 = \frac{T_* \cdot m}{(m^2 + 1) \cdot 2\pi} \text{ for mean wind speeds } \bar{u} < 2.5 \text{ m s}^{-1} \text{ and} \tag{4c}$$

$$T_3 = \frac{T_* \cdot m}{(m^2 + 1) \cdot 2\pi} \text{ for } \bar{u} \geq 2.5 \text{ m s}^{-1} \tag{4d}$$

$$T_* = 200 \cdot m + 350 \tag{4e}$$

$$m = \frac{8.5}{(\bar{u} + 1)^2} \text{for } \bar{u} < 2.5 \text{ m s}^{-1}\text{, and m = 0 for } \bar{u} \geq 2.5 \text{ m s}^{-1} \tag{4f}$$

The empirical relationships for T_* and m are based on observations using a sonic anemometer in the city of Graz (Austria). For higher wind speeds ($\bar{u} \geq 2.5$ m s^{-1}) eq. (1a and 1b) collapse on the classical Langevin equation for homogeneous turbulence.

A direct assessment of the uncertainties related with the dispersion model is impossible. In order to obtain some estimate a comparison of modeled concentrations with GRAL and observations during the Prairie Grass experiment was made. The Prairie Grass experiment (Barad M. L. 1958) included 10-minute near-surface sampling along five arcs, 50 to 800 m, downwind from a near-surface point source release of sulfur dioxide. The 20-minute releases were conducted during July and August 1956, with an equal number of cases occurring during the daytime and nighttime. The sampling was for the 10-minute period in the middle of the 20-minute release. All in all 44 experiments were used in this study. As our interest is on the model performance very close to the source, only the results for the 50 m sampling arc are briefly discussed. Figure 4 depicts a comparison of observed and modeled maximum concentrations at 50 m distance from the release point. The lines indicate the one to one relationship and a deviation of +/- 30 %. As can be seen almost all cases fall within this range of uncertainty. The coefficient of determination was found to be 0.94.

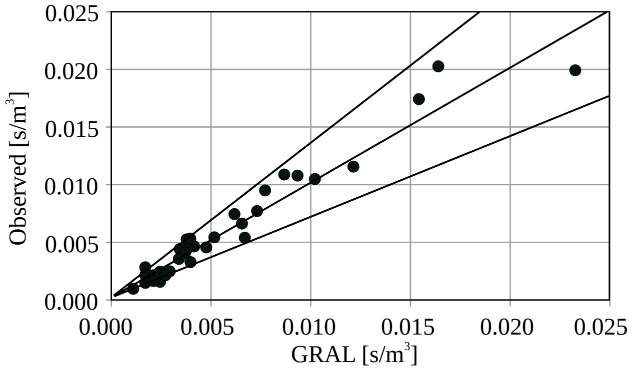

Figure 4.

Observed and modeled maximum concentrations at 50 m distance from the release point for the Prairie Grass Experiment (44 cases)

Results

Emission factors for PM were obtained by modelling the dispersion from the test field, treating it as an area source. It was assumed in the simulations, that the PM emissions are initially mixed up to 2 m above ground level due the tractor induced turbulence. Figure 5 shows an example of observed PM10-concentrations for plowing and packing. From the observed concentration minima during the experiment, the background concentrations for PM10, PM2.5, and PM1 were determined.

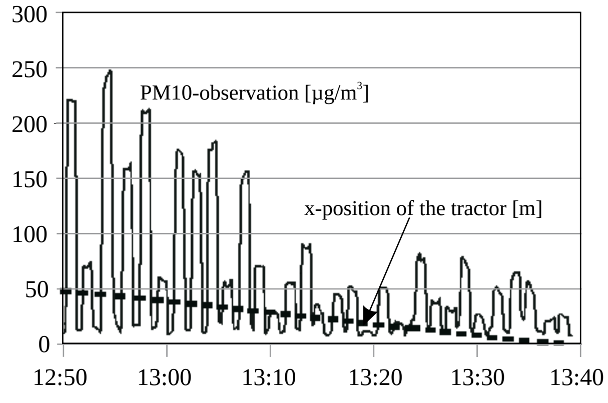

Figure 5:

Example of observed PM10-concentrations for plowing and packing

For each experiment an hourly average concentration was calculated by integrating the observed peaks and subtracting the estimated background concentration. From the dispersion simulation, emission factors in units of [kg h^{-1}] and [kg] were obtained respectively. By division through the area of the test field the final emission factors in units of [mg m^{-2}] could be derived. Table 2 lists the observed meteorological conditions during the tests. Although the stability class is subject to some uncertainty as it had to be estimated based on the wind speed, cloud cover, time of the day, and season, model simulations applying other stability classes showed only little influence on the concentration. The reason is the very close location of the PM measurement site to the test field.

Table 2:

Observed meteorological conditions during the experiments

	Wind-speed [m s^{-1}]	Wind direction [deg.]	Stability class (PGT)	Relative humidity [%]	Temperature [°C]
Plowing and packing	2.7	170	C	40	24
Harrowing	1.9	212	B	34	27
Disking	3.1	96	D	45	13
Cultivating	1.1	113	B	29	27
Plowing	2.9	13	D	53	27

Table 3 lists the calculated emission factors for the different agricultural operations for PM10, PM2.5, and PM1. Having in mind all the possible influencing factors on the emissions such as dispersion model uncertainty, wind speed, relative humidity, soil moisture, land preparation, it is somewhat surprising to find with one exception a relatively narrow range for the emission factors. However, during dry conditions emissions for similar activities can rise up by a factor of 10 as can be seen for plowing.

Table 3:

Emission factors for PM10, PM2.5, and PM1 for different agricultural operations

	PM10 [mg m^{-2}]	PM2.5 [mg m^{-2}]	PM1 [mg m^{-2}]
Plowing and packing	120	5	1
Harrowing	82	29 1)	<1
Disking	137	12	3
Cultivating	186	6	2
Plowing (dry conditions)	1045	129	13

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