Primary particulate matter emissions and trends from Canadian agriculture

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Abstract

The Agricultural Particulate Matter Emissions Indicator (APMEI) has been developed to estimate Particulate Matter (PM) emissions from agriculture in Canada and to assess potential emission-reduction measures. The APMEI estimates atmospheric emissions of primary PM from wind erosion, land preparation, crop harvesting, fertilizer and chemical application, crop residue burning, grain handling, pollen, animal feeding operations and animal carcass burning for the Census years from 1981 to 2011. The APMEI assessed both the state and the trend of emissions of primary PM resulting from Canadian agricultural activities. Total PM emissions from agricultural sources in Canada decreased from 1981 to 2011, with a decline of 63% for TSP, 58% for PM_{10} and 61% for $PM_{2.5}$. In 2011, Canadian agricultural PM emissions were 3066 kt for TSP, 1190 kt for PM_{10} and 276 kt for $PM_{2.5}$. Wind erosion, land preparation and crop harvesting were the principal sources of particulate emissions from cultivated cropland. Wind erosion alone generated about half of the total agricultural PM emissions in Canada. Land preparation was the second largest source of agricultural PM emissions, accounting for 17% to 36% of the total depending on the PM classes, and crop harvesting contributed 10% of the total PM emissions. Since there is a seasonal pattern to the dominant sources of PM emissions, the monthly emissions from the three main agricultural sources were quantified and are presented for 2011.
Keywords: agriculture, wind erosion, crop harvesting, land preparation, corn pollen, emission factor, particulate matter, particles, air quality, air contaminants.

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1 Introduction

Particulate matter (PM) is considered as an air pollutant due to its adverse effects on human health and the environment. Three classes of PM were reported in this indicator: total suspended particulate (TSP), which consists of all PM with aerodynamic diameter <100µm, PM_{10}, which consists of PM with aerodynamic diameter <10µm and $PM_{2.5}$, which consists of PM with aerodynamic diameter <2.5µm. The emission of PM from agricultural operations is an emerging air quality issue with important implications for the health of agricultural workers and animals. The agricultural sector contributes both primary and secondary PM. Primary agricultural PM in Canada mainly consist of soil particles suspended in the atmosphere due to land preparation and wind erosion of exposed fields, plant material ejected by combine harvesters during crop harvesting and by subsequent grain handling. Secondary PM emissions from the agricultural sector originate mostly from ammonia volatilization in presence of appropriate precursors. The Agricultural Particulate Matter Emissions Indicator (APMEI) has been developed to estimate the primary PM emissions from agriculture at the soil landscape polygons of Canada (SLC) using activity data based on the 5-yr Census of Agriculture (Census). It was first developed for the 2006 Census as part of the Agri-Environmental Indicator of Agriculture and Agri-Food Canada. This second edition includes 2011 Census data and modifications based on an in-depth audit undertaken by Environment Canada during the transfer of the indicator to the Pollutant Inventories and Reporting Division. To ensure temporal homogeneity, all the Census years were recalculated based on the most recent methodology. As well, this edition also includes monthly PM emissions estimates for the main PM sources for the Census year of 2011.

2 Methodology

The APMEI was designed to quantify annual primary PM emissions from agricultural operations at the SLC scale based on the 5-yr Census of Agriculture data. Ten sources were covered in the inventory: wind erosion, land preparation, crop harvest, grain handling, pollen emission, fertilizer and chemical application (agrochemical), animal feeding operations, crop residue burning and animal carcass burning. Emissions estimates were conducted for the ten provinces in Canada. The emissions estimates for each sector were calculated using an emission factor approach, where the PM emissions are based upon an activity level and an emission factor:

$$ER_{i,j} = AP_{i,j} \times EF_{i,j} \quad (1)$$

where $ER_{i,j}$ is the emission rate of SLC polygon j for activity i, $AP_{i,j}$ is the intensity of activity i at SLC polygon j, and $EF_{i,j}$ is the emission factor of SLC polygon j for activity i.

The main sources for emission factors were the US EPA AP-42 (4^{ed} & 5^{ed}), the California Air Resources Board (CARB) and peer-reviewed scientific papers. The methodology was transferred to Environment Canada, for inclusion in the Air

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Pollutant Emissions Inventory (APEI) with the reporting of other air pollutants (e.g. GHG emissions) from agriculture. An audit to compare the PM emission results of Environment Canada and Agriculture and Agri-Food Canada, locate any inconsistencies and to implement new additions to methodologies was completed in winter 2015. In the audit, emission estimations were similar between the two indicators, with any discrepancies explained by slight differences in activity data, the inclusion of additional sources (such as pollen, agrochemicals and agricultural burning). Emissions from grain handling are included under industrial emissions in the APEI and were not included in the audit.

2.1 Wind Erosion

Windblown dust emissions from agricultural sources are calculated using eqn. (1), where the Wind Erosion Equation [1] is used to compute the emission factor. This equation was modified to account for soil cover change (SLR) [2, 3] in relation to crop canopy cover, crop residues and snow cover. The equation to calculate the wind erosion emission factor (t ha^{-1} yr^{-1}) is as follows [4]:

$$EF_{i,j} = A \times I_j \times K_i \times C_j \times L'_{i,j} \times SLR_{i,j} \quad (2)$$

where A is the portion of total wind erosion losses (A = 0.025 for TSP, 0.0125 for PM_{10}, and 0.0025 for $PM_{2.5}$), I_j is the soil erodibility (t ha^{-1} yr^{-1}), K_i is the dimensionless surface roughness factor for crop type i, C_j is a dimensionless climatic factor, $L'_{i,j}$ is a dimensionless unsheltered field width factor and $SLR_{i,j}$ is the soil loss rate defined as the ratio of the soil loss for a soil under a given canopy cover (or soil cover) divided by the soil loss from bare soil.

2.1.1 Wind erosion factors

Erodibility is calculated based on the SLC [5], using the percentage of silt, clay and sand of each polygon, and processed according to the Canadian Soil Texture Triangle. Crop roughness was found in a US EPA report [6], and matched to the most similar Census crop type. The climatic factor was calculated based on the proposed methodology by Skidmore [7], modified for SI units:

$$C = 386 \times \frac{\left(V \times \frac{1000}{3600}\right)^3}{PEI^2} \quad (3)$$

$$PEI = 3.16 \times \sum_{i=1}^{12} \left(\frac{Pi}{1.8 \times Ti + 22}\right)^{10/9} \quad (4)$$

where V is the average monthly 10-m wind velocity (km h^{-1}), T_i is the monthly temperature (°C) and P_i is the monthly precipitation (mm).

Unsheltered field width was calculated by linear interpolation based on the erodibility (I) times the roughness (K). Soil loss rate was calculated using equations for soil and canopy cover, by CARB [2, 3], where the larger SLR value was used in the final factor calculation:

$$SLR_{SC} = e^{-0.0438 \times (SC)} \quad (5)$$

$$SLR_{CC} = e^{-0.201 \times (CC^{0.7688})} \quad (6)$$

where SC is the soil cover (%) and CC is the canopy cover (%).

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2.2 Land preparation

The AP-42 [8] defines the PM emissions from agricultural land preparation as a function of soil texture, the area prepared and the number of agricultural events per year. In the APMEI, tillage, which is the common practice for Canadian producers to prepare land for seeding and controlling weeds, was represented by three main management practices: conventional tillage, reduced tillage and no-tillage. Conservation tillage has fewer tilling events per year compared to conventional tillage. The emission rate $ER_{i,j}$ (kg yr^{-1}) was calculated as follows:

$$ER_{i,j} = \sum_k (EF_j \times CA_i \times NP_{i,k} \times TP_k) \quad (7)$$

where, EF_j is the emission factor (kg ha^{-1}), CA_i is the agricultural tilling area for crop type i (ha yr^{-1}), $NP_{i,k}$ is the number of tilling events per year for crop type i and tillage practice type k and TP_k is the percentage of each management practice k. The emission factor (kg ha^{-1} yr^{-1}) for land preparation was calculated as [8]:

$$EF_j = \sum 5.38 \times k \times s_{i,j}^{0.6} \times p_{i,j} / \sum_i p_{i,j} \quad (8)$$

where 5.38 is a constant (kg ha^{-1} pass^{-1}), k is the particle size multiplier, $k = 1$ for TSP, 0.21 for PM_{10} and 0.042 for $PM_{2.5}$, $s_{i,j}$ is the silt content (%) for soil type i, defined as the mass fraction of particles <75 μm diameter in the first 10-cm of soil, and $p_{i,j}$ is the percentage of soil type i in polygon j. The silt content in the APMEI was determined according to the soil texture class of the SLC [5], based on Table 4.8-3 in US EPA [9]. Information on the number of agricultural events per year for crop type and tillage practice type was taken from a soil cover indicator published by AAFC [10].

2.3 Crop harvesting

Particulate matter emissions generated from agricultural harvesting are due to mechanical disturbances in the field caused by combines processing plant material and vehicles traveling over the field. Harvest emissions (kg yr^{-1}) are calculated using the emission factor approach, eqn. (1).

The emission factors of PM_{10} (kg ha^{-1}) proposed by CARB [3] were adopted for crops types reported in the Census and used to calculate PM emissions from agricultural harvest. The emission factors for TSP and $PM_{2.5}$ were calculated from the PM_{10} values using the soil size speciation value for agricultural tilling. Houck *et al* [11] found the scaling factors are 2.2 for TSP and 0.2 for $PM_{2.5}$. The harvested areas (ha yr^{-1}) by crop type and SLC were based on the Census.

2.4 Pollen

Most of the atmospheric pollen emissions originate from anemophilous plants (i.e. using wind pollination). In agriculture, corn pollen is the most significant contributor to PM emissions. Due to its diameter between 70 and 100 μm and spherical shape reported by Wodehouse [12], corn pollen only contributes to TSP emissions. PM emissions (kg yr^{-1}) are calculated using the emission factor approach, eqn. (1). The emission factors (kg ha^{-1}) are derived from studies [13–15] as follows:

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$$EF = PG \times PS \times MP \times PD \quad (9)$$

where PG is the pollen grains per plant (old hybrids: 15 10^6 pollen grains; new hybrids: 3 10^6 pollen grains), PS is the percentage of the pollen production that is shed (85 %), MP is the mass per pollen grain (247 10^{-12} kg) and PD is the plant density (~86500 plant ha^{-1}). Modern hybrids were mostly used by 2001 [16]. Prior to 2001, the pollen emission factor was 272 kg ha^{-1} while afterwards it was 55 kg ha^{-1}.

2.5 Agrochemicals

Particulate matter emissions are generated from both fertilizer and pesticide applications. PM emissions (kg yr^{-1}) from agrochemicals were calculated using the emission factor approach, eqn. (1). The emission factors were reported in MetroVancouver [17], where fertilizer emission factors were 2.23 kg t^{-1} for TSP, 1.09 kg t^{-1} for PM_{10}, and 0.31 kg t^{-1} for $PM_{2.5}$, while pesticide emission factors were 1.67 kg ha^{-1} for TSP, 0.82 kg ha^{-1} for PM_{10}, and 0.23 kg ha^{-1} for $PM_{2.5}$. The amounts of agrochemicals applied per ha, were derived from the Census.

2.6 Agricultural burning

Particulate matter emissions from agricultural burning are dependent on the type of crop burned and the manner of combustion. The emission rate *ER* (kg yr^{-1}) is calculated as follows:

$$ER_{i,j} = EF_i \times FL_i \times A_{i,j} \quad (10)$$

where EF_i is the emission factor, from studies [18, 19] for crop type *i* (kg t^{-1}), FL_i is the fuel loading for crop type *i* (t ha^{-1}) and $A_{i,j}$ is the area of residue burned per year per polygon and crop type (ha yr^{-1}).

The fuel loading values for field crops reported in AP-42 [19] does not account for the temporal and spatial variations of fuel loadings. Ideally, fuel loading should be estimated and recorded at the time of each burn. To replicate this, fuel loadings were estimated using the following approach:

$$FL_i = CY_i \times R_{AGi}/1000 \quad (11)$$

where, CY_i is the yield for crop *i* (kg ha^{-1}) and R_{AGi} is the ratio of above ground residue dry matter to yield for crop *i*, from Janzen *et al.* [20]. Crop yields were reported by Statistics Canada at the provincial level.

The activity data, $A_{i,j}$, were estimated from the data collected from FEMS [21]. Since FEMS only reports provincial burning ratios, it was assumed that the burning ratio was the same for all the crops, and the burning ratio was applied to all the crops and SLC polygons in that province.

2.7 Grain handling

Grain handling accounts for all processes used in grain elevators. Grain elevators were separated into four groups based on their location and function: primary, process, transfer and terminal elevators. Recent studies reported in AP-42 [19],

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shows that a PM reduction of 60 to 80% can be achieved. In this indicator, 75% control efficiency was assumed and used for all the elevators.

Emissions from the four types of grain elevators were calculated using the emission factor approach, eqn. (1). Emission factors for grain handling (kg t^{-1}) were taken from the AP-42 [19], and the mass of grain handled (t yr^{-1}), was taken from the Canadian Grain Commission [22].

2.8 Animals

There are two sectors that encompass animals, and both use the emission factor approach, eqn. (1). They are animal feeding operations (AFOs) and animal carcass burning. Concerning animal emissions, only outdoor contributions were considered. This greatly reduced PM emissions from animals, especially AFOs.

For AFOs, the EF (kg $head^{-1}$ yr^{-1}) for each animal type was calculated as:

$$EF_i = \frac{BM_i}{500} \times EF_{AU(i)} \times CF_i \times 10^{-3} \tag{12}$$

where BM_i is the average body mass (kg) for animal type i, $EF_{AU(i)}$ is the emission factor (g AU^{-1} d^{-1} with AU: animal unit (500 kg AU^{-1})) adopted from [23–26] and CF_i was the annual confinement or production time (d) for animal type i taken from [27–29]. Since no values were reported for PM_{10} and $PM_{2.5}$, the emission factors for TSP are multiplied by 0.45 and 0.1, respectively [30].

For animal carcass burning, the emission rate ER (kg yr^{-1}) for each animal type was calculated as follows:

$$ER_{i,j} = EF_i \times AN_{i,j} \times POI_i \tag{13}$$

where $ER_{i,j}$ is the PM emission rate for animal type i (kg yr^{-1}), EF_i is the emission factor (kg $head^{-1}$) for animal type i, $AN_{i,j}$ is the animal population for animal type i (head), and POI_i is the percentage of incinerated animal type i carcass.

The emission factors used in animal carcass burning are taken from two reports [26, 31]. Since there were no PM_{10} or $PM_{2.5}$ emission factors, they were estimated using particle size fractions for uncontrolled medical waste incineration from the AP-42 [19]. In addition, Boadi *et al.* [28] and Leeson [29] compiled average animal weights, which are used to convert given emission factors from reports to kg $head^{-1}$. The data from FEMS [21] was used to get the proportion of dead animals that were incinerated.

3 Results

3.1 2011 agricultural PM emissions

In 2011, the primary PM emissions for the Canadian agricultural sector totaled 3066 kt for TSP, 1190 kt for PM_{10} and 276 kt for $PM_{2.5}$. Wind erosion was the dominant source of PM emissions, followed by land preparation and crop harvesting. Cropland is the dominant land cover producing TSP emissions for the main activities (Figure 1), followed by unimproved pasture. Due to the strong reduction of summer fallow in the Prairies, its contribution to TSP emissions

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caused by wind erosion was limited (<100 kt), but was still an important source of emissions during land preparation (~300 kt).

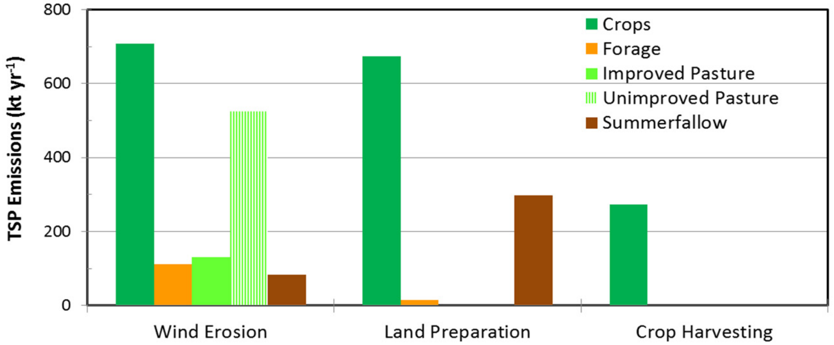

Figure 1: Contribution of land cover type to 2011 TSP emissions (wind erosion, land preparation and crop harvesting).

The dominant sources (i.e. wind erosion, land preparation and crop harvesting) are the same in 2011 for the three PM emission classes TSP, PM_{10} and $PM_{2.5}$ (Figure 2) for the various agricultural activities. However, crop residue burning mostly contributed $PM_{2.5}$, while corn pollen only contributed TSP. Each of the other agricultural activities contributed less than 3% of PM emissions.

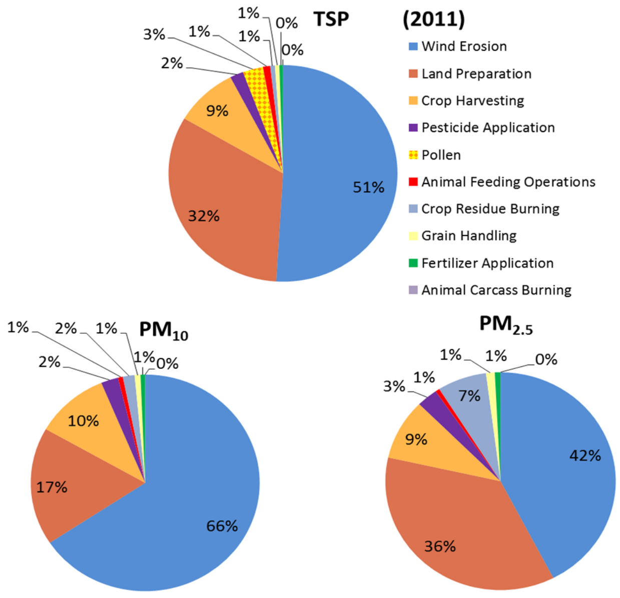

Figure 2: Proportion of the various primary PM sources for Canadian agriculture emissions in 2011.

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3.2 Monthly PM emissions in 2011

The two major periods of high PM emissions caused by wind erosion (Figure 3) were in the spring (highest PM emissions in April) and in the fall when bare soil is exposed in the fields (no snow, residues, or vegetation cover).

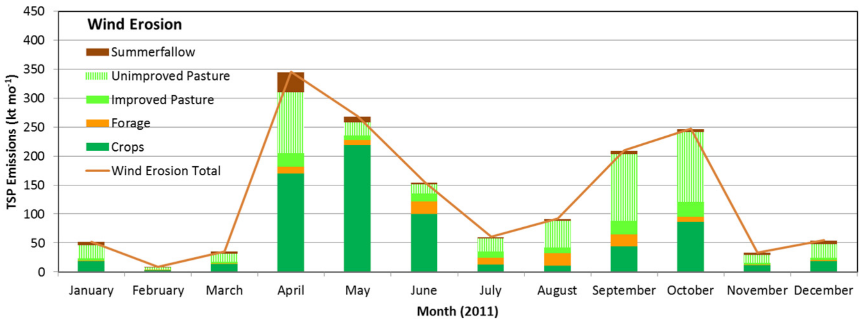

Figure 3: Monthly TSP emissions resulting from wind erosion for different land cover types in 2011.

The land preparation carried out in the spring contributed greater quantities of TSP emissions compared to the fall tillage (Figure 4). The peak of PM emissions from crop harvesting occurred in October (Figure 4).

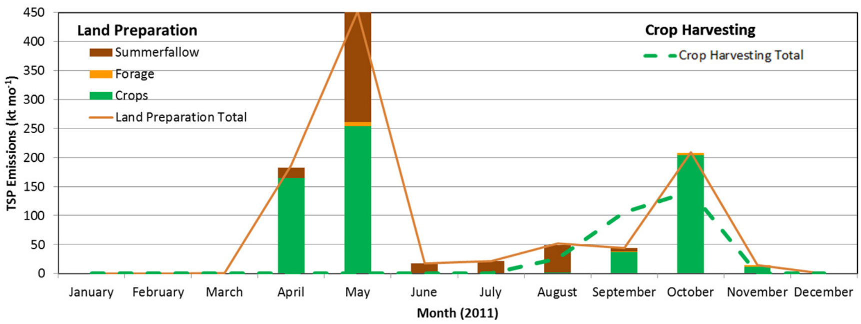

Figure 4: Monthly TSP emissions resulting from land preparation for different land cover types and from crop harvesting in 2011.

3.3 PM emissions trends between 1981 and 2011

Most of the agricultural PM emissions originated from the Prairies provinces of Canada, which have the largest area of cultivated land (Table 1). In 2011, the TSP emissions were 1518 kt in Saskatchewan, followed by 777 kt in Alberta, and 368 kt in Manitoba. Negligible TSP emissions were observed for the other provinces, except for Ontario (232 kt TSP) and Quebec (130 kt TSP).

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Table 1: PM emissions by province of Canada (BC: British Columbia, AB: Alberta, SK: Saskatchewan, MB: Manitoba, ON: Ontario, QC: Quebec, AC: Atlantic Canada) for the agriculture Census years.

	TSP Emissions (kt yr^{-1})						
	1981	**1986**	**1991**	**1996**	**2001**	**2006**	**2011**
BC	29	28	27	25	24	23	19
AB	2053	1962	1796	1527	1253	1027	777
SK	4672	4148	3690	3137	2775	2079	1518
MB	772	675	598	542	497	418	368
ON	643	565	562	488	490	255	232
QC	161	171	182	193	243	129	130
AC	29	26	46	26	27	23	21
CANADA	8360	7575	6901	5938	5308	3954	3066
	PM_{10} Emissions (kt yr^{-1})						
	1981	**1986**	**1991**	**1996**	**2001**	**2006**	**2011**
BC	8	8	8	8	6	7	5
AB	712	688	632	588	474	412	325
SK	1707	1529	1357	1248	1107	883	647
MB	255	230	210	202	173	152	131
ON	89	84	81	71	61	57	49
QC	25	24	24	26	27	26	26
AC	7	7	7	7	6	6	5
CANADA	2803	2571	2319	2150	1856	1543	1190
	$PM_{2.5}$ Emissions (kt yr^{-1})						
	1981	**1986**	**1991**	**1996**	**2001**	**2006**	**2011**
BC	2	2	2	2	2	2	1
AB	184	176	159	144	110	90	68
SK	409	364	322	286	243	184	139
MB	67	61	54	52	50	43	37
ON	32	31	30	26	23	21	18
QC	9	9	9	9	11	10	10
AC	3	2	2	2	2	2	2
CANADA	707	644	578	522	441	353	276

A generally decreasing trend was observed between 1981 and 2011 in the total emissions of TSP, PM_{10} and $PM_{2.5}$ (Table 1). The decline over the 30 years was 63% for TSP, 58% for PM_{10} and 61% for $PM_{2.5}$. It reflected the changes in land use and management practices. The adoption of conservation tillage (reduced tillage and no-till) and the reduction of summer fallow in the Prairies resulted in most to the PM emission reduction.

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4 Concluding remarks on mitigating PM emissions

Most PM emissions were associated with crop production. The overall reduction in PM emissions mainly resulted from reduced tillage and increased adoption of no-till that increased soil cover, decreased passes during land preparation, as well as the a reduction in the area of summer fallow and changes in the area of perennials, pastures and grasslands.

Particulate matter emissions associated with land preparation, agrochemical application and crop harvest could be reduced by better accounting for weather conditions (e.g. low wind speed and high relative humidity) to schedule the practice.

More research is needed to develop emission factors relevant to current management practices, to better understand the impact on PM emissions of weather conditions, as well as how the adoption of other beneficial management practices such as using forages in rotations, growing winter cover crops, and using strip cropping, contour cultivation and windbreaks affects PM emissions. Such studies would contribute to reduce the uncertainty of the PM emission indicator.

References

[1] Woodruff, N.P., & Siddoway, F.H., A Wind Erosion Equation. *Soil Sci. Soc. Am. Proc.* **29**, pp. 602-608, 1965.

[2] CARB. Windblown Dust - Agricultural Lands (Section 7.12). *Emission Inventory Procedural Manual Volume III*: *Methods for Assessing Area Source Emissions*, California Air Resource Board: California, 1997.

[3] CARB. *Emission Inventory Procedural Manual Volume III*: *Methods for Assessing Area Source Emissions*, California Air Resource Board: California, 2003.

[4] Western Regional Air Partnership, 2004. Fugitive Dust Handbook (Chapter 7). *Agricultural Wind Erosion,* Countless Environmental: California, 2006.

[5] Soil Landscapes of Canada. Version 3.0. http://sis.agr.gc.ca/cansis/nsdb/slc/v3.0/intro.html.

[6] US EPA. *Control of Open Fugitive Dust Sources. EPA-450/3-88-008,* Office of Air Quality: North Carolina, 1988.

[7] Skidmore, E.L., Wind Erosion Climatic Erosivity. *Climatic Change,* **9**, pp. 195-208, 1986.

[8] US EPA. *Compilation of Air Pollutant Emission Factors. Volume I. Stationary Point and Area Sources. AP-42, 4th Edition (and Supplements),* Office of Air Quality: North Carolina, 1985 http://www.epa.gov/ttn/chief/ap42/oldeditions.html.

[9] US EPA. *National air pollutant emission trends, procedures document, 1990-1996. EPA-454/R-98-008.* Office of Air Quality: North Carolina, 1998.

[10] Huffman, E.C. and Coote, D., Soil Cover in Canada, 1981-2006. *Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series. Report #3,* pp. 31-35, 2010.

www.witpress.com, ISSN 1743-3541 (on-line)

[11] Houck, J.E., Chow, J.C., Watson, J.G., Simons, C.A. & Pritchett, L.C., *Determination of Particle Size Distribution and Chemical Composition of Particulate Matter from Selected Sources in California, Final Report*, California Air Resource Board: California, 1989.
[12] Wodehouse, R. P., *Pollen Grains: Their Structure, Identification, and Significance in Science and Medicine,* McGraw-Hill: New York, 1935.
[13] Goss J.A., Development, physiology and bio-chemistry of corn and wheat pollen. *The Botanical Review*, **34(3)**, pp. 333-358, 1968.
[14] Kiesselbach, T.A., The Structure and Reproduction of Corn. *Biologia Plantarum,* **44(2)**, p. 238, 1949.
[15] Miller P.D., Maize Pollen: Collection and Enzymology (Chapter 45), *Maize for Biological Research*, Plant Molecular Biology Association: USA, pp. 279-282, 1985.
[16] Reid, L. Personal Communication, 14 January 2014, Corn Breeder, Agriculture Agri-Foods Canada, Ottawa, Canada.
[17] MetroVancouver. 2005 Lower Fraser Valley air emissions. Inventory & Forecast and BackCast, 2010 http://update.metrovancouver.org/about/publications/Publications/2005-LFV-Air_Emissions_Inventory-Forecast-Backcast.pdf.
[18] Jenkins, B. *Atmospheric Pollutant Emission Factors from Open Burning of Agricultural and Forest Biomass by Wind Tunnel Simulations*, UC Davis: California, 1996.
[19] US EPA. *Compilation of Air Pollutant Emission Factors. Volume I. Stationary Point and Area Sources. AP-42, 5th Edition (and Supplements)*, Office of Air Quality: North Carolina, 1995 http://www.epa.gov/ttnchie1/ap42/.
[20] Janzen, H.H., Beauchemin, K.A., Bruinsma, Y., Campbell, C.A., Desjardins, R.L., Ellert, B.H. & Smith, E.G., The Fate of Nitrogen in Agroecosystems: An Illustration Using Canadian Estimates. *Nutr. Cycl. Agroecosyst*, **67**, pp. 85-102, 2003.
[21] Statistics Canada. Farm Environmental Management Survey (FEMS), 2006 http://www.statcan.gc.ca/cgi-bin/imdb/p2SV.pl?Function=getSurvey&SDDS=5044&lang=en&db=imdb&adm=8&dis=2.
[22] Canadian Grain Commission. Grain elevator and storage capacity totals combined for all provinces and elevator types, 2010. http://www.grainscanada.gc.ca/wa-aw/geic-sgc/summary-results-sommaire-resultats-eng.asp.
[23] Roumeliotis, T.S. & Van Heyst, B.J., Size fractionated particulate matter emissions from a broiler house in southern Ontario, Canada. *Sci. Total Environ*. **383**, pp.174-182, 2007.
[24] Seedorf, J., Hartung, J., Schroeder, M., Linkert, K.H., Pedersen, S., Takai, H., Johnsen, J.O., Metz, J.H.M., Groot Koerkamp, P.W.G., Uenk, G.H., Phillips, V.R., Holden, M.R., Sneath, R.W., Short, J.L., White, R.P. & Wathes, C.M., Temperature and Moisture Conditions in Livestock Buildings in Northern Europe. *J. Agric. Eng. Res.* **70**, pp. 49-57, 1998.

www.witpress.com, ISSN 1743-3541 (on-line)

[25] Takai, H., Pedersen, S., Johnsen, J.O., Metz, J.H.M., Groot Koerkamp, P.W.G., Uenk, G.H., Phillips, V.R., Holden, M.R., Sneath, R.W., Short, J.L., White, R.P., Hartung, J., Seedorf, J., Schroder, M., Linkert, K.H., & Wathes, C.M., Concentrations and Emissions of Airborne Dust in Livestock Buildings in Northern Europe. *J. Agric. Eng. Res.* **70**, pp. 59-77, 1998.
[26] Van Heyst, B., *Evaluation of Emission Factors for the Improvement of the Estimation Methodology for Particulate Matter from Agricultural Poultry Industry*, Environment Canada and University of Guelph, 2005.
[27] ASAE. Manure Production and Characteristics. *ASAE Standard,* 2005.
[28] Boadi, D., Ominski, K.H., Fulawaka, D.L. & Wittenberg, K.M., Improving Estimates of Methane Emissions Associated with Enteric Fermentation of Cattle in Canada by Adopting an IPCC (Intergovernmental Panel on Climate Change) Tier-2 Methodology. *Canadian Journal of Animal Science*, pp. 459-467, 2004.
[29] Leeson, S., *PM Emissions from the Canadian Poultry Industry II: Activity Factors*. Draft Report #5 to Environment Canada, 2005.
[30] TNO. The Co-ordinated European Programme on Particulate Matter Emission Inventories, Projections and Guidance (CEPMEIP) project, 2001 http://www.air.sk/tno/cepmeip/.
[31] AEA Technology. Atmospheric Emissions from Small Carcass Incinerator. *AEAT/ENV/R/0920,* **(3)**, 2002.

www.witpress.com, ISSN 1743-3541 (on-line)