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The impact of distance to the cereal plot on the annual emission of diesel exhaust caused by intra-farm transportation

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Abstract. Machines and heavy-duty vehicles used in agriculture are powered almost exclusively by diesel engines. Diesel engines make a significant contribution to air pollution in most European countries. Aside from the engine properties, their use affects the annual diesel exhaust (DE) emission. The enlarging of farm production areas results in longer travelling distances to plots, which cause a higher fuel consumption and annual DE emission. The aim of the present study is to explain annual DE caused by transportation of equipment and materials, depending on plot distance and tillage technology.

The calculation of annual DE emission is based on on-road transportation work hours related to cereal plot. In the process of composing a calculation model, all technology/technical equipment used during the whole crop year on the plot is taken into account. The model incorporates two components from the model designed by the author: the transport of field operation units (FOUs) and the transport of technological materials. The simulations include considered specific DE emissions for on-road transport of agricultural machines.

The simulations show that plot distance to the farm centre and tillage technology has significant impact on annual DE emission, especially on NO_X amount. The greater the distance from plot to the farm centre, the higher is the emission. The emission is lowest in the case of direct drilling and highest when conventional tillage is used. The average values for CO, NO_X, HC and PM are 7.2, 44.4, 2.6 and 1.9 g ha^{-1} km^{-1} respectively, in the case of conventional tillage.

Key words: crop year, exhaust emission, distance to the plot, cereal, tillage technology

INTRODUCTION

Machines and heavy-duty vehicles used in agriculture are powered almost exclusively by diesel engines which make a significant contribution to air pollution in most European countries (Lindgren & Hansson, 2002). Diesel fuel combustion results in the production of particulate matter (PM), as well as gaseous compounds, including NO_X (nitrogen oxides) and precursors of ozone. PM consists of an elemental carbon core with a large surface area to which hundreds of chemicals and transition metals are attached (Riedl & Diaz-Sanchez, 2005). Most mechanistic studies have attributed the pro-inflammatory and adjuvant effects of PM to these chemical constituents (Li et al., 2000). The majority of PM are classified as fine (2.5–0.1 μm) or ultra fine (< 0.1 μm) particles, but these primary PM can coalesce to form aggregates of varying sizes. It has been postulated that because smaller particles have a greater relative surface area, they should carry proportionally more chemicals and have greater biological effects (Oberdorster & Utell, 2002). Petroleum diesel exhaust (DE) exposure has been linked to several health effects, including lung cancer (Madden, 2008). Chehregani & Kouhkan (2008) conclude from their research that DE particles not only have toxic effect on organisms regarding the induction of allergy, but are also capable of causing allergen release, and induction of new pollen protein (allergen) formation.

Growing public concern with emissions, especially of NO_X and PM, and their impact on health and environment, has led to increasingly tighter regulations (Lindgren & Hansson, 2002). Stage III A emission standards in the European Union for non-road vehicles became effective from the beginning of 2006 until 2012, depending on the engine power (Saint-Gobain, 2009). US EPA standard Tier III A has been implemented since 2008. The subsequent challenge will be to effect category Stage III B and Tier III B of the emission standards as of 2011. This will call for extensive intervention in the engineering for engines and auxiliary aggregates (Agritechnica, 2009).

Aside from the engine properties, the use of machines impacts DE. The connection between fuel consumption and DE strongly depends on engine utilization (Hansson et al., 2001). Lindgren & Hansson (2002) studied the effects of varying engine control strategies and engine transmission characteristics on the engine emissions from agricultural tractors. They found that by using varying driving strategies and transmission characteristics, it is possible to influence the amount of emissions to a considerable extent without affecting the time or fuel consumption for the operation. However, for on-road transportation in the agricultural sector, only hourly emission has been studied; there is no literature available on researches for annual emission for transportation operation depending on cereal plot distance and tillage technology.

The annual amount of DE emitted by engines depends largely on the amount of fuel they consume during the crop year. Viil & Võsa (2006) show in their study that tillage technology plays a significant role in annual fuel consumption. The present author studied inputs and outputs in cereal production depending on tillage technology, plot area and plot distance to the farm centre (Tamm, 2009). The study indicated that annual fuel amount per hectare consumed for transportation depends on these factors as well. Many grain producers are trying to enlarge their arable land, as it is generally known that the use of a larger tillage area enables the farmer to minimize the prime price of grain (Suomi et al., 2003, Gwyer et al., 2005) and maximize capacity for profit. However, enlarging the area of farm production results in longer travelling distances to plots, which cause higher fuel consumption and the annual amount of DE.

The aim of the present study is to explain annual DE emission caused by transportation of equipment and materials; depending on plot distance and tillage technology. The experiments were conducted using computer model simulation. The approach was to calculate annual emission values for transportation of materials and machines during the crop year for cereals with respect to plot distance and tillage technologies. The simulated tillage technologies are direct drilling, minimised tillage and conventional tillage at different plot distances and areas. The results from this study are considered to be useful for cereal producers, to enhance their knowledge about the impact of the land use and technological options on air pollution.

MATERIALS AND METHODS

In the present study, the plot distance denotes the shortest route for an agricultural machine from farm centre to nearest entry point in the plot. The farm centre is the storage location for most of the farm's field operation units (FOUs) and technological materials (seed, fertilisers, plant chemicals, water and yield).

The calculation of annual DE emission is based on transportation work hours related to cereal plot. In the process of composing a calculation model, all technology/technical equipment used during the whole crop year on the plot is taken into account. The model incorporates two components from the model composed by the author (Tamm, 2009): both the on-road transport of FOUs and technological materials.

While calculating the on-road transportation duration of FOUs, it is considered that a field operation can be performed with several different FOUs and during numerous workdays on a plot. It is presumed that the operator returns with an FOU to the farm centre at the end of the work day.

In the case of on-road transporting materials, it is considered that several hauling cycles and numerous vehicles can be used for moving one type of material. The materials are differentiated by the class of the payload usage of transporters and this defines the factor of the payload usage of the wagon and transportation durations (Tamm, 2009).

The annual DE is calculated with formula:

$$Q = e_{ex} \xi N P \qquad (1)$$

where Q – annual DE emission (g), e_{ex} – specific DE emission (g kWh^{-1}), ξ – engine power usage during transportation time, N – nominative power of engine (kW) and P – transportation time (h).

The simulations take into account specific DE emissions for on-road transport of agricultural machines: CO – 1.3 g kWh^{-1}, NO_X – 8.02 g kWh^{-1}, HC (hydrocarbons) 0.46 g kWh^{-1} and PM 0.34 g kWh^{-1} (Lindgren & Hansson 2002).

The cereal production data chosen for the simulations were previously used in the calculations for economic comparison of different pre-sowing tillage and sowing technologies (direct drilling, conventional, and minimum tillage) (Tamm, 2009). The machinery was chosen considering an average Estonian cereal production family-farm where most machines are farm-owned. This is not necessarily the best or optimum machinery, but the opinions stated here are those of experts at the Estonian Research Institute of Agriculture. In the calculations, for the purpose of simplification, it is assumed that all travels related to the plot start from the farm centre (Tamm, 2009). The present calculations are made for spring cereal plots, which account for the largest portion of Estonian farming.

The operational performances and hourly fuel consumption of the field operation units depend on tractors. The machinery includes two tractors with engine powers of 100 kW and 75 kW (T1 and T2 in tables). In all variations, the length of the work day is calculated to be 8 h, with a time loss factor of 0.85. The average workday length factors in loss of workdays due to unsuitable weather conditions. The on-road transportation speed is considered to be 30 km h^{-1} for the tractor and 20 km h^{-1} for the combine. The engine power usage during transportation time is considered to be 40% from nominative power (Hansson et al. 2001). The cereal production FOUs used in simulated technologies are presented in Table 1. The farm has two trailers designated H1 and H2; the water tank is (VT) (Table 2). In Estonia, approximately 50% of the agricultural plots range from 10–50 ha (Tamm, 2009). The plot area, 16 ha, used in present simulations, is chosen from that interval. The transportation hours used in calculations for plot distance 20 km are used as the example shown in Tables 1 and 2. These values differ for other plot distances and areas.

Table 1. The on-road transportation time of FOU if plot area is 16 ha and the distance is 20 km, for different tillage technologies (Tamm, 2009).

FOU	Engine power, kW	The on-road ransportation time, h		
		Conventional	Minimum	Direct drilling
Tedding	75			1.3
Stubble ploughing	100	1.3	1.3	
Ploughing (T1)	100	2.6		
Ploughing (T2)	75	2.6		
Cultivating	75	1.3	1.3	
Drilling	100	1.3	1.3	1.3
Harrowing	100	1.3	1.3	
Spraying	100	1.3	1.3	1.3
Spraying	100	1.3	1.3	1.3
Spraying	100	1.3	1.3	1.3
Combine	300	6	6	6

Table 2. The on-road transportation time of materials if plot area is 16 ha and the distance is 20 km for all tillage technologies (Tamm, 2009).

Material	Amount, kg ha^{-1}	Usage rate of payload	Transportation unit	Payload, t	Transportation time, h
Barley seed	230	1	T1+H1	10	1.33
NPK-fertilizer	300	1	T1+H1	10	1.33
Water for spraying	3×300	1	T2+VT	5	4
Yield of barley	2250	1	T1+H1	10	4
Yield of barley	2250	1	T2+H2	10	4

RESULTS AND DISCUSSION

Figure 1 shows that plot distance essentially affects the sum of the annual DE emissions. The average difference of this parameter is 560 g ha^{-1} km^{-1} in the case of conventional tillage. Evaluation of single DE components shows that distance has the biggest impact on NO_X (Figure 2) because it has a relatively high content in DE compared to other studied components. The average change of CO, NO_X, HC and PM is 7.2, 44.4, 2.6 and 1.9 g ha^{-1} km^{-1} respectively in the case of conventional tillage.

The farther the distance from plot to farm centre, the greater is the influence of the tillage technology on the annual amount of DE emissions (Figure 1). The conventional technology affects emissions depending on plot distance more than other technologies because of a bigger number of FOUs needed to transport to the plot as compared to other technologies (Table 1). Direct drilling has the least impact on annual DE emission. The anomalies in the lines on the graphs (Figs. 1–2) are caused by changes in the number of travelling times related to the specific work or material transported. Among machines, the combine has highest impact on the annual DE emissions because of its large engine power and relatively long transportation duration. The latter is caused by low transport speed in combination with a dramatic shortening of the daily harvesting time and the need for more visits to the plot, especially in the case of a large plot and long distance.

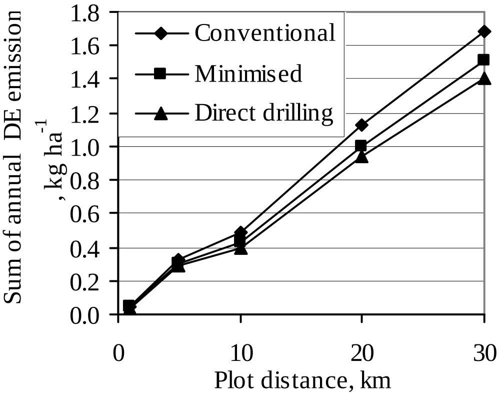

Figure 1. Sum of annual DE emission (CO + NO_X + HC+PM) depending on plot distance and tillage technology.

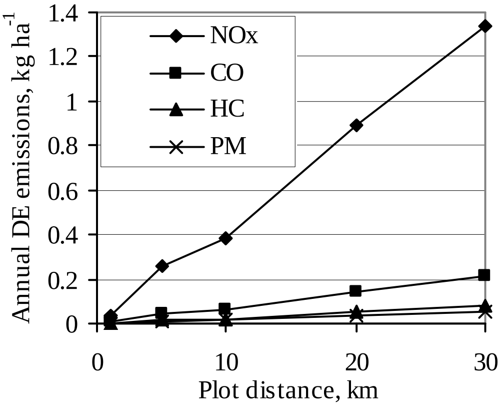

Figure 2. Annual DE emission for different polluting components depending on plot distance in the case of conventional tillage.

The average CO, NO_X, HC and PM emission per one transportation hour is 79.6, 491.5, 28.2 and 20.8 g h^{-1} respectively. These figures are bigger than values published by Lindgren & Hansson (2002), which are 55.3, 393.2, 22.4 and 16.7 g h^{-1} respectively for an 81 kW tractor. The probable reason is that the engine load 40% chosen in the present simulation for transportation of a 300 kW combine and a 100 kW tractor with an unloaded wagon is too high. Hansson et al. (2001) report possible power usage of 40 % for transport and 15% for low-load transport with a 70 kW tractor. There is a lack of data in the literature about engine power usage of combines during on–road transportation; further investigation is needed. According to Lindgren & Hansson (2002) the CO, NO_X, HC and PM emission values for harrowing with the same tractor per one operation hour are 40.2, 563.8, 17.8 and 14.9 g h^{-1}, respectively. The difference between the transportation and the soil cultivation scenario is caused by the different power requirements – 49 and 59 kW, correspondingly.

The present calculation model incorporates two components: the transport of FOUs and the transport of technological materials (seed, fertilisers, plant chemicals, water and yield). A third component can also affect annual DE emission - management drives (e.g. plot inspection, transport of labour, spare parts, etc.). The model for calculation of annual DE emission depending on cereal plot distance will also be complemented with the third component to offer cereal producers a better overview of the impact of production options on air pollution.

CONCLUSIONS

Plant producers can influence the annual DE emissions by their planning of land usage and the choice of technologies. Summarised results of the simulation experiment have shown that cereal plot distance to the farm centre and tillage technology has a significant impact on annual DE emission, especially on NO_X amount. The greater the distance from plot to farm centre, the higher is the annual DE emission. Annual DE emission is lowest in the case of direct drilling and highest when conventional tillage is used. The model used for calculating annual DE emissions needs complementary development to improve predicting of annual DE emission caused by on-road travels between plot and farm centre in cereal production.

REFERENCES

Agritechnica 2009. Machinery and Equipment Trends at Agritechnica 2009. Cited 11 November 2009. Updated October 2009. http://youtractor.com/blog/farm-machinery/machinery-and-equipment-trends-at-agritechnica-2009/.

Ahlgren, S., Baky, A. Bernesson, S., Nordberg, Å., Norén, O. & Hansson, P.-A. 2008. Future fuel supply systems for organic production based on Fischer–Tropsch diesel and dimethyl ether from on-farm-grown biomass. *Biosystems Engineering* **99**, 145–155.

Chehregani, A., & Kouhkan, F. 2008. Diesel exhaust particles and allergenicity of pollen grains of Lilium martagon. *Ecotoxicology and Environmental Safety* **69**, 568–573.

Fredriksson, H., Baky, A., Bernesson, S., Nordberg, Å., Norén, O. & Hansson, P.A. 2006. Use of on-farm produced biofuels on organic farms – evaluation of energy balances and environmental loads for three possible fuels. *Agricultural Systems* **89**, 184–203.

Gwyer, B., King, T., McKenzie, B. & Stothers, S. 2005. Land Expansion: Establishing Values and Options. *Manitoba Agriculture, Food and Rural Initiatives*. Cited 30 August 2007. Updated May 2005: http://www.gov.mb.ca/agriculture/ financial/farm/cap07s01.html.

Hansson, P.-A., Lindgren, M., & Norén, O. 2001. A Comparison between different methods of calculating average engine emissions for agricultural tractors. *Journal of Agricultural Engineering Research*, **80**, 37–43.

Li, N., Venkatesan, M.I., Miguel, A., Kaplan, R., Gujuluva, C. & Alam, J.et al. 2000. Induction of heme oxygenase-1 expression in macrophages by diesel exhaust particle chemicals and quinones via the antioxidant-responsive element, *J Immunol* **165**, 3393–3401.

Lindgren, M. & Hansson, P. -A. 2002. Effects of Engine Control Strategies and Transmission Characteristics on the Exhaust Gas Emissions from an Agricultural Tractor. *Biosystems Engineering*, **83**, 55–65.

Madden, M. C. 2008. Complex issues with examining diesel exhaust toxicity: Is the task getting easier or harder? *Experimental and Toxicologic Pathology* **60**, 135–140.

Oberdorster, G. & Utell, M.J. 2002. Ultrafine particles in the urban air: to the respiratory tract – and beyond? *Environ Health Perspect* **110**, A440–A441

Riedl, M., & Diaz-Sanchez, D. 2005. Biology of diesel exhaust effects on respiratory function. *Journal of Allergy and Clinical Immunology* **115**, 221–228.

Saint-Gobain. 2009. Emission standards in the European Union for non-road vehicles. http://www.ceraclean.com/en/download/NonRoad_EU.pdf Cited 11 November 2009. Updated November 2008.

Suomi, P., Lötjönen, T. & Mikkola, H. 2003. Modelling of grain harvesting and storing. *Nordic Association of Agricultural Scientists 22nd Congress*, July 1–4 2003, Turku, Finland.

Tamm, K. 2009. The dependency on the structure of machinery and the locality of plots on cereal farm work activities. A thesis for applying for the degree of Doctor of Philosophy in Agricultural Machinery. Estonian University of Life Sciences. Tartu. 127 pp.

Viil, P. & Võsa, T. 2006. Influence of Differentiated Soil Tillage on Crop Yield. – *Transactions of ERIA* **71**, 315–326.