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Analysis of Air Pollutant Emission Inventory from Farm Tractor Operations in Korea †

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Abstract: Due to the decline in agricultural labor force and rapid aging of farmers, agricultural machinery is becoming larger, higher-performance, and diversified. Tractors use diesel combustion in various operations and emit a number of pollutants, which are the primary and secondary sources for particulate matter (PM) and other air pollutants. In this study, an air pollutant emission inventory for tractor was analyzed and compared with the inventory developed by a national agency. Riding tractors were divided into 3 sub-categories based on engine size. In addition, tractor emissions were classified according to the usage time of each operation. Eight air pollutants such as CO, NOx, SOx, TSP, VOCs, PM_{10}, $PM_{2.5}$ and NH_3 were included in the inventory. Geographic information system (GIS) was used to spatially assign air pollutants variables into 17 provinces and metropolitan cities in the Republic of Korea. The results showed that the total yearly emissions in 2017 were 3,298 Mg/yr, 9,110 Mg/yr, 4 Mg/yr, 567 Mg/yr, 756 Mg/yr, 567 Mg/yr, 522 Mg/yr and 33 Mg/yr for CO, NOx, SOx, TSP, VOCs, PM_{10}, $PM_{2.5}$ and NH_3 respectively. The results also showed that total pollutant emissions of tractors were increased 10% compared to the emission inventory developed by a national agency.

Keywords: Farm Tractor; Diesel Emission; Air Pollutant; Emission Inventory; Geographic Information System

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1. Introduction

Tractors are the main power machines used in agricultural work. Farm tractors are used in a variety of agricultural operations, with most work equipment attached and used in agriculture. Tasks such as farmland cultivation, leveling, sowing, fertilizer, and composting will begin at the beginning of the year. During crop cultivation and harvesting, tractors perform tasks such as loader, bailing, and transportation. At the end of 2020, the total number of small, medium and large tractors exceeded 300,000, and the diesel consumption of agricultural free-tax oil in 2019 reached 824,935 kl [1, 2].

The production process of agricultural products has a great impact on the environment. Most of the impact is related to mechanization, especially tractor emissions [3]. Agricultural machinery is an important non-road vehicle source that can emit multiple pollutants and make a primary and secondary contribution to air pollution [4]. non-road vehicle in the contribute significantly to energy consumption and air pollution. These types of vehicles are mostly diesel fuel, which has proven to be a major source of nitrogen compounds (NOx) and particulate matter (PM) [5]. The engine of a tractor operating in agriculture burns a large amount of fuel and emits combustion gas [6].

Air pollutants PM, NOx, CO, VOCs, etc. emitted by agricultural machinery and diesel internal combustion engines have a great impact on the surrounding environment and human health [7]. Since the exhaust gas of the internal combustion engine is not applied when evaluating industrial indicators and economic indicators, it is not possible to immediately know the numerical values and influence. However, when the air that people breathe is polluted and agricultural products are cultivated on contaminated agricultural land, or when polluted water is used, human health is adversely affected. [9, 10].

Algirdas Janulevičius [11] collected data on engine load, fuel consumption and operating modes to study emissions characteristics during tractor operations, and presented the average fuel consumption and CO, CO_2, and NOx emissions of the engine. Daniela Lovarelli analyzed [12] air pollutants emitted from ploughing, spike harrowing, sowing and rolling operations with engine exhaust gases emissions analyzer (CO_2, CO and NOx).

To calculate the emissions of air pollutants in agricultural machinery, the National Institute of Environmental research of the Republic of Korea uses Tier 3 methodology of the EMEP/EEA(European Monitoring and Evaluation Programme/European Environment Agency) Guidebook, which is technology stratified by equipment. The type and number of agricultural machinery holdings, average annual activity, load factor, average rated power, etc. determine the amount of agricultural machinery air pollutants emitted. The tractor holdings used to calculate the air pollution emissions of tractors is not classified according to small, medium, large, and size, and the total number of tractors is used, so the accuracy of emission drops. In addition, the average rated output is fixed at 33.1 kW, which was studied in 1999, and does not reflect the average rated output due to the automation and upsizing of tractors. Reflecting these matters, this research intends to advancement the air pollution emissions of internal combustion engines of agricultural machinery.

In this study, the inventory of air pollutants generated by farm tractor operations including walking and riding tractors were calculated and analyzed. Riding tractors were further divided into 3 subcategories according to their engine power outputs for more precise investigation. Eight types of air pollutants, including CO, NOx, SOx, TSP, PM_{10}, $PM_{2.5}$, VOCs and NH_3, were calculated using the number of tractors and their operating hours in 2017, and the spatial distribution of the pollutants was visualized by geographic information system (GIS).

2. Materials and Methods

2.1. Estimation Method of Air Pollutant Emissions and Emission Factor

In this study, the emission of air pollutants (CO, NOx, SOx, TSP, PM2.5, VOCs, NH3) from farm tractor in the Korea were estimated for the based year 2017 by using the EMEP/EEA's Tier 3 methodology. For other pollutants, including CO, NOx, TSP, $PM_{2.5}$, VOCs, NH_3 the method of estimating the emissions the equation used is given below [13]:

$$E_{i,j} = \sum \{N_i \times HP_i \times LF \times HRS_i \times EF_{i,j}\} \quad (1)$$

Where $E_{i,j}$ (kg/yr) is total amount of air pollutants emitted, N_i (unit) is number of farm machinery holdings, HP_i (kW) is average rated power, LF (=0.48) is load factor, HRS_i (hr/yr) is average annual activity, $EF_{i,j}$ (kg/(kWh-unit)) is emission factor, i is farm machinery type, j is air pollutant type.

For SOx emissions, the fuel consumption coefficient according to the rated output of the farm tractor is applied to the sulfur content (Equation 2).

$$EF = FF(g/kWh\text{-}unit)/1000 \times k \times \text{fuel sulfur weight percent } (\%) / 100 \quad (2)$$

Where EF (kg/(kWh-unit)) is emission factor, FF (g/(kWh-unit)) is fuel consumption coefficient, k (=2.0) is constant (grams of SOx formed from one gram of sulfur).

Table 1 shows the air pollutant emission factors by tractors for the farm tractor.

Table 1. Emission factors of farm tractors.

Machinery	Emission factor(kg/kWh-unit)						
	CO	NOx	TSP	$PM_{2.5}$	VOCs	NH_3	SOx
Walking Tractor (Power Tiller)	6.80	13.60	1.36	1.251	0.48	0.00004	5.42
Riding Tractor	2.48	7.84	0.39	0.359	0.48	0.00003	5.38 5.30 5.30

2.2. Average Annual Activity Hours of Farm Tractors

Activity hours of agricultural tractors, were obtained from the Survey on the utilization of Agricultural Machinery and Farmwork Mechanization Rate published by the Rural Development Administration (RDA). Table 2 shows the types of agricultural tractors and the annual activity hours associated with agricultural operation [14].

Table 2. Average annual activity hours of farm tractors.

Operation type [4]	Average activity hours (hr/yr)	
	Walking tractor (Power tiller)	Riding tractor
TL	1.8	20.4
LL	-	16.1
HW	4.9	50.6
FS	-	8.1
PP	18.3	-
CS	-	6.1
SY	22.9	-
LD	-	30.6
BL	-	3.4
TP	41.3	15.9
Others	2.2	13.7
Total	91.4	164.8

[4] TL: Tilling, LL: Leveling, HW: Harrowing, FS: Fertilizer spreading, PP: Pumping, CS: Compost spreading, SY: Spraying, LD: Loading, BL: Baling, TP: Transporting.

2.3. Number Holdings and Average Rated Power of Farm Tractor

The number of farm tractor could be directly obtained from the Agricultural Machinery Holdings Survey yearbook [15]. As of 2017, the total number of agricultural machinery registered in South Korea is 1,918,745. Among them, farm tractors are 857,216 units, account for 45 percent. The holding status of farm tractors was shown in Table 3.

Farm tractors include a two wheeled walking tractor(power tiller) and four wheeled riding tractor. in this study, walking tractors and riding tractors Air pollutants are calculated, and riding tractors were further divided into 3 subcategories according to their engine power outputs for more precise investigation. The riding tractor can be divided into small, medium and large according to the diesel engine power. The range of small, medium and large engine power of riding tractor is less than 29.4 kw, more than 29.4 kw and less than 44.1 kw, and more than 44.1 kw, respectively. Average Rated Power is defined as a weighted average value with a normal distribution and is calculated by the number of tractors and the rated power.

Table 3. Registration status of farm tractors in Korea as of 2017 and Average rated power.

Machinery	Size(ARP range) [2]	ARP(kW) [3]	Unit(ea)
Walking Tractor(Power Tiller)	-	6.7	567,070
Riding Tractor	S(kW < 29.4)	23.0	73,403
	M(29.4 ≤ kW < 44.1)	39.0	148,538
	L(44.1 ≤ kW)	52.1	68,205
	Sub total		290,146

[2] S: Small, M: Medium, L: Large. [3] ARP: Average rated power. ARP rated power is defined as a weighted average value and calculated from the number of tractors and their rated power.

2.4. Geographic Information System(GIS)

To calculate the domestic spatial distribution of total air pollutant emissions from farm tractors, an open source geographic information system (GIS) software (QGIS, Windows 10) was used for 9 provinces and 8 metropolitan cities.

3. Results and Discussion

The air pollutant emission inventory for farm tractor usage in Korea was refined by categorizing the rated power of tractors and the types of operation tractors routinely perform. Table 4 and Figure 1 shows the calculated inventory. In 2017, yearly amounts of CO, NOx, SOx, TSP (incl. PM_{10}), $PM_{2.5}$, VOCs, and NH_3 emitted from agricultural tractors were predicted to be 3,300 Mg, 9,110 Mg, 4 Mg, 567 Mg, 522 Mg, 759 Mg, and 33 Mg, respectively. The yearly amounts of total air pollutants emitted from one unit of walking tractors, small, medium, and large riding tractors were estimated to be 7.0 kg, 20.5 kg, 34.6 kg, and 46.3 kg, respectively.

Table 4. Calculated amounts of air pollutant substances emitted from farm tractor operations in 2017 (unit: Mg/yr).

Machinery		CO	NOx	SOx($\times 10^2$)	TSP	PM_{25}	VOCs	NH_3($\times 10^1$)
Walking Tractor (Power Tiller)		1,132	2,260	60.5	226	208	340	66.6
Riding Tractor	Small	332	1,049	48.2	52.2	48.0	64.2	40.1
	Medium	1,137	3,590	162.7	178.7	164.5	220	137.5
	Large	697	2,200	99.8	109.6	100.9	134.9	84.3
	Sub Total	2,170	6,850	311	341	313	419	262
Total		3,300	9,110	371	567	522	759	329

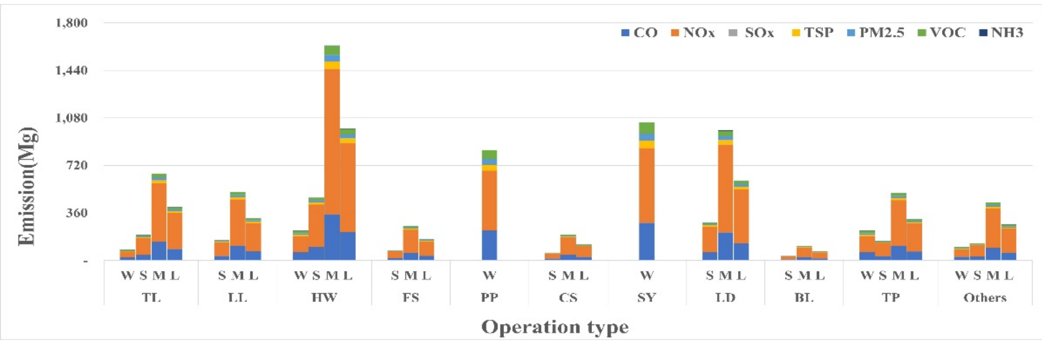

Figure 1. Calculated amount of air pollutant substance various farming practices by farm tractors. (TL: Tilling, LL: Leveling, HW: Harrowing, FS: Fertilizer spreading, PP: Pumping, CS: Compost spreading, SY: Spraying, LD: Loading, BL: Baling, TP: Transporting, W: Walking tractor, S: Riding tractor small, M: Riding tractor medium, L: Riding tractor large).

Looking at the average activity hours by type of farm tractor, walking tractor is mainly used for transporting, pumping and spraying operation, and riding tractor is mainly used for tilling, harrowing and loading operating. As the area of cultivated land increases and the size of the tractor increases, the riding tractor replaces the tilling and harrowing operations that the walking tractor used to do in the past. The most emitted air pollutant in the transporting operations, which is the main work of walking tractor, is NOx 1,023 Mg/yr, and the emission of $PM_{2.5}$, which is the main concern of air pollution, is 153.5 Mg/yr. Riding tractors mainly emit a large amount of CO and NOx, and are emitted in the order of medium size, large size, and small size. The NOx emissions from the by engine output of the Riding tractor are as follows. The harrowing operation is medium size 1,103 Mg/yr, large size 676 Mg/yr, small size 322 Mg/yr, and the tilling work is medium size 445 Mg/yr, large size 273 Mg/yr, small size 130 Mg/yr. Farm tractor operation needs to be done efficiently to reduce air pollutant emissions from farm tractors.

Our results of air pollutant emission inventory for farm tractors were 10% more than those established by the NIER. The discrepancy should be due to the way how to assign values for average rated power of riding tractors. The NIER used a single value of 33.1 kW for all 209,149 tractors, while values of 23, 39, and 52.1 kW were used to represent 73,403 small size, 148,538 middle size, and 68,205 large size tractors, respectively, in this study. The spatial distribution of the total amount of tractor air pollutant emission in Korea were generated at the province metropolitan city-level using a GIS technique, as shown in Figure 2.

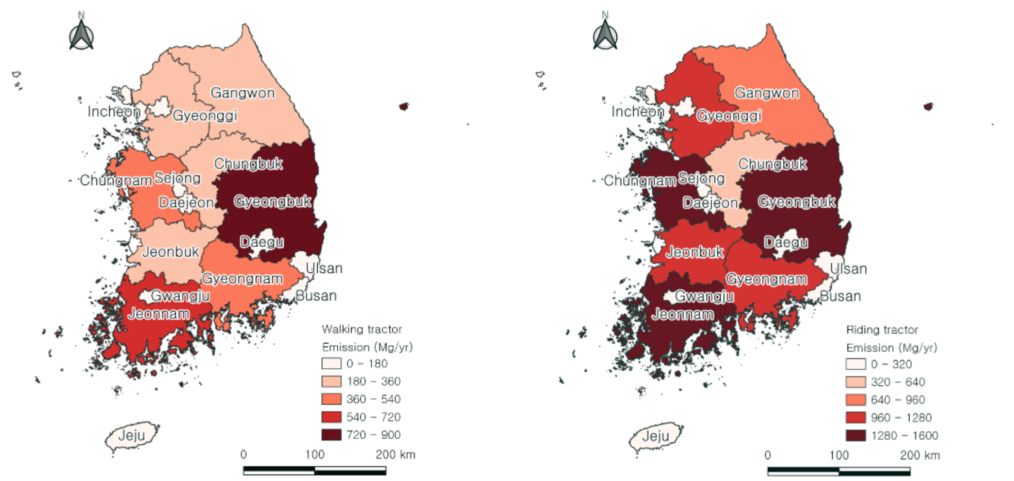

Figure 2. Spatial distribution of the total calculated air pollutant substances emitted from walking tractors (left) and riding tractors (right) over 9 provinces and 8 metropolitan cities in the Korea.

4. Conclusions

In this study, the air pollutant emission inventory of Korean farm tractors was refined by using the EEA tier 3 methodology. The air pollutant emission inventory for farm tractor usage in Korea was refined by categorizing the rated power of tractors and the types of operation tractors perform. Yearly amounts of CO, NOx, SOx, TSP(incl. PM_{10}), $PM_{2.5}$, VOCs, and NH_3 emitted from farm tractors were predicted to be 3,298 Mg, 9,110 Mg, 3.7 Mg, 567 Mg, 522 Mg, 756 Mg, and 33 Mg, respectively. Among the non-road vehicle pollutants calculated by the National Institute of Environmental Research (NIER) Air Policy Support System (CAPSS, Clean Air Policy Support System) in 2017, the emissions of agricultural machinery are CO 3,018 Mg/yr, NOx 8,223 Mg/yr, SOx 3 Mg/yr, TSP(incl. PM_{10}) 523 Mg/yr, $PM_{2.5}$ 481 Mg/yr, VOCs 705 Mg/yr, and NH_3 29 Mg/yr [16]. Our results of air pollutant emission inventory for farm tractors were 10% more than those established by the NIER. The discrepancy should be due to the way how to assign values for average rated power of riding tractors.

The farm tractor's agricultural walking tractor emitted the most diesel emissions during the transportation process, and the riding tractor emitted the most amount of diesel emissions during the tilling, harrowing, and loading operations. In order to reduce the air pollutants emitted by inefficient agricultural operating, it is necessary to analyze the working style of the farm tractor in detail. It is necessary to predict future air pollutant emissions through past farm tractor air pollutant inventory analysis.

5. Patents

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References

1. MAFRA. *Agricultural Machinery Holdings Survey 2020.*; Ministry of Agriculture, Food and Rural Affairs, Sejong, Korea, 2020; pp. 10.
2. NHCF. *Agricultural cooperative yearbook 2020.*; National Agricultural Cooperative Federation, Seoul, Korea, 2020; pp. 209.
3. Bacenetti, J.; Lovarelli, D.; Facchinetti, D.; Pessina, D. An environmental comparison of techniques to reduce pollutants emissions related to agricultural tractors. *biosystems engineering* **2018**, *171*, 30-40.
4. Lang, J.; Tian, J.; Zhou, Y.; Li, K.; Chen, D.; Huang, Q.; Xing, X.; Zhang, Y.; Cheng, S. A high temporal-spatial resolution air pollutant emission inventory for agricultural machinery in China. *Journal of Cleaner Production* **2018**, *183*, 1110-1120.
5. Zhao, Y.; Qiu, L.P.; Xu, R.Y.; Xie, F.J.; Zhang, Q.; Yu, Y.Y.; Nielsen, C.P.; Qin, H.X.; Wang, H.K.; Wu, X.C.; Li, W.Q.; Zhang, J. Advantages of a city-scale emission inventory for urban air quality research and policy: the case of Nanjing, a typical industrial city in the Yangtze River Delta, China. *Atmospheric Chemistry and Physics* **2015**, *15*, 12623-12644.
6. Janulevicius, A.; Juostas, A.; Pupinis, G. Engine performance during tractor operational period. *Energy Conversion and Management* **2018**, *68*, 11-19
7. Zhou, W.; Chen, C.; Lei, L.; Fu, R.; Sun, Y. Temporal variations and spatial distributions of gaseous and particulate air pollutants and their health risks during 2015–2019 in China. *Environmental Pollution* **2021**, *272*, 116031
8. Beak, K.M.; Kim, M.J.; Kim, J.Y.; Seo, Y.K.; Beak, S.O. Characterization and health impact assessment of hazardous air pollutants in residential areas near a large iron-steel industrial complex in Korea. *Atmospheric Pollution Research* **2020**, *11*, 1754-1766.
9. Kim, L.S.; Jeon, J.W.; Son, J.Y.; Kim, C.S.; Ye, J.; Kim, H.J.; Lee, C.H.; Hwang, S.M.; Choi, S.D. Nationwide levels and distribution of endosulfan in air, soil, water, and sediment in South Korea. *Environmental Pollution* **2020**, *265*, 115035.
10. Enyoh, C.E.; Verla, A.W.; Qingyue, W.; Ohiagu, F.O.; Ohiagu, F.O.; Chowdhury, A.H.; Enyoh, E.C.; Chowdhury, T.; Verla, E.N.; Chinwendu, U.P. An overview of emerging pollutants in air Method of analysis and potential public health concern from human environmental exposure. *Trends in Environmental Analytical Chemistry* **2020**, *28*, e00107.
11. Janulevicius, A.; Juostas, A.; Pupinis, G. Engine performance during tractor operational period. *Energy Conversion and Management*, **2013**, *68*, 11-19.
12. Lovarelli, D.; Fiala, M.; Larsson, G. Fuel consumption and exhaust emissions during on-field tractor activity: A possible improving strategy for the environmental load of agricultural mechanization. *Computers and Electronics in Agriculture*, 2018, 151, 238-248.
13. NIER. *A Handbook of Method for National Air Pollutant Emission Estimation*; National Institute of Environmental Research, Sejong, Korea, 2013; pp. 199-203.
14. RDA. *Survey on the Utilization of Agricultural Machinery and Farmwork Mechanization Rate*; Rural Development Administration, Jeonju, Korea, 2018, pp. 23-27.
15. MAFRA. *Agricultural Machinery Holdings Survey 2017.*; Ministry of Agriculture, Food and Rural Affairs, Sejong, Korea, 2018; pp. 12.
16. National Air Pollutants Emission Service. Available online: https://airemiss.nier.go.kr/user/boardList.do?handle=160&siteId=airemiss&id=airemiss_030500000000 (accessed on 5 May 2021).