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

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Abstract: Due to the decline in the agricultural labor force and rapid aging of farmers, agricultural machinery is becoming larger, higher-performance, and diversified. In this study, an air pollutant emission inventory for agricultural tractors was analyzed and compared with the inventory developed by a national agency. Agricultural tractors include walking and riding tractors and, further, riding tractors were divided into three subcategories based on their engine size. In addition, tractor emissions were classified according to the usage time of each operation. Seven air pollutants, such as CO, NO_x, SO_x, TSP, VOCs (PM₁₀), PM_{2.5}, and NH₃, were included in the inventory. The results showed that the total yearly emissions in 2017 were 3300 Mg, 9110 Mg, 4 Mg, 567 Mg, 522 Mg, 759 Mg, and 33 Mg for CO, NO_x, SO_x, TSP, VOCs, PM₁₀, PM_{2.5}, and NH₃, respectively. The most emitted air pollutant in the transporting operation using walking tractors is NO_x, and the amount of emission is 1023 Mg/y. Riding tractors mainly emit a large amount of NO_x, in the order of medium, large, and small tractors. The NO_x emissions from medium, large, and small riding tractors are 1103 Mg/y, 676 Mg/y, and 322 Mg/y, respectively, from harrowing operations and are 445 Mg/y, 273 Mg/y, and 130 Mg/y, respectively, from tilling operations. The results also showed that the total pollutant emissions from tractors were increased 10% compared to the emission inventory developed by a national agency due to categorizing riding tractors into three subcategories. A geographic information system (GIS) was used to spatially assign air pollutant variables to 17 provinces and metropolitan cities in Korea.

Keywords: agricultural tractor; diesel emission inventory; air pollutant; 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, fertilizing, and composting will begin at the beginning of the year. During crop cultivation and harvesting, tractors perform tasks such as loading, 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 vehicles need a large quantity of fossil fuels and their emissions cause significant air pollution problems. These types of vehicles mostly use diesel fuel, which has proven to be a major source

of nitrogen compounds (NO_x) 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, such as PM, NO_x, CO, volatile organic compounds (VOCs), etc., emitted by agricultural machinery and diesel internal combustion engines have a great impact on the surrounding environment and human health [7,8]. 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 [6] 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, CO₂, and NO_x emissions of the engine. Daniela Lovarelli analyzed [11] air pollutants emitted from ploughing, spike harrowing, sowing, and rolling operations with an engine exhaust gases emissions analyzer (CO₂, CO, and NO_x).

To calculate the emissions of air pollutants in agricultural machinery, the National Institute of Environmental Research of the Republic of Korea uses the 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, and large size; 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 make advancement in 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 three subcategories according to their engine power outputs for more precise investigation. Seven types of air pollutants, including CO, NO_x, SO_x, total solid particle (TSP), PM_{2.5}, VOCs, and NH₃, were calculated using the agricultural tractor inventory data and operating hours in 2017, and the spatial distribution of the pollutants was visualized by a 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, including CO, NO_x, SO_x, TSP, PM_{2.5}, VOCs, and NH₃, from farm tractors in the Korea was estimated for the year 2017 by using the EMEP/EEA's Tier 3 methodology. For air pollutants, including CO, NO_x, TSP, PM_{2.5}, VOCs, and NH₃, the amount of emissions was calculated using the equation given below [12]:

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

where, $E_{i,j,k}$ is the total amount of air pollutant emitted from a specific region (kg/y); $N_{i,k}$ is the number of tractors in a specific region (each); HP_i is the average rated power of tractor (kw); LF is the load factor of agricultural practice (=0.48); HRS_i is the average annual activity of tractors (hr/y); $EF_{i,j}$ is the emission factor (kg/(kWh-each)); i is agricultural tractor type ($i = 1, \dots, 4$); j is the type of air pollutant ($j = 1, \dots, 7$); and k is region ($k = 1, \dots, 17$).

For SO_x emissions, the fuel consumption coefficient, according to the rated output of the farm tractor, is applied to the sulfur content, and the emission factor is calculated by the following Equation (2):

$$EF_i = FF_i \text{ (g/kWh-each)} / 1000 \times m \times \text{Fuel sulfur weight percent (\%)} / 100 \quad (2)$$

where EF_i is emission factor (kg/(kWh-each)); FF_i is fuel factor (g/(kWh-each)); m is constant (=2.0) (grams of SO_x formed from one gram of sulfur); and i is farm tractor type ($i = 1, \dots, 4$).

Table 1 shows the air pollutant emission factors of agricultural tractors.

Table 1. Emission factors of farm tractors.

Machinery	Emission Factor (kg/kWh-Unit)						
	CO	NO _x	TSP	PM _{2.5}	VOCs	NH ₃	SO _x
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 Agricultural Tractors

Activity hours of agricultural tractors were obtained from the survey on the utilization of agricultural machinery and farm-work mechanization rates published by the Rural Development Administration (RDA) in Korea. Table 2 shows the types of agricultural tractors and the annual activity hours associated with various agricultural operations [13].

Table 2. Average annual activity hours for various operations of agricultural tractors.

Operation Type ¹	Average Activity Hours (hr/y)	
	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

¹ 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 of Holdings and Average Rated Power of Agricultural Tractor

The number of agricultural tractors was directly obtained from the Agricultural Machinery Holdings Survey yearbook [14]. As of 2017, the total number of agricultural machines, such as tractors, rice transplanters, combine harvesters, etc., registered in Korea was 1,918,745 units. Among them, agricultural tractors were 857,216 units, accounting for 45% of total agricultural machinery in Korea. The holding status of agricultural tractors is shown in Table 3.

Agricultural tractors include a two-wheeled walking tractor (power tiller) and a four-wheeled riding tractor. In this study, air pollutants emitted from walking and riding tractors were 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 engine power for small, medium, and large riding tractors is less than 29.4 kw, equal and more than 29.4 kw and less than 44.1 kw, and equal 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. Average rated power and the number of agricultural tractors in Korea, as of 2017.

Machinery	Size ¹ (ARP Range)	ARP ² (kW)	Unit (ea)
Walking Tractor (Power Tiller)	-	6.7	567,070
Riding Tractor	S < 29.4 kW	23.0	73,403
	29.4 kW ≤ M < 44.1 kW	39.0	148,538
	44.1 kW ≤ L	52.1	68,205
Subtotal			290,146

¹ S: Small, M: Medium, L: Large. ² ARP: Average rated power. ARP 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 visualize the spatial distribution of total air pollutant emissions from agricultural tractors in Korea, a piece of 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 agricultural 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 show the calculated inventory. In 2017, yearly amounts of CO, NO_x, SO_x, TSP (PM₁₀), PM_{2.5}, VOCs, and NH₃ emitted from agricultural tractors were calculated as 3300 Mg, 9110 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 and small, medium, and large riding tractors were estimated to be 7.0 kg, 20.5 kg, 34.6 kg, and 46.3 kg, respectively.

Figure 1. Calculated amount of air pollutant substance various farming practices by agricultural 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: Small riding tractor, M: Medium riding tractor, L: Large riding tractor.

Looking at the average activity hours by type of agricultural tractor, walking tractors are mainly used for transporting, pumping, and spraying operations, and riding tractors are mainly used for tilling, harrowing, and loading operations. 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 the walking tractor, is NO_x, and the amount of emission is 1023 Mg/y, and the amount of emission of PM_{2.5}, which is the main concern of air pollution, is 153.5 Mg/y. Riding tractors mainly emit a large amount of CO and NO_x, in the order of medium, large, and small tractors. The NO_x emissions from medium, large, and small riding tractors are 1103 Mg/y, 676 Mg/y, and 322 Mg/y, respectively, from harrowing operations and are 445 Mg/y, 273 Mg/y, and 130 Mg/y, respectively, from tilling operations. Utilization of riding tractors needs to be done efficiently to reduce air pollutant emissions, especially from harrowing operations.

Table 4. Calculated amounts of air pollutant substances emitted from agricultural tractor operations in 2017 (Mg/y).

Machinery		CO	NO _x	SO _x ($\times 10^{-2}$)	TSP	PM _{2.5}	VOCs	NH ₃ ($\times 10^{-1}$)
Walking Tractor (Power Tiller)		1132	2260	60.5	226	208	340	66.6
Riding Tractor	Small	332	1049	48.2	52.2	48.0	64.2	40.1
	Medium	1137	3590	162.7	178.7	164.5	220	137.5
	Large	697	2200	99.8	109.6	100.9	134.9	84.3
	Subtotal	2170	6850	311	341	313	419	262
Total		3300	9110	371	567	522	759	329

Our air pollutant emission inventory results for agricultural tractors were 10% more than those established by the NIER. The discrepancy could be due to the way values were assigned for the average rated power of riding tractors. The NIER method 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 air pollutant emissions from agricultural tractors in Korea was 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 substance emitted from walking tractors (left) and riding tractors (right) over 9 provinces and 8 metropolitan cities in Korea.

4. Conclusions

In this study, the current air pollutant emission inventory of Korean agricultural tractors was refined by using the EEA Tier 3 methodology. The air pollutant emission inventory for agricultural tractor usage in Korea was calculated by categorizing the rated power of tractors into four subcategories. Yearly amounts of CO, NO_x, SO_x, TSP (including PM₁₀), PM_{2.5}, VOCs, and NH₃ emitted from agricultural tractors were calculated as 3298 Mg,

9110 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 were 3018 Mg/y of CO, 8223 Mg/y of NO_x, 3 Mg/y of SO_x, 523 Mg/y of TSP (including PM₁₀), 481 Mg/y of PM_{2.5}, 705 Mg/y of VOCs, and 29 Mg/y of NH₃ [15]. Our air pollutant emission inventory results for agricultural tractors were 10% more than those established by the NIER. The discrepancy could be due to the way values were assigned for the average rated power of riding tractors.

Walking tractors emitted the most diesel emissions during transportation operation, and riding tractors emitted the most air pollutant emissions during the tilling and harrowing operations. In order to reduce the air pollutants emitted by inefficient agricultural operations, it is necessary to analyze agricultural practices utilizing agricultural tractors in detail. It is necessary to predict future air pollutant emissions through past agricultural tractor air pollutant inventory analysis.

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