 doi:10.20944/preprints202112.0006.v1

Article

Comparison of Diesel Tractor Emissions in Korea

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Abstract: Due to the shortage of agricultural labor forces and rapid aging of farmers, the utilization of tractors is becoming popular and essential in Korea. Tractors can be classified into two types, a walking tractor called as a power tiller and a riding tractor. In this study, agricultural tractors including walking and riding types were categorized into 4 levels by rated output power. And diesel emission inventory of tractors was established and analyzed using 2011 and 2019 survey data in Korea. Emission inventory including CO, NOx, SOx, TSP(PM_{10}), $PM_{2.5}$, VOCs and NH_3 were established using Tier 3 methodology. The total amount of emission using agricultural tractors was decreased about 13% from 2011 to 2019. The number of walking tractors were decreased by about 19% in 8 years, on the other hand that of riding tractors were increased by about 12%. However, the emission reduction is about 48% for walking tractors and the emission increment is about 5% for riding tractors. Thus, the total emission from agricultural tractors was decreased by about 16% in those periods. It is due to the decrease of 21% and 15% in the hours of use of walking and riding tractors, respectively, in 2019. Walking tractors mainly emit air pollutants from spraying and transporting. Riding tractors mainly 61% of total air pollutants emits from soil preparation and transporting operations. Geographic information system (GIS) was used to spatially assign air pollutants variables into 17 provinces and metropolitan cities in Korea. High emission generating regions and changes of emissions during 8 years were clearly seen in GIS analysis. High air pollutant emitting regions are mainly located in the western and southern regions of Korea, which have plenty of arable areas compared to other regions in Korea.

Keywords: Agricultural Tractor; Diesel Emission; Air Pollutants; Emission Inventory; Geographic Information System

1. Introduction

In 2019, the total cultivated land in Korean was 1,643,465 ha, and the amount of production was 4,375x10^3 tons, 8,186 x10^3 tons, 2,206 x10^3 tons and 65 x10^3 tons of grain crops, vegetables, fruits, and specialty crops, respectively [1, 2]. Due to the decline of agricultural labor forces and rapid aging of farmers, the utilization of agricultural machinery is becoming popular. Recently, there is a trend that farmers are utilizing bigger size tractors comparing to 2010 in Korea [3]. The mechanization rate of rice farming is more than 99%, and that of the other major agricultural works in open field farming is about 62% in average in 2019 [4].

Tractor is a multi-purpose vehicle that performs major agricultural operations while driving with various implements such as a plow, a rotary, or a baler, and is frequently used in Korean agriculture [5, 6]. Tractors are used to do many agricultural practices such as tillage, harrowing, fertilizer and compost spreading, and transportation in almost every

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agricultural sector of grain, vegetable, fruit production, and livestock husbandry. Tractors usually use a diesel as a fuel and emit a lot of pollutant substances which are primary and secondary sources of particulate matter (PM) and the other air pollutants. PM is considered as one of the most concerning air pollutants due to its effect on human health and environment both in urban and rural area [7, 8, 9, 10, 11, 12, 13]. The non-road mobile machinery sector including tractors largely contributes to the emissions of PM10 and PM2.5, being responsible for 7.4% and 16.4% of the total emissions respectively [14].

An emission inventory can show the temporal and spatial distributions and changes in pollutants in a certain area over a period of time. Currently, the global level non-road machinery activities and emission data are difficult to obtain, and the development of emission models and inventories is still being undertaken. Only the NONROAD model, developed by the U.S. Environmental Protection Agency (EPA), has been widely used [15].

Mobile sources can exhaust many kinds of pollutants including sulfur dioxide (SO_2), nitrogen oxides (NOx), total hydrocarbons (THC), carbon monoxide (CO) and particulate matter (PM)) during the process of fuel combustion. These pollutants can cause direct or indirect adverse influences to air pollution [16, 17, 18], human health [19, 20] and climate change [21, 22, 23]. For example, emitted PM could directly increase atmospheric particulate matter with a diameter below 2.5 μm (PM2.5) concentrations; as important fine particle precursors, SO_2 and NOx can transform into sulfate and nitrate, making a secondary contribution to the PM2.5 [24, 25].

In this study, a diesel emission inventory for agricultural tractors including 2 wheeled driving (2WD) and 4 wheeled driving (4WD) tractors was established and analyzed using 2011 and 2019 data in Korea by categorizing tractors in terms of their rated powers. Also, emission characteristics of seven air pollutants from various field operations was analyzed. In addition, the spatial distribution of the amount of eight pollutants was visualized by geographic information system (GIS) and was investigated on country scale.

2. Materials and Methods

2.1. Calculation of Air Pollutant Amount Emitted from Farm Tractor Operation

Emitted amounts of seven air pollutant substances due to tractor operation were calculated by the method of NIER [26]. The formula is shown in Equation (1):

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

where, $E_{i,j,k}$ is Total amount of air pollutant emitted from specific region (kg/yr); $N_{i,k}$ is Number of machinery of specific region (unit); HP_i is Average rated power of tractor (kw); LF is Load factor (=0.48); HRS_i is Average annual activity of tractor (hr/yr); $EF_{i,j}$ is Emission factor (kg/(kWh-unit)); i is Farm tractor type (walking, riding)(i=1, ···, 4); j is type of air pollutant(j=1, ···, 8); k is region(k=1, ···,10).

The NIER handbook gives the emission factors for CO, NOx, TSP, $PM_{2.5}$, VOCs, and NH_3 but the following equation is used to calculate the emission factor for SOx [21].

$$EF_i = FF_i \text{ (g/kWh-unit)} / 1000 \times 1 \times \text{Fuel sulfur weight percent(\%)} / 100 \quad (2)$$

where, EF_i is Emission factor (kg/(kWh-unit)); FF_i is Fuel factor (g/(kWh-unit)); l is constant (=2.0) (grams of SOx formed from one gram of sulfur); i is Farm tractor type (walking, riding)(i=1, ···, 4).

2.2. Number of Farm Tractors

In agricultural machinery statistic data from the Ministry of Agriculture, Food and Rural Affairs (MAFRA) in Korea, the number of agricultural tractors were categorized into two groups, a power tiller so called as a walking 2WD tractor and a farm tractor known as a riding 4WD tractor. The farm tractor group contains three subgroups, small, medium, large, categorized by tractor's engine rated powers. The Table 1 shows statistic

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data of tractors used in Korean agriculture in 2011 and 2019. Table 1 shows the number of tractors each year in Korea. Table 2 shows the average rated powers of diesel tractors used for calculating diesel emissions.

Table 1. Registration status of farm tractor in Korea.

Tractor Type	Engine Size (rated power range)	Unit (ea)	
		2011	2019
Power tiller	-	666,897	544,005
Farm Tractor	S [1](S≤29.4kW)	73,901	73,604
	M [2](29.4kW≤M<44.1kW)	142,856	150,283
	L [3](44.1kW≤L)	51,114	74,793
	Sub Total	267,871	298,680

[1] S: Small, [2] M: Medium, [3] L: Large.

Table 2. Average rated power of tractors.

Tractor Type	Engine Size (rated power range)	ARP [4] (kW)
Power tiller	-	6.7
Farm Tractor	S [1](S<29.4kW)	23.0
	M [2](29.4kW≤M<44.1kW)	39.0
	L [3](44.1kW≤L)	52.1

[1] S: Small, [2] M: Medium, [3] L: Large, [4] ARP: Average rated power.

2.2. Average Annual Operating Hours of Farm Tractor

Average annual operating hours are given in Table 3 according to tractor types as well as some typical agricultural practices. Survey data by the Rural Development Administration (RDA) on the utilization of agricultural machinery were used to identify the average annual operating hours of agricultural tractors [4, 27].

Table 3. Average annual operating hours of farm tractors.

Tractor type	Operation Type	Average Annual Activity (hr/yr)	
		2011	2019
Power Tiller	TL [1]	3.7	1.4
	HW [2]	6.1	3.8
	PP [3]	9.1	10.5
	SY [4]	25.2	19.9
	TP [5]	56.5	34.3
	Others	0.2	2.3
	Total	100.8	72.2
Farm Tractor	TL [1]	21.1	18.1
	HW [2]	31.5	44.6
	LL [6]	11.7	14.1
	FS [7]	6.9	8.2
	CS [8]	16.6	5.7
	LD [9]	13.2	23.4
	BL [10]	6.9	2.7
	TP [5]	29.1	14.0
	Other	13.9	9.1
	Total	153.7	139.9

[1] TL: Tilling, [2] HW: Harrowing, [3] PP: Pumping, [4] SY: Spraying, [5] TP: Transporting,

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[6] LL: Leveling, [7] FS: Fertilizer spreading, [8] CS: Compost spreading, [9] LD: Loading, [10] BL: Baling.

2.3. Emission Factor of Farm Tractor

Table 4 shows emission and fuel factors required to calculate the amount of six air pollutants emitted from agricultural tractors.

Table 4. Emission Factors of Six Air Pollutants of Agricultural Tractors.

Tractor Type	Size	Emission Factor(kg/kWh-unit)						
		CO	NOx	TSP (PM_{10})	$PM_{2.5}$	VOCs	NH_3	Fuel Factor
Power Tiller		6.80	13.60	1.36	1.251	2.04	0.00004	0.00542
Farm Tractor	S [1]	2.48	7.84	0.39	0.359	0.48	0.00003	0.00538
	M [2]							0.00530
	L [3]							0.00530

[1] S: Small, [2] M: Medium, [3] L: Large. Total Suspended Particles (TSP) includes PM_{10}.

2.4. Visualization of Emissions

To calculate the domestic spatial distribution of total air pollutant emissions from tractors, an open source geographic information system (GIS) software (QGIS, Windows 10 version) was used. The total of 9 provinces and 1 total metropolitan city (TMC) including 8 metropolitan cities was analyzed in the study. Based on the geocoded residential addresses, individual exposure to the various variables was assessed applying GIS program. QGIS is a widely-used, open-source GIS visualization tool that allows users to produce, edit, visualize and analyze spatial data. It supports vector and raster format, as well as a database format and functionalities (QGIS, 2021).

3. Results and Discussion

3.1. Total Emissions of Agricultural Tractors

The air pollutant emission inventory for agricultural tractors in 2011 and 2019 in Korea was calculated. Tables 5 and 6 show that the amount of air pollutants emitted from various agricultural practices from agricultural tractors. The two main sources of air pollutants emitted from walking tractor are transporting and spraying. They emit about 81% of emission from waling tractors. Riding tractors are heavily used in soil preparation, which emits about 42% of air pollutants, including tilling, harrowing and leveling, for seeding and planting in Korea. Figure 1 shows the change of calculated total emissions in agricultural tractors categorized into 4 groups. The total amount of emission using agricultural tractors was decreased about 13% from 2011 to 2019. The number of power tillers were decreased by about 19% in 8 years, on the other hand that of farm tractors were increased by about 12%. However, the emission reduction is about 48% for power tillers and the emission increment is about 5% for farm tractors. Thus, the total emission from agricultural tractors was decreased by about 16% in those periods. It is due to the decrease of 21% and 15% in the hours of use of walking and riding tractors, respectively, in 2019. However, the total amount of air pollutants emitted from large size riding tractors was increased by about 33% in 2019. Recently, Korean farmers are showing a tendency of using large size riding tractors to reduce working hours in the fields.

Table 5 . Calculated amounts of air pollutants emitted from agricultural tractors operations in 2011.

unit: Mg/yr

Machinery	Operation Type	CO	NOx	SOx (×10²)	TSP	$PM_{2.5}$	VOCs	NH_3 (×10)
Walking Tractor	TL [1]	53.9	107.8	2.88	10.78	9.92	16.17	3.17

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(Power Tiller)		HW [2]	88.9	177.7	4.75	17.77	16.35	26.7	5.23
		PP [3]	132.6	265	7.08	26.5	24.4	39.8	7.80
		SY [4]	367	734	19.61	73.4	67.5	110.1	21.6
		TP [5]	823	1,646.3	44.0	164.6	151.4	246.9	48.4
		Other	2.91	5.83	0.16	0.583	0.536	0.874	0.0171
		Sub Total	1,469	2,940	78.4	296	270	441	86.2
Riding Tractor	Small	TL [1]	42.7	135.1	6.21	6.7	6.2	8.3	5.17
		HW [2]	63.9	202	9.28	10.0	9.2	12.4	7.73
		LL [6]	23.7	74.9	3.44	3.7	3.4	4.6	2.87
		FS [7]	14.0	44.2	2.03	2.2	2.0	2.7	1.690
		CS [8]	33.6	106.3	4.89	5.3	4.9	6.5	4.07
		LD [9]	26.7	84.5	3.89	4.2	3.9	5.2	3.23
		BL [10]	19.6	62.1	2.86	3.1	2.8	3.8	2.38
		TP [5]	58.9	186.3	8.57	9.3	8.5	11.4	7.13
		Other	28.2	89.0	4.09	4.43	4.07	5.45	3.41
		Sub Total	311	984	45.3	49.0	45.1	60.3	37.7
	Medium	TL [1]	140.0	442	20.0	22.0	20.2	27.1	16.90
		HW [2]	209	661	29.9	32.9	30.3	40.5	25.3
		LL [6]	77.6	245	11.1	12.2	11.20	15.00	9.38
		FS [7]	45.7	145.0	6.55	7.19	6.62	8.85	5.53
		CS [8]	110.0	348	15.80	17.30	15.90	21.3	13.30
		LD [9]	87.5±	277	12.50	13.80	12.70	16.9	10.60
		BL [10]	64.3	203	9.21	10.10	9.31	12.4	7.78
		TP [5]	193.0	610	27.6	30.30	27.9	37.3	23.3
		Other	92.1	291	13.20	14.50	13.30	17.8	11.10
		Sub Total	1,019	3,220	145.9	160.3	147.5	197.3	123.3
	Large	TL [1]	66.9	211	9.57	10.50	9.68	12.90	8.09
		HW [2]	99.9	316	14.30	15.70	14.50	19.30	12.10
		LL [6]	37.1	117.0	5.31	5.83	5.37	7.18	4.48
		FS [7]	21.9	69.1	3.13	3.44	3.16	4.23	2.64
		CS [8]	52.6	166.0	7.53	8.27	7.61	10.20	6.36
		LD [9]	41.8	132.0	5.99	6.58	6.05	8.90	5.06
		BL [10]	30.7	97.2	4.40	4.83	4.45	5.95	3.72
		TP [5]	92.2	291	13.20	14.50	13.30	17.80	11.20
		Other	44.0	139.0	6.31	6.93	6.38	8.52	5.33
		Sub Total	487	1,540	69.7	76.6	70.5	94.3	58.9
	Sub Total		1,818	5,746	261	286	267	352	220
Total			3,290	8,683	339	580	537	792	306

[1] TL: Tilling, [2] HW: Harrowing, [3] PP: Pumping, [4] SY: Spraying, [5] TP: Transporting, [6] LL: Leveling, [7] FS: Fertilizer spreading, [8] CS: Compost spreading, [9] LD: Loading, [10] BL: Baling.

Table 6 . Calculated amounts of air pollutants emitted from agricultural tractors operations in 2019.

unit: Mg/yr

Machinery	Operation Type	CO	NOx	SOx (×10²)	TSP	$PM_{2.5}$	VOCs	NH_3 (×10)
Walking Tractor (Power Tiller)	TL [1]	16.64	33.3	0.900	3.33	3.06	4.99	0.980
	HW [2]	40.4	80.8	2.20	8.08	7.43	12.12	2.38
	PP [3]	124.8	250	6.70	25.0	23.0	37.4	7.34

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		SY [4]	237	473	12.60	47.3	43.5	71.0	13.91
		TP [5]	408	815	21.8	81.5	75.0	122.3	24.0
		Other	27.3	54.7	1.500	5.47	5.03	8.20	1.610
		Sub Total	853	1,707	45.6	170.7	157.0	256	50.2
Riding Tractor	Small	TL [1]	36.5	115.4	5.30	5.74	5.29	7.07	4.42
		HW [2]	90.0	284	13.10	14.15	13.02	17.4	10.88
		LL [6]	28.4	89.9	4.10	4.47	4.12	5.51	3.44
		FS [7]	16.54	52.3	2.40	2.60	2.39	3.20	2.00
		CS [8]	11.50	36.3	1.700	1.808	1.664	2.23	1.390
		LD [9]	47.2	149.2	6.90	7.42	6.83	9.14	5.71
		BL [10]	5.45	17.22	0.800	0.856	0.788	1.054	0.660
		TP [5]	28.2	89.3	4.10	4.44	4.09	5.47	3.42
		Other	18.36	58.0±	2.70	2.89	2.66	3.55±	2.22
		Sub Total	282	892	41.0	44.4	40.8	54.6	34.1
	Medium	TL [1]	126.2	399	18.10	19.85	18.27	24.3	15.27
		HW [2]	311	983	44.50	48.91	45.0	60.20	37.62
		LL [6]	98.3	311	14.10	15.46	14.23	19.03	11.89
		FS [7]	57.2	180.8	8.20	8.9	8.28	11.07	6.92
		CS [8]	39.8	125.7	5.70	6.25	5.75	7.69	4.81
		LD [9]	163.2	516	23.4	25.7	23.6	31.6	19.74
		BL [10]	18.83	59.5	2.70	2.96	2.73	3.64	2.28
		TP [5]	97.6	309	14.00	15.35	14.13	18.90	11.81
		Other	63.5	201	9.10	9.98	9.19	12.28	7.68
		Sub Total	976	3,080	139.7	153.4	141.2	188.8	118.0
	Large	TL [1]	83.9	265	12.00	13.18	12.15	16.24	10.15
		HW [2]	207	654	29.6	32.52	29.9	40.0	25.01
		LL [6]	65.4	207	9.40	10.28	9.46	12.65	7.91
		FS [7]	38.0	120.2	5.40	5.98	5.50	7.36	4.60
		CS [8]	26.4	83.5	3.80	4.16	3.83	5.12	3.20
		LD [9]	108.5	343	15.50	17.06	15.71	21.0	13.12
		BL [10]	12.52	39.6	1.800	1.969	1.812	2.42	1.510
		TP [5]	64.9	205	9.30	10.21	9.40	12.56	7.85
		Other	42.2	133.4	6.00	6.64	6.11	8.17	5.10
		Sub Total	649	2,050	92.9	102.0	93.9	125.5	78.5
	Sub Total		1,906	6,030	274	300	276	369	231
Total			2,760	7,730	319	470	433	625	281

[1] TL: Tilling, [2] HW: Harrowing, [3] PP: Pumping, [4] SY: Spraying, [5] TP: Transporting, [6] LL: Leveling, [7] FS: Fertilizer spreading, [8] CS: Compost spreading, [9] LD: Loading, [10] BL: Baling.

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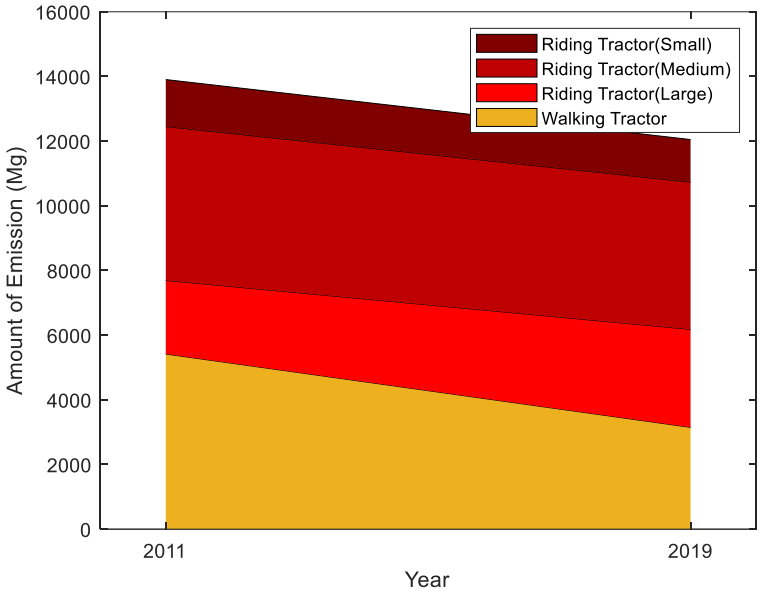

Figure 1. Calculated average total air pollutant substances emitted from walking and riding tractors.

3.2. Air Pollution Emissions from Farm Tractor Operations

The diesel emission inventory for agricultural tractors in Korea was refined by categorizing the rated power of riding tractors into 3 sub-groups. Figures 2 and 3 show that calculated amounts of average air pollutants emission from various agricultural operations by walking and riding tractors, respectively. Walking tractors mainly emit air pollutants from spraying and transporting. In particular, in the case of transporting, 2,639 Mg of air pollutants was emitted in 2011 and 1,429 Mg of air pollutants was emitted in 2019. Riding tractors mainly emit air pollutants from soil preparation and transporting operations. About 61% of total air pollutants are emitted from those operations. Particularly air pollutant emission from loading in 2019 was nearly doubled compared to 2011. Korean farmers are using riding tractors as loading heavy material recently.

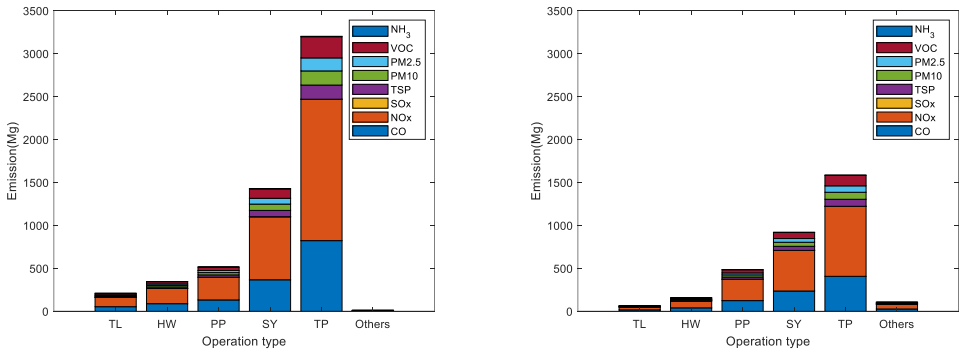

Figure 2. Calculated amounts of average air pollutant substances emission of from various agricultural operations by walking tractor in 2011 (left) and 2019 (right). TL: Tilling, HW: Harrowing, PP: Pumping, SY: Spraying, TP: Transporting

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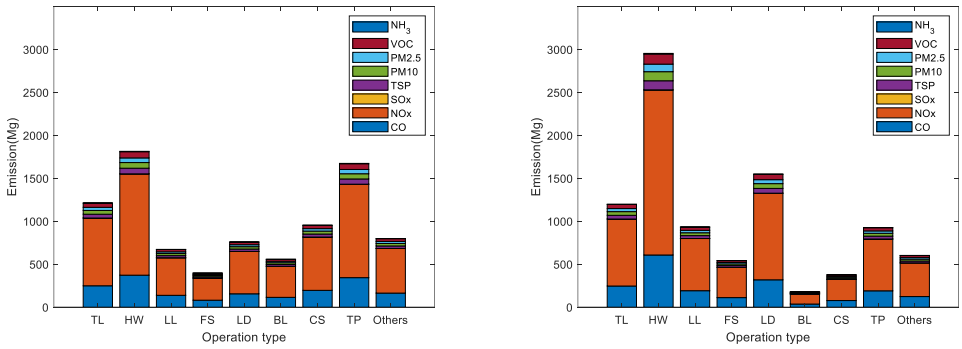

Figure 3. Calculated amounts of average air pollutant substances emission of from various agricultural operations by riding tractor in 2011 (left) and 2019 (right). TL: Tilling, HW: Harrowing, LL: Leveling, FS: Fertilizer spreading, LD: Loading, BL: Baling, CS: Compost spreading, TP: Transporting

3.3 Spatial and Temporal Distribution of Air Pollutant Emissions

The amount of air pollutants emitted by Korean agricultural tractors was calculated on a region-level. Tables 7, 8, 9, and 10 show the calculated air pollutant emissions of 10 regions in Korea. Total emissions of CO, NOx, SOx, TSP, $PM_{2.5}$, VOCs and NH_3 from walking tractors in 2011 were 1,469 Mg, 2,940 Mg, 0.78 Mg, 296 Mg, 270 Mg, 441 Mg and 8.6 Mg, respectively. Also, total emissions of CO, NOx, SOx, TSP, $PM_{2.5}$, VOCs and NH_3 from walking tractors in 2019 were 853 Mg, 1,716 Mg, 0.46 Mg, 171 Mg, 157 Mg, 257 Mg and 5.0 Mg, respectively. In 2019, walking tractor emissions of Gyeongsangbuk-do, Jeollanam-do, and Gyeongsangnam-do account for 23%, 16% and 13% of the total emissions. Total emissions of CO, NOx, SOx, TSP, $PM_{2.5}$, VOCs and NH_3 from riding tractors were 1,818 Mg, 5,746 Mg, 3 Mg, 286 Mg, 263 Mg, 352 Mg and 22 Mg, respectively in 2011 and were 1,906 Mg, 6,030 Mg, 3 Mg, 300 Mg, 276 Mg, 369 Mg and 23 Mg, respectively in 2019. Gyeongsangbuk-do and Jeollanam-do are major regions emitting about 30% and 32% of total air pollutants utilizing walking and riding tractors in 2019.

Table 7. Calculated air pollutant emissions of walking tractor by region in Korea (2011).

Region	Emission (Mg/yr)							
	CO	NOx	SOx(×10²)	TSP	$PM_{2.5}$	VOCs	NH_3(×10)	Total
CHB [1]	100	199	5	20	18	30	6	349
CHN [2]	192	384	10	38	35	58	11	673
GAW [3]	85	171	5	17	16	26	5	299
GYB [4]	306	613	16	61	56	92	18	1,074
GYG [5]	129	258	7	26	24	39	8	453
GYN [6]	195	390	10	39	36	58	11	684
JEB [7]	133	265	7	27	24	40	8	465
JEJ [8]	32	65	2	6	6	10	2	114
JEN [9]	232	464	12	46	43	70	14	814
TMC [10]	64	128	3	13	12	19	4	225
Total	1,469	2,940	78	296	270	441	86	5,425

[1] CHB: Chungcheongbuk-do, [2] CHN: Chungcheongnam-do, [3] GAW: Gangwon-do,
[4] GYB: Gyeong sangbuk-do, [5] GYG: Gyeonggi-do, [6] GYN: Gyeongsangnam-do,
[7] JEB: Jeollabuk-do, [8] JEJ: Jeju-do, [9] JEN: Jeollanam-do, [10] TMC: Total of 8 metropolitan city

Table 8. Calculated air pollutant emissions of walking tractor by region in Korea (2019).

Region	Emission (Mg/yr)							
	CO	NOx	SOx(×10²)	TSP	$PM_{2.5}$	VOCs	NH_3(×10)	Total
CHB [1]	58	116	3	12	11	18	3	205
CHN [2]	100	199	5	20	18	30	6	351

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GAW [3]	50	100	3	10	9	15	3	177
GYB [4]	195	389	10	39	36	57	11	683
GYG [5]	64	127	3	13	12	19	4	224
GYN [6]	113	225	6	23	21	34	7	397
JEB [7]	76	151	4	15	14	23	4	267
JEJ [8]	23	46	1	5	4	7	1	80
JEN [9]	135	270	7	27	25	41	8	475
TMC [10]	43	84	2	25	8	13	3	151
Total	853	1,707	46	171	157	256	50	3,149

[1] CHB: Chungcheongbuk-do, [2] CHN: Chungcheongnam-do, [3] GAW: Gangwon-do,
[4] GYB: Gyeong sangbuk-do, [5] GYG: Gyeonggi-do, [6] GYN: Gyeongsangnam-do,
[7] JEB: Jeollabuk-do, [8] JEJ: Jeju-do, [9] JEN: Jeollanam-do, [10] TMC: Total of 8 metropolitan city

Table 9. Calculated air pollutant emissions of riding tractor by region in Korea (2011).

Region	Emission (Mg/yr)							
	CO	NOx	SOx(×10²)	TSP	$PM_{2.5}$	VOCs	NH_3(×10)	Total
CHB [1]	108	342	16	17	16	21	13	490
CHN [2]	253	801	36	40	38	49	31	1,148
GAW [3]	127	402	18	20	18	25	15	576
GYB [4]	270	854	39	43	39	52	33	1,223
GYG [5]	259	819	37	41	38	50	31	1,173
GYN [6]	207	655	30	33	31	40	25	939
JEB [7]	210	664	30	33	30	41	25	951
JEJ [8]	30	94	4	5	4	6	4	134
JEN [9]	273	864	39	43	41	53	33	1,238
TMC [10]	79	249	11	12	11	15	10	357
Total	1,818	5,746	261	286	267	352	220	8,493

[1] CHB: Chungcheongbuk-do, [2] CHN: Chungcheongnam-do, [3] GAW: Gangwon-do,
[4] GYB: Gyeong sangbuk-do, [5] GYG: Gyeonggi-do, [6] GYN: Gyeongsangnam-do,
[7] JEB: Jeollabuk-do, [8] JEJ: Jeju-do, [9] JEN: Jeollanam-do, [10] TMC: Total of 8 metropolitan city

Table 10. Calculated air pollutant emissions of riding tractor by region in Korea (2019).

Region	Emission (Mg/yr)							
	CO	NOx	SOx(×10²)	TSP	$PM_{2.5}$	VOCs	NH_3(×10)	Total
CHB [1]	113	358	16	18	16	22	14	512
CHN [2]	256	810	37	40	37	50	31	1,160
GAW [3]	137	433	20	22	20	27	17	620
GYB [4]	312	986	45	49	45	60	38	1,411
GYG [5]	230	727	33	36	33	45	28	1,041
GYN [6]	219	694	32	35	32	42	27	993
JEB [7]	228	720	33	36	33	44	28	1,030
JEJ [8]	32	103	5	5	5	6	4	147
JEN [9]	291	919	42	46	42	56	35	1,315
TMC [10]	88	278	13	14	13	17	11	398
Total	1,906	6,030	274	300	276	369	231	8,906

[1] CHB: Chungcheongbuk-do, [2] CHN: Chungcheongnam-do, [3] GAW: Gangwon-do,
[4] GYB: Gyeong sangbuk-do, [5] GYG: Gyeonggi-do, [6] GYN: Gyeongsangnam-do,
[7] JEB: Jeollabuk-do, [8] JEJ: Jeju-do, [9] JEN: Jeollanam-do, [10] TMC: Total of 8 metropolitan city

The spatial distribution of the total amount of tractor air pollutant emission in Korea were visualized at the region-level using a GIS technique, as shown in Figures 4 and 5. Figure 4 (a) shows the emissions in 2011 and Figure 4 (b) shows the emissions in 2019 from walking tractors. Regions

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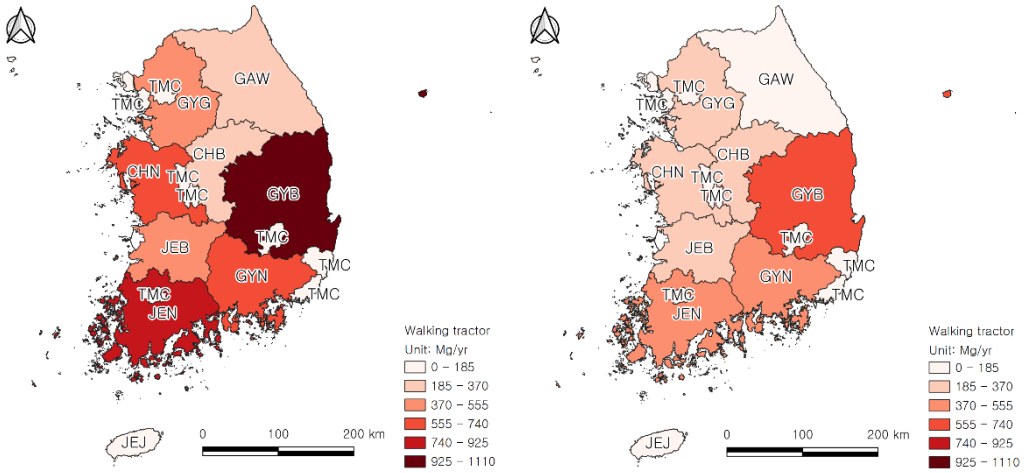
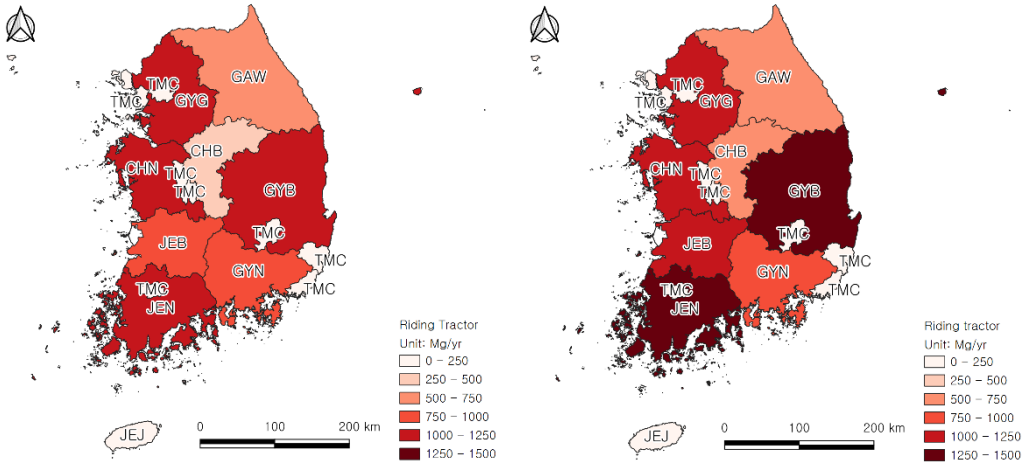
with high emissions are mainly southern regions such as: Gyeongsangbuk-do, Jeollanam-do, and Gyeongsangnam-do. In the case of Gyeongsangbuk-do compared to other regions, it emits about 22.7% of total air pollutants in 2019. Figure 5 (a), (b) shows the emissions from riding tractors in 2011 and 2019. Gyeongsangbuk-do and Jeollanam-do emit about 31.6% of total air pollutants in 2019. Figures 4 and 5 show that the emission of the walking tractor is decreasing, but the emission of the riding tractor is increasing in Gyeongsangbuk-do region. In 2011, riding tractor emissions were in about same range in Chungcheongnam-do, Gyeongsangbuk-do, Gyeonggi-do, and Jeollanam-do, but in 2019, the emission range in Gyeongsangbuk-do, Jeollanam-do, Chungcheongbuk-do and Jeollabuk-do increased by one level. These high-emission areas are mainly located in the western and southern regions of Korea, which have plenty of arable areas compared to other regions in Korea. However, riding tractor emissions are much lower in Gangwon-do and Chungcheongbuk-do. This area is mainly mountainous, so there is little agricultural area to produce agricultural products. Metropolitan cities with high population generate less emissions from agricultural tractors compared to other regions.



(a) (b)

Figure 4. Spatial distribution of emissions from walking tractors in 2011 (left) and 2019 (right).



(a) (b)

Figure 5. Spatial distribution of emissions from riding tractors in 2011 (left) and 2019 (right).

4. Conclusions

In this study, agricultural tractors including walking and riding types were categorized into 4 levels by rated output power and diesel emissions of tractors were analyzed

using 2011 and 2019 survey data in Korea. Emission inventory including CO, NOx, SOx, TSP(PM_{10}), $PM_{2.5}$, VOCs and NH_3 were established using Tier 3 methodology. As a result, the annual emissions of CO, NOx, SOx, TSP(PM_{10}), $PM_{2.5}$, VOCs and NH_3 of agricultural tractors were 3,290 Mg, 8,683 Mg, 3.39 Mg, 580 Mg, 537 Mg, 792 Mg and 30.6 Mg, respectively in 2011 and 2,760 Mg, 7,730 Mg, 3.19 Mg, 470 Mg, 433 Mg, 625 Mg and 28.1 Mg, respectively in 2019. The total amount of emission using agricultural tractors was decreased about 13% from 2011 to 2019. The number of walking tractors were decreased by about 19% in 8 years, on the other hand that of riding tractors were increased by about 12%. However, the emission reduction is about 48% for walking tractors and the emission increment is about 5% for riding tractors. Thus, the total emission from agricultural tractors was decreased by about 16% in those periods. It is due to the decrease of 21% and 15% in the hours of use of walking and riding tractors, respectively, in 2019. Walking tractors mainly emit air pollutants from spraying and transporting. In particular, in the case of transporting, 2,639 Mg of air pollutants was emitted in 2011 whereas 1,429 Mg of air pollutants was emitted in 2019. Riding tractors mainly emit air pollutants from soil preparation and transporting operations. About 61% of total air pollutants are emitted from those operations. High emission generating regions and changes of emissions during 8 years were clearly seen in GIS analysis. High air pollutant emitting regions are mainly located in the western and southern regions of Korea, which have plenty of arable areas compared to other regions in Korea.

Author Contributions: Conceptualization, G.G.H. and S.M.K.; software, G.G.H.; validation, G.G.H., M.H.K. and S.M.K.; investigation, J.H.J.; resources, J.M.L. and G.G.H.; writing—original draft preparation, G.G.H.; writing—review and editing, M.H.K. and S.M.K.; visualization, J.H.J.; supervision, S.M.K.; project administration, S.M.K.; funding acquisition, S.M.K. All authors have read and agreed to the published version of the manuscript.

Funding: This work was carried out with the support of "Study on Particulate Matter Outbreak Source Characteristics during Agricultural Practice and Inventory Integration (Project No. PJ01428301)" Rural Development Administration, Korea.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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