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Article

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Assessment on the Magnesia/Mineral Supplier-Treated Korean Cattle Compost (MMC) for the Reduction of Water Pollution and the Recovery of Soil through Field Test

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Abstract: The soil in north Gyeongsangbuk-do is mostly made up of sand, which lacks various essential minerals for growing crops, and also increases the pollution of the surrounding water when it rains. Therefore, the applicability of water pollution reduction and soil restoration was examined by using compost prepared by mixing MgO and mineral sources in a weight ratio of 1:2 with the existing Korean cattle compost. MgO used is a powder obtained by activating $MgCO_3$ natural stone at 800°C for 2 hours, and the mineral source was made by adding white soil to a sulfuric acid solution and heating it at 80°C for 1 h and then recovering the sulfuric acid solution. After spraying the prepared compost on 20 farmland, water pollution and soil fertility were measured through analysis of water and soil items such as TOC, BOD, T-N, and T-C before and after spraying. When newly prepared compost was applied to the soil, the concentrations of TOC, BOD, T-N, and TP were reduced by 19.09%, 28.0%, 30.9%, and 27.5%, respectively, compared to commercial compost. On the basis of these results, it was confirmed that newly prepared compost is better than commercial compost for the water pollution reduction effect and the inhibition of green algae generation. Through soil analysis, the levels of EC and effective phosphoric acid in the soil were lower in the newly prepared compost than in the commercial compost. It is expected that soil fertility can be increased by reducing the rate of nutrient loss caused by rainfall.

Keywords: BOD, Effective phosphoric acid, MgO/mineral supplier-treated compost, T-N, TOC, T-P

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Introduction

Consumption of meat is increasing rapidly due to the improvement of the people's income level, livestock farms also continue to expand. However, as the livestock industry grows, problems such as indiscriminate loading and discharging of manure emitted from livestock have arisen, resulting in negative environmental effects [1,2]. Therefore, since over a decade ago, Korea’s Ministry of Agriculture, Food and Rural Affairs has proposed measures to resource livestock manure in the mid- to long-term to realize sustainable livestock farming, such as developing an eco-friendly livestock standard model, creating an environmentally friendly livestock industry, energizing livestock manure, and strengthening livestock odor management capabilities [3]. However, despite these measures, in reality, environmental improvements to manure from livestock have not actually met expectations. To this day, residents near livestock farms are constantly exposed to damage caused by livestock manure exceeding environmental capacity, improper treatment of facilities, and spraying compost that does not meet standards. As of 2018, the amount of livestock manure generated is 43,805 m^3/day, and the consignment treatment cost is set at 10,000 won to 30,000 won in Korean money depending on the region. If these are added up annually, the processing cost becomes approximately 100 billion won or more, and if the other purification and resource conversion costs are combined, it forms a market of 500 billion won or more per year. In addition to the direct treatment cost of livestock manure, it is estimated to have a market worth trillion won if the cost of indirect treatment due to water pollution caused by the loss of manure is added. Livestock manure is generally recognized as a waste with a strong odor, and it is difficult to make it into eco-friendly compost [4,5]. However, a technology that can produce livestock manure as compost with functional and efficiency is required so that it can change this perception and establish itself as a new source of income for livestock farmers.In general, the northern part of Gyeongsangbuk-do is mostly distributed in highlands due to its geographical characteristics, and because various essential minerals on the surface are lost downstream each year due to rainy seasons and typhoons, it is mainly made of decomposed granite soil. This soil is mostly a sand component and is a soil that lacks various minerals to grow crops [6]. Commonly, compost produced by Korean cattle manure has only high organic content, relatively low mineral content, and more mineral loss occurs compared to other composts [7]. As such, due to the insufficient mineral components included in Korean cattle compost, more compost must be sprayed on the farmland and additionally, chemical fertilizers must be sprayed continuously. Therefore, it is necessary to manufacture Korean cattle compost that is rich in minerals that meet the current composting problems facing Korean cattle farmers and the topographical characteristics of the northern region of Gyeongsangbuk-do. In addition, practical compost manufacturing technology measures should be introduced that can simultaneously consider economic benefits and environmental protection aspects that can prevent the increase in cost due to massive compost spraying, the outflow of excessive nutrients from farmland, and deterioration of water pollution. Therefore, it is necessary to manufacture mineral-rich compost to suit the treatment problems of manure facing Korean cattle farmers and the topographic characteristics of the northern part of Gyeongsangbuk-do. In addition, practical compost manufacturing technology measures should be introduced that can simultaneously consider economic benefits and environmental protection aspects that can prevent cost increase due to massive compost spraying, the outflow of excessive nutrients from farmland, and deterioration of water pollution.

By the preceding studies of this author, a maturity accelerator was developed to enhance the functionality and efficiency of Korean cattle compost. The developed maturity accelerator was prepared by mixing magnesia (MgO) with a mineral supplier. Where, MgO becomes $Mg(OH)_2$ through a reaction with moisture in the compost. This not only shows the effect of removing moisture in the compost, but also promotes maturity of compost by forming an air layer in the compost by the removed moisture. In addition, $Mg(OH)_2$ is eluted as Mg^{2+} ions and serves as a Mg source required for struvite synthesis [8-13]. OH- ions helped to remove a significant amount of odors such as ammonia gas through the role of raising the pH in the compost. The mineral supplier is easily ionized when sprayed on farmland as a major mineral component source, and thus serves to easily supply various mineral components to the soil.

This study aims to explore the possibility of whether the manufactured MMC can actually reduce water pollution and restore soil. To this end, 20 sites in 5 areas near Songya stream were selected, and MMC and CC as a contrast role were sprayed on farmland, respectively. After that, various items of water and soil before and after spraying were analyzed and compared to measure the degree of water pollution and fertility of the soil.

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Material and Methods

Materials

CC to be used in the test was green star, a compost for livestock sold by Pungsan Fertilizer Co., Ltd. MMC was a compost prepared through a maturity process for 4 weeks after mixing MgO and a mineral supplier (called maturity accelerator in this study), and then adding it to Korean cattle compost. MgO used in the study is in the form of a powder with a particle size of 10 to 100 μm by activating $MgCO_3$ natural stone at 800°C for 2 hr [14]. The mineral solution was prepared by injecting a sulfuric acid solution into white soil of about 10 mm, applying heat at 80°C for 1 hour, stagnating for 1 day, and recovering a sulfuric acid solution in which minerals were dissolved. The mineral supplier was made by combining mineral solution: dolomite = 1:2.

Investigation area

Fig. 1 shows the topography of the five areas Dochon-ri, Gwangpyeong-ri, Jeojeon-ri, Lee Songcheon-ri, and Gyo-ri near the Songya stream. A total of 20 sites for each area were selected to spray CC and MMC on farmland, and before (B: MMC, b: CC) and after (A: MMC, a: CC) are listed in Table 1.

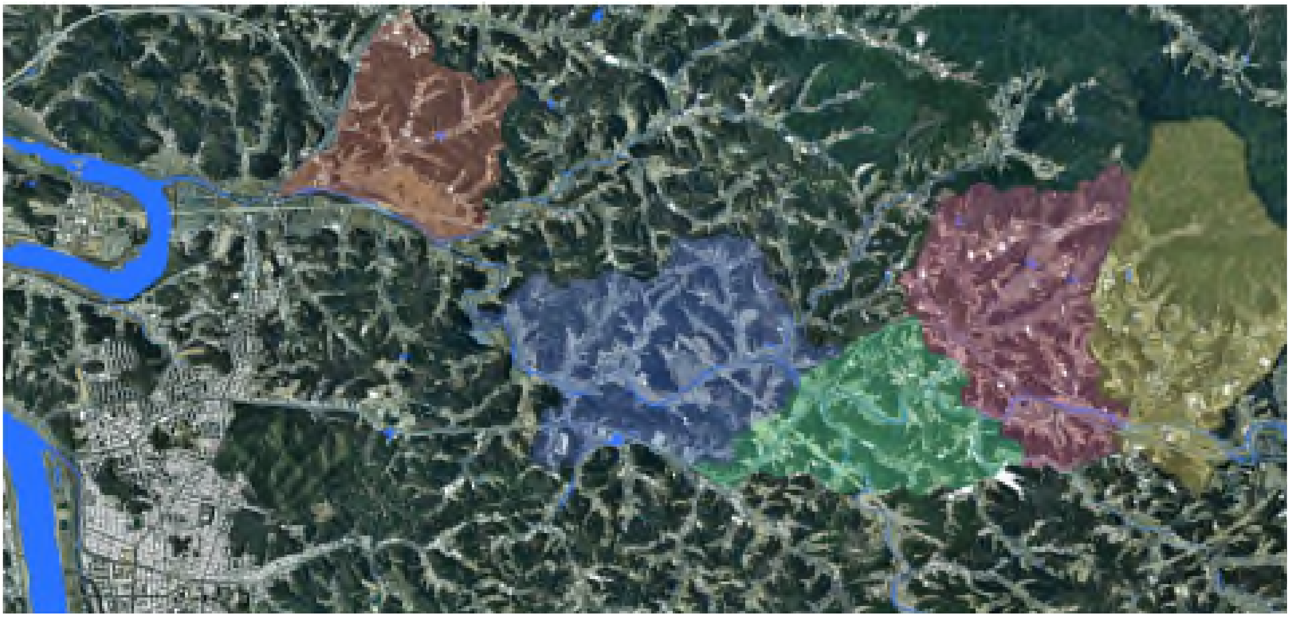

Fig. 1. Five test areas located near Songya stream: Docheon-ri, Gwangpyeong-ri, Jeojeon-ri, Isongcheon-ri, and Gyo-ri from right side.

Table 1. Spraying sites of CC and MMC

Site	Docheon-ri	Docheon-ri	Docheon-ri	Gwang-pyeong-ri	Gwang-pyeong-ri	Gwang-pyeong-ri	Jeojeon-ri	Jeojeon-ri	Isong-cheon-ri	Gyo-ri
CF	b1	b2	b3	b4	b5	b6	b7	b8	b9	b10
	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10
MMF	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10

(A; after, B; before, a; MMF, b; CF)

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Sampling site and period

Water samples were selected from the effluent flowing into Sonya stream. The number of samples were 10 in total, 3 at Dochon-ri, 3 at Gwangpyeong-ri, 2 at Jeojeon-ri, 1 at Songcheon-ri, and 1 at Gyo-ri. The water sample collection was conducted during the rainy period (March to April in 2022) after compost spraying. 10 soil samples were collected from the compost-sprayed sites. Soil collection period was same as water collection period. Blue and red color indicate the sampling sites of MMC and CC, respectively (Fig. 2).

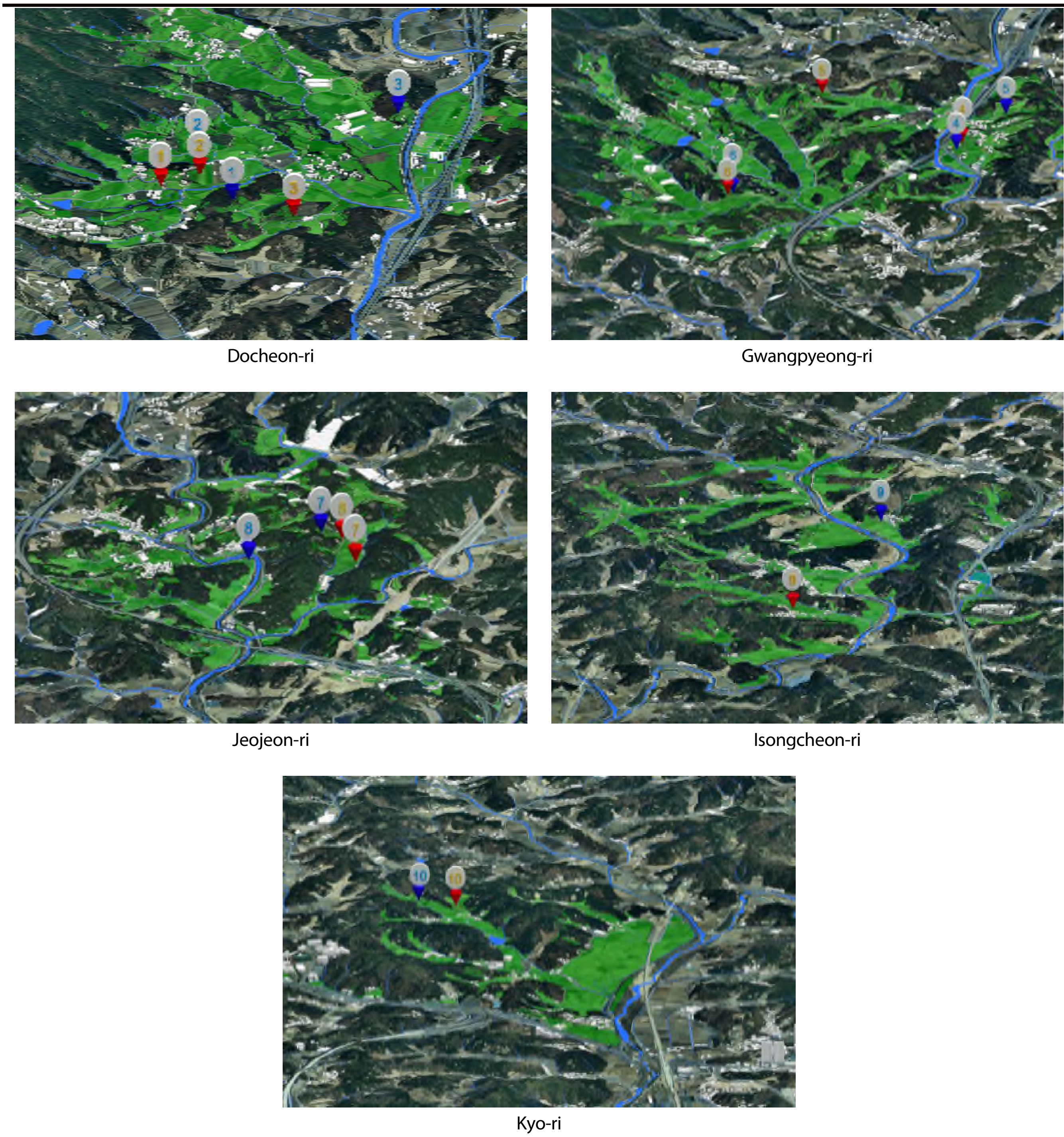

Fig. 2. Sample collection sites. (blue: MMC, red: CC)

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Analysis items of water and soil

For water samples, five items were analyzed: biological oxygen demand (BOD), total organic carbon (TOC), total suspended solid (TSS), total nitrogen (T-N), and total phosphorus (T-P), and for soil samples, five items were analyzed: pH, electrical conductivity (EC), effective phosphoric acid, organic matter, and cation exchange capacity (CEC). All of these items were measured according to the Korean agricultural environment resource analysis method.

Results and Discussion

Chemical component

Table 2 shows the analysis results of the chemical components for CC and MMC. As shown, the main components constituting CC and MMC were MgO, SiO_2, P_2O_5, K_2O, and CaO. The MgO weight ratio of MMC was approximately three times higher than that of CC, and this result is attributed to the reason for adding MgO to Korean cattle compost. Except for MgO, the contents of all oxides were almost similar. Sodium (Na), chlorine (Cl), potassium (K), phosphorus (P), and sulfur (S) are mostly ingredients emitted from the litter or manure of Korean cattle.

Table 2. Chemical components of CC and MMC (unit: wt. %)

Constituents	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	Fe_2O_3	Other oxides	Organics
CF	0.71	2.30	0.55	3.37	4.71	1.19	1.12	3.76	7.53	0.54	0.36	73.86
MMC	0.64	6.39	0.67	3.05	4.39	1.78	0.96	3.12	8.96	1.16	0.41	68.46

Analysis of heavy metal

In order to use MMC as compost, it must comply with the livestock composting process specifications related to heavy metals. According to this standard, it is stipulated that arsenic (As) 45 mg/kg or less, cadmium (Cd) 5 mg/kg or less, mercury (Hg) 2 mg/kg or less, lead (Pb) 130 mg/kg or less, chromium (Cr) 200 mg/kg or less, copper (Cu) 360 mg/kg or less, nickel (Ni) 45 mg/kg or less, and zinc (Zn) 900 mg/kg or less. As a result of analyzing heavy metals in MMC, arsenic, cadmium, chromium, mercury, nickel, and lead were not detected, and copper, zinc, iron, and aluminum were detected in somewhat trace amounts, but were significantly lower than the allowable livestock composting standard.

Measurement of ammonia generation and degree of maturity

Maturity accelerator were prepared by homogeneously mixing MgO : mineral supplier = 1:1 by weight, and then added to the Korean cattle compost. Subsequently, the compost's maturity was performed at three livestock farms during 4 weeks. For ammonia gas analysis, 1 g of sample was added to a 1 L Tedler bag and left in a sealed state for 24 hours. Then, the gas of the Tedler bag was collected in an ammonia gas adsorption tube and analyzed using a thermal desorption gas chromatograph-mass spectrometer (ATD-GC/MS, Clarus 690 GC, Clarus SQ8T, PerkinElmer, USA). The degree of maturity was analyzed using a compost maturity determiner (CoMMe-100) after making the sample in a moisture state enough to prevent moisture from flowing out, storing it in a maturity measuring container for 24 hours, inserting a maturity measuring kit that responds to ammonia gas and carbon dioxide, and allowing it to stand for 30 minutes. Table 3 shows the amount of ammonia gas and the degree of maturity after maturing the compost for 4 weeks. As you can see, the ammonia gas removal rate was 85% in A Farm, 92% in B Farm, and 89% in C Farm, showing a removal rate of more than 85% in most cases. With regard

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to maturity, as the degree of maturity appeared in the middle of maturity and late maturity in all farms after 4 weeks, it was found that the maturity accelerator was effective in promoting the maturity of Korean cattle compost.

Table 3. Determination of ammonia gas and maturity (unit: ppm)

Maturity		A farm	B farm	C farm
NH_3 gas	Before	1650	790	1450
	4 weeks	250	65	160
Maturity	Before	early	early	early
	4 weeks	mid	late	mid

Mineral elution test

The mineral elution test was performed using MMC-treated and -untreated Korean cattle compost. The analysis method is as follows. The sample was air-dried for 24 hours, filtered by a 10 mesh sieve, and 0.5 g was taken and eluted in 50 mL of distilled water. After that, the sample was shaken at 150 rpm for 30 minutes, filtered through a glass fiber filter paper, and then the filtrate was analyzed with an inductively coupled plasma/atomic emission spectrometer (ICP-AES, Agilent 7800, Agilent Technologies, USA). Table 4 listed the analysis results for the elution of the minerals by MMF-treated and -untreated compost. As shown, potassium (K) and phosphorus (P), which are major mineral elements, showed a slight decrease, but increased by 1.51, 1.57, and 2.75 times for Ca, Mg, and S, respectively. In addition, the elution amount of trace minerals increased by 3.15 times for boron (B), 8.78 times for iron (Fe), 5.06 times for manganese (Mn), 4.38 times for zinc (Zn), 4.38 times for copper (Cu), 1.88 times for nickel (Ni), and 5.26 times for molybdenum (Mo). Considering these results, it is thought that when Korean cattle compost treated with MMC is sprayed on farmland, a significant amount of minerals can be eluted into the soil, making the soil fertile.

Table 4. Mineral elution by MMC-untreated and MMC-treated Korean cattle compost (unit: ppm)

Mineral	Major					Trace						
Element	K	Ca	Mg	P	S	B	Fe	Mn	Zn	Cu	Ni	Mo
MMC-untreated cattle compost	432.6	327.6	264.9	6.48	4.61	0.13	0.28	2.74	0.13	0.011	0.017	0.15
MMC-treated cattle compost	429.4	497.6	416.5	5.97	12.70	0.41	2.46	13.89	0.59	0.049	0.032	0.79

Analysis of water items

TSS

TSS is a substance that floats without precipitation in water and includes soil particles with a particle size of less than 1 um and organic substances with a specific gravity of less than 1. The higher the TSS level, the higher the turbidity of water [15]. Figs. 3(a) and 3(b) show the amount of change in the TSS concentration in water before and after spraying of CC and MMC on farmland. Regarding CC, the concentration of TSS was distributed from 336 to 1360 mg/L before spraying CC on farmland and from 364 to 1,044 mg/L after spraying for all sites under test. After CC spraying, Gwangpyeong-ri site (No. 6) showed the greatest decrease in TSS. Whereas, the site with the greatest increase was Jeojeon-ri (No. 5). Among the 10 sites, 6 sites decreased TSS and 4 sites increased after spraying, so the effect of CC on TSS change was relatively insignificant.

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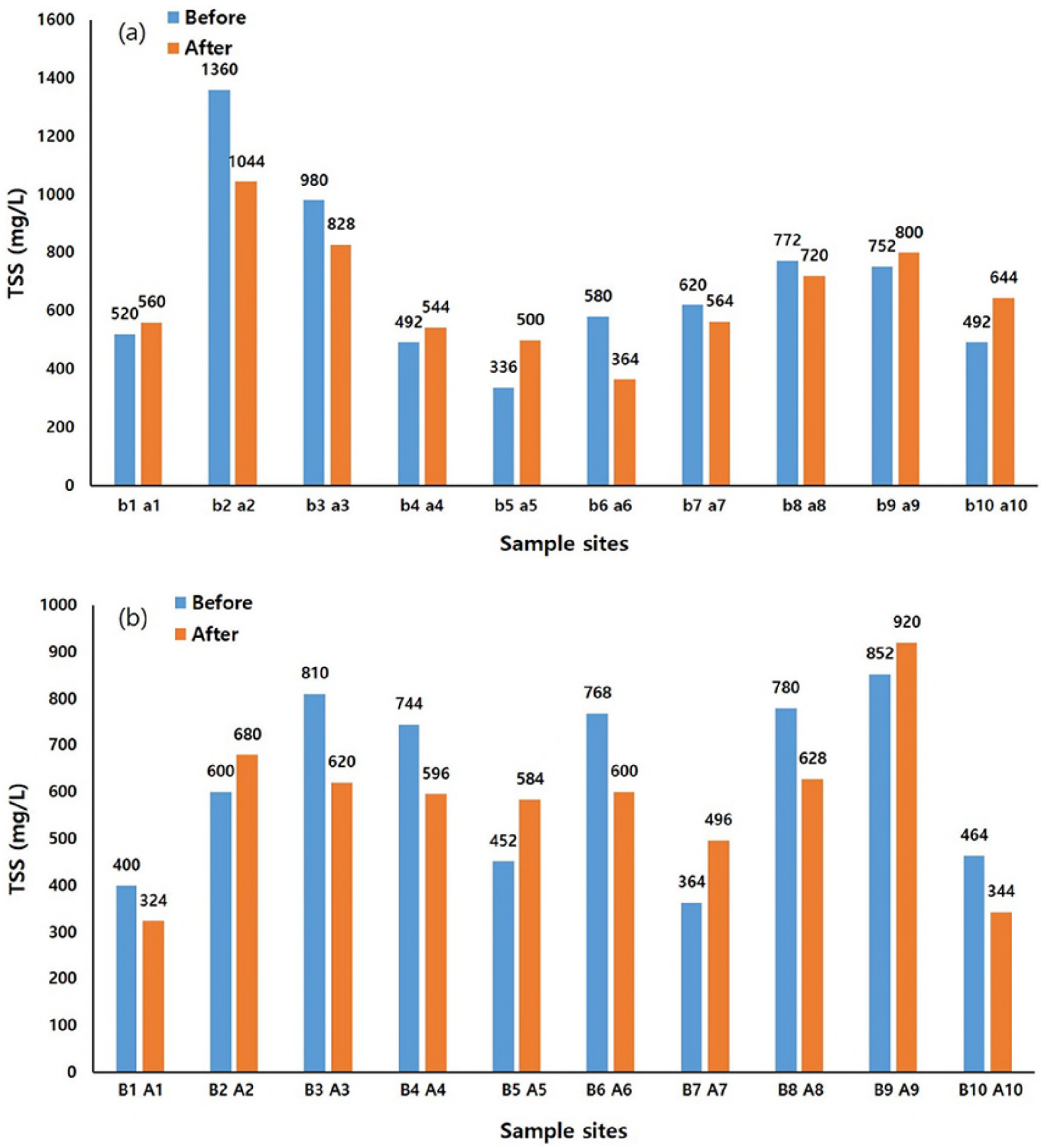

Fig. 3. Amount of change in the TSS concentration in water before and after spraying of (a) CC and (b) MMC on farmland.

As for MMC, the distribution of TCC concentration before and after spraying was 364 to 852 mg/L and 324 to 920 mg/L, respectively. After MMC spraying, the site where TSS decreased the most was the Dochon-ri (No. 3). On the contrary, Jeojeon-ri site (No. 7) showed the largest increase in TSS. Among 10 sites, 6 sites showed a decrease in TSS and 4 sites increased when comparing before and after spraying. As a result, the effect on the change in TSS by MMC was extremely inadequate. For MMC, the average concentration of TSS for 10 sites was 623.4 mg/L before spraying and 579.2 mg/L after spraying, which was reduced by 0.93 times. For CC, the average concentration of TSS was 690.4 mg/L before spraying and 656.8 mg/L after spraying, with a 0.95-fold decrease in TSS. Considering the above results, it was confirmed that MMC spraying could reduce TSS by 2.34% compared to spraying CC on farmland. However, since the difference in TSS change is not so large, it is thought that even if MMC is sprayed on farmland, it does not significantly affect the amount of change in TSS.

TOC

TOC refers to the total amount of organic carbon contained in water. It is an indicator of the degree of contamination

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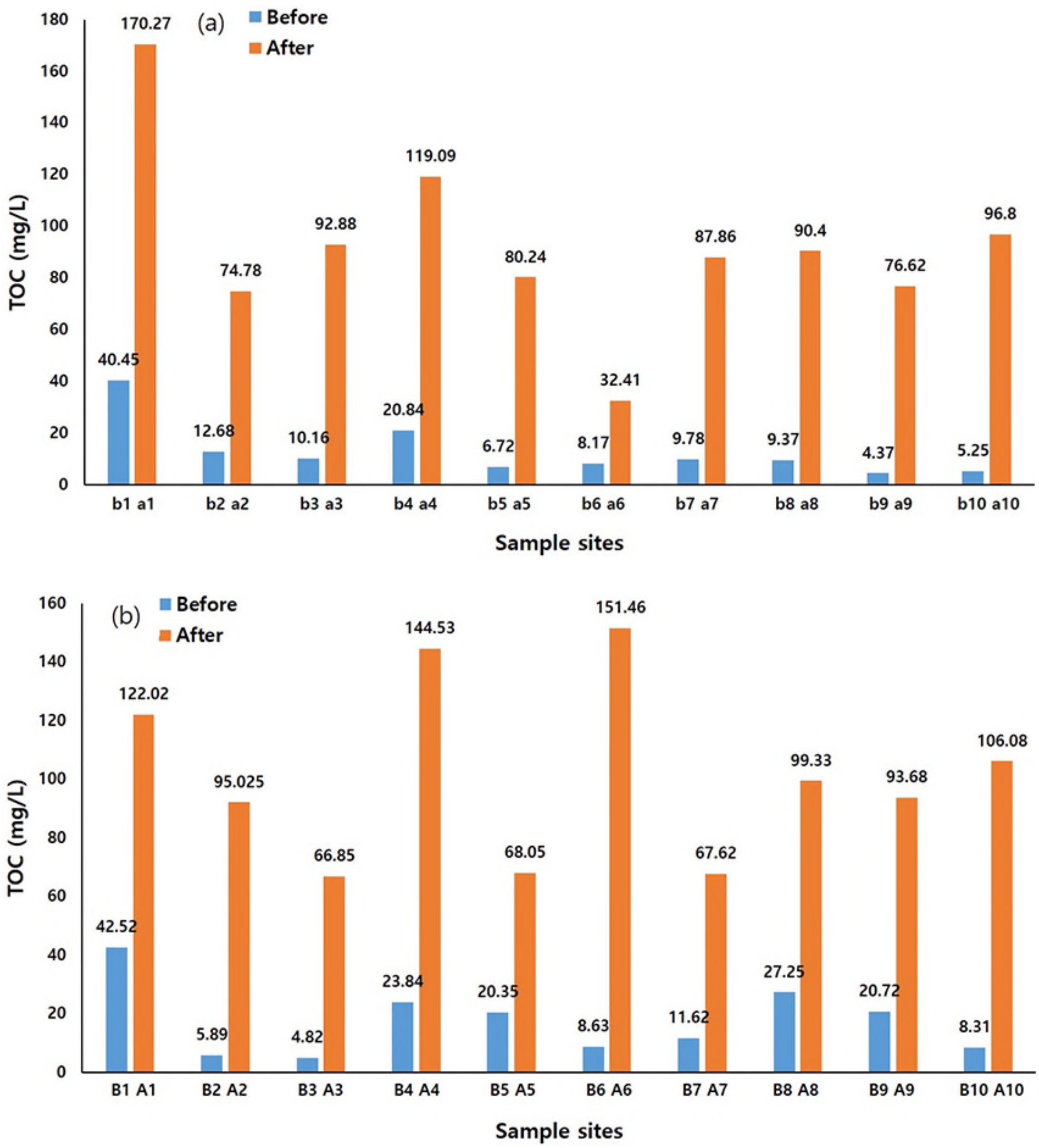

Fig. 4. Amount of change in the TOC concentration in water before and after spraying of (a) CC and (b) MMC on farmland.

of water quality and is the sum of soluble and particulate organic carbon. The high TOC content causes the rapid depletion of oxygen in the water because it requires a lot of oxygen to decompose and stabilize organic matter, and consequently, water is easily decomposed due to lack of oxygen [16].

The amount of change in the TOC concentration in water before and after spraying of CC and MMC on farmland is shown in Figs. 4(a) and 4(b). In terms of CC, it was observed that there was a large difference in the amount of change in TOC concentration in water before and after spraying. The concentrations of TOC before and after spraying were found to be 4.37 to 40.45 mg/L and 32.41 to 170.27 mg/L, respectively. No decrease in TOC was observed at all sites after spraying. The site with the largest increased TOC was Gyo-ri (No. 10), which increased 17.43 times from 5.25 mg/L to 96.8 mg/L. Even in the case of MMF, the amount of change in TOC in water was very large before and after spraying. The concentration range of TOC for 10 sites was between 4.82 mg/L and 42.52 mg/L before spraying and 66.85 mg/L and 151.46 mg/L after spraying. When comparing before and after spraying, there was no decrease in TOC at all sites. The site where TOC increased the most was the Gwangpyeong-ri (No. 6), and the TOC concentration at this site increased 16.55 times from 8.63 mg/L before spraying

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to 151.46 mg/L after spraying. After spraying of MMC on 10 test sites, the average concentration of TOC was 17.4 mg/L before spraying and 101.5 mg/L after spraying, with an increase ratio of 5.83 times. By contrast, in the case of CC, the average concentration of TOC increased from 12.8 mg/L before spraying to 92.1 mg/L after spraying, and its increase rate was 7.21 times. Considering these results, MMC spraying was able to reduce the concentration of TOC in water by 19.1% compared to CC spraying on farmland, so it is thought that MMC is more effective in reducing TOC-related water pollution than CC.

BOD

BOD states the amount of oxygen consumed by aerobic microorganisms in water to decompose organic matter. It is a method of indirectly measuring the amount of organic matter through a change in dissolved oxygen (DO) in the process of decomposing organic matter by a microorganism. The higher the BOD, the more contaminated water containing organic matter [17]. Figs. 5(a) and 5(b) represent the amount of change in the BOD concentration in water before and after spraying of CC and MMC on farmland. As seen, for CC, it was observed that the BOD concentration of water before and after spraying

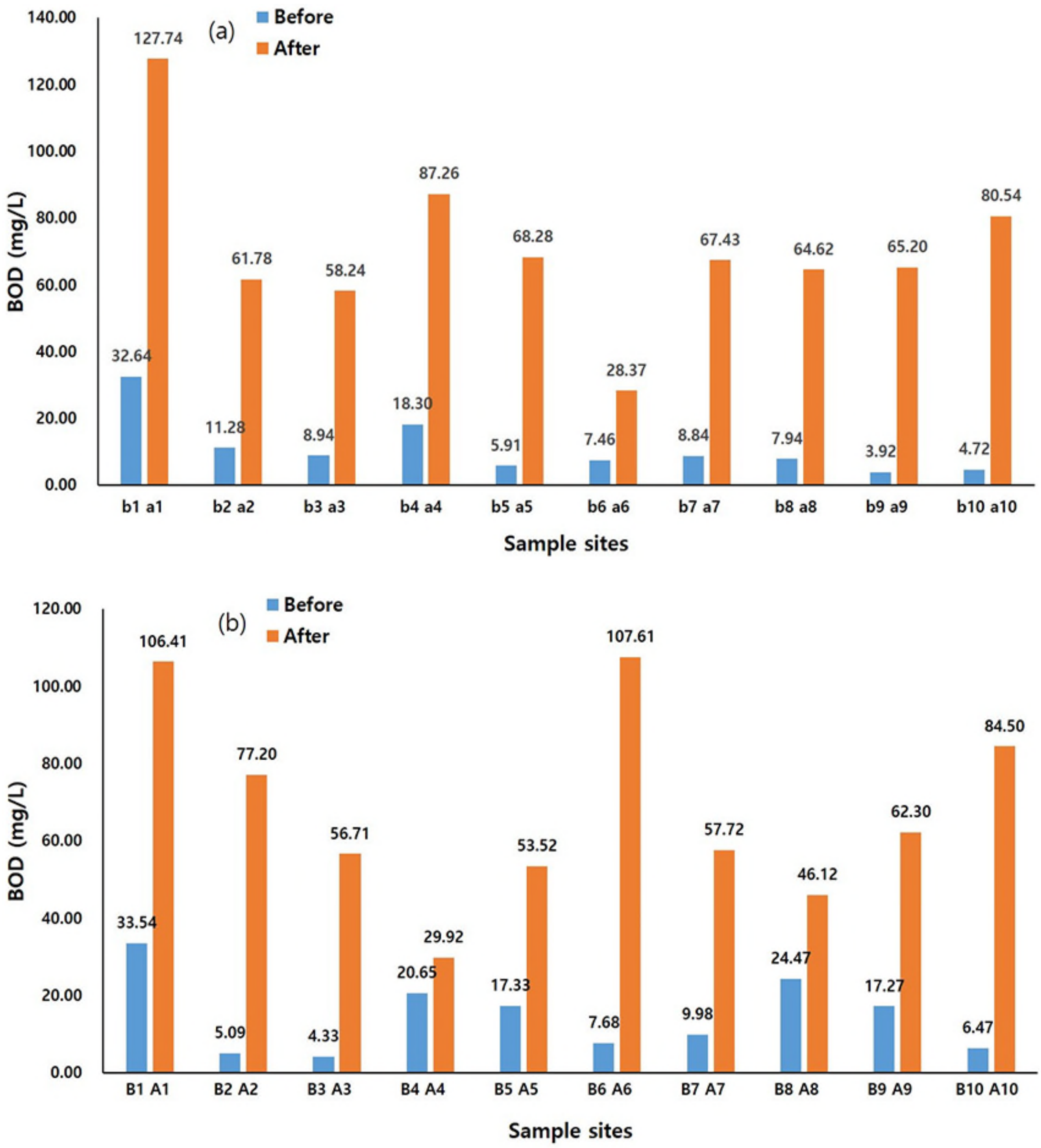

Fig. 5. Amount of change in the BOD concentration in water before and after spraying of (a) CC and (b) MMC on farmland.

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was significantly changed at all sites. The BOD concentration range was 3.92~32.64 mg/L before spraying and 28.37~127.74 mg/L after spraying. Overall, there was no decrease in BOD after spraying, but all increased. Among the 10 sites, the site where the most remarkable increase in BOD was Gyo-ri (No. 10), and the BOD at this site increased 16.06 times from 4.72 to 80.54 mg/L. In relation to MMC, the BOD change in water before and after spraying was similar to that of CC. The BOD concentration for 10 sites ranged from 4.33 to 33.54 mg/L before spraying and from 29.92 to 107.61 mg/L after spraying. There was no decrease in BOD at all sites after spraying, and the site where BOD increased the most was Gwangpyeong-ri (No. 6), which increased 13.01 times from 7.68 to 107.61 mg/L. The average concentration of BOD for 10 sites after spraying of MMC was 14.7 mg/L before spraying and 68.2 mg/L after spraying, and its increase rate was 4.64 times. Meanwhile, in the case of CC, the average concentration of BOD increased 6.45 times from 11.0 mg/L before spraying to 71.0 mg/L after spraying. As a result of analysis, it was verified that when MMC was sprayed on farmland, the BOD in water could be further reduced by 28% compared to CC, which is believed that MMC can play a important role in suppressing BOD in water.

T-N

T-N represents the sum of organic nitrogen (protein, peptide, manure, and factory wastewater) and inorganic nitrogen (ammonia nitrogen, nitrite nitrogen, and nitrite nitrogen). T-N present in water acts as a nutrient salt of aquatic plants and excessively proliferates algae. This temporarily depletes oxygen in the water or blocks light in the water, thereby inhibiting ecosystem circulation [18]. Figs. 6(a) and 6(b) show the amount of change in the T-N concentration in water before and after spraying of CC and MMC on farmland. As you can see, in relation to CC, the concentration range of T-N was from 6.24 to 37.78 mg/L before spraying and was 12.47 to 38.52 mg/L after spraying. No decrease in T-N was observed at all sites after spraying. The site with the most increased T-N was Dochon-ri (No. 1), where increase rate of T-N concentration was 2.59 times from 10.31 to 36.98 mg/L. In the case of MMC, the concentration distribution of T-N was 6.4~85.53 mg/L before spraying and 14.64~79.3 mg/L after spraying. The site where T-N decreased the most after spraying was Jeojeon-ri (No. 8), which decreased by 26.2% from 72.59 to 53.57 mg/L. In contrast, the site with the largest increased T-N was Gwangpyeong-ri (No. 6), and its concentration increased 3.52 times from 6.4 to 28.95 mg/L. Regarding MMC, the average concentration of T-N for 10 test sites increased 1.18 times from 28.0 mg/L before spraying to 33.1 mg/L after spraying. On the other hand, when CC was sprayed, the average concentration of T-N increased 1.71 times from 14.0 mg/L before spraying to 24.0 mg/L after spraying. Based on these results, it is believed that T-N in water can be reduced by 30.9% with MMC compared with CC.

T-P

T-P is referred to as the sum of orthophosphate/phosphate, condensed phosphate, and organophosphorus. and represents the total amount of phosphorus contained in water. In water, it is well known as one of the nutrients essential for the growth of aquatic life and is a major component that induces excessive growth of algae [9]. The amount of changes in T-P concentration in water before and after spraying of CC and MMC on farmland are shown in Figs. 7(a) and 7(b). As shown, after CC spraying, T-P concentration in water increased in all 10 sites. Before spraying, T-P was distributed in the range of 0.6 and 7.09 mg/L, and after spraying, T-P was ranged from 8.63 to 19.31 mg/L. The site where T-P increased the most was Gyo-ri (No. 10), and the increase rate of its concentration was 12.7 times. The change in T-P concentration in water after MMC spraying showed a similar trend to that of CC. The T-P concentration in water for 10 sites was 1.47~9.89 mg/L before spraying, and T-P was 10.17~21.13 mg/L after spraying. An increase in the T-P concentration was observed in all sites after MMC spraying. The site where T-P increased the most was Dochon-ri (No. 2) and its concentration increased 8.27 times. In relation with MMC, The average concentration of T-P for 10 test sites was 4.8 mg/L before spraying and 14.7 mg/L after spraying, and the increase rate of its concentration was 3.06 times. On the other hand, in the case of CC, the average concentration of T-P increased 4.22 times from 2.9 mg/L before spraying and 12.0 mg/L after spraying. Consequentially, it was found that T-P decreased by 27.52% more when using MMC instead of CC.

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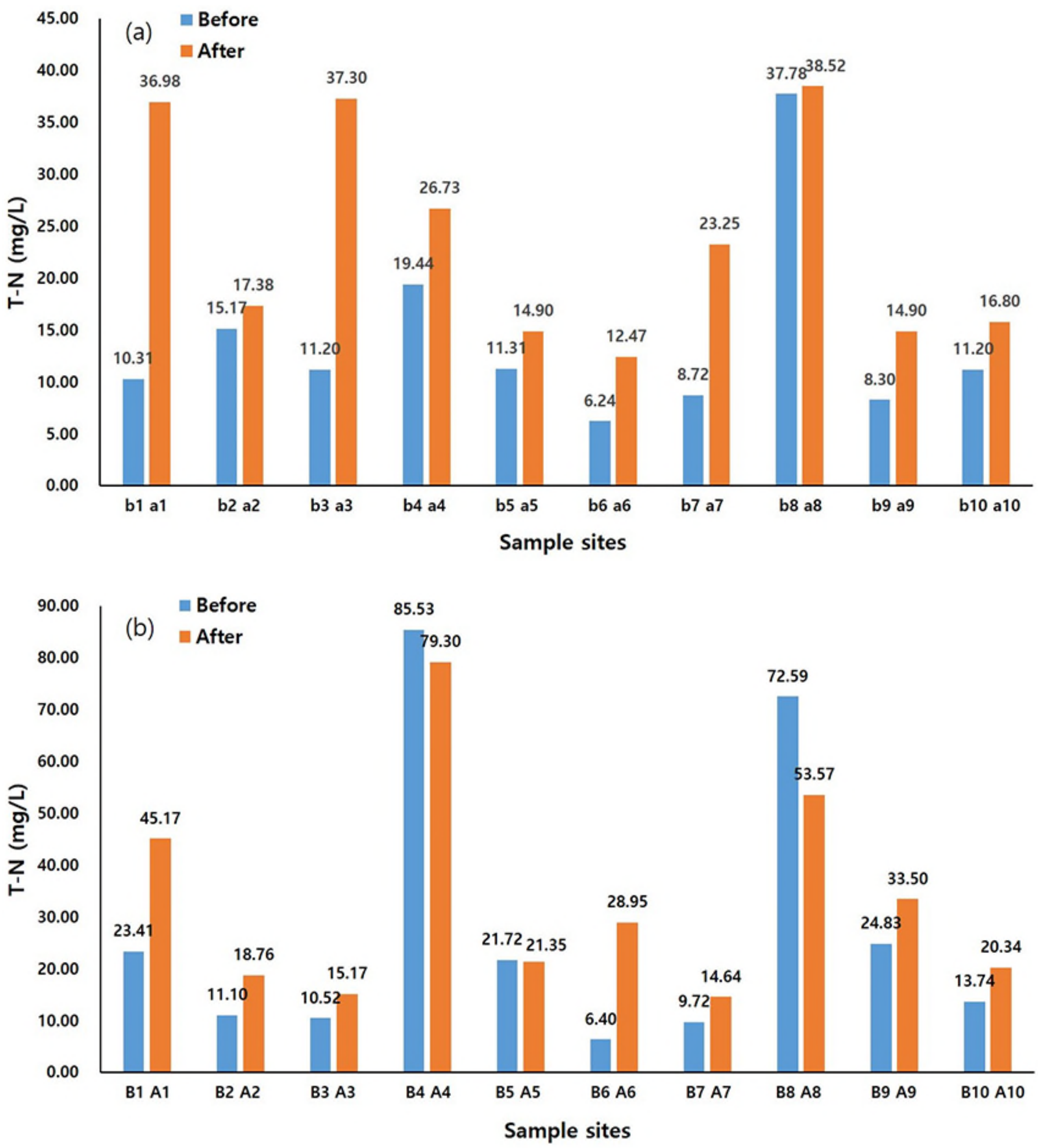

Fig. 6. Amount of change in the T-N concentration in water before and after spraying of (a) CC and (b) MMC on farmland.

Analysis of soil items

EC

EC is a measure of the dissolved capacity of ionic substances, and high electrical conductivity means that ions are well soluble in water. The dissolved ions include cations and anions. Most of the cations are inorganic elements such as potassium, sodium, calcium, and magnesium, and the anions refer to chlorine ions, sulfate ions, and nitric acid ions. When the electrical conductivity of the soil is high, a lot of various ions are dissolved out. However, in compost, as the boiling proceeds, the amount of ions that are temporarily dissolved tends to decrease due to stabilization [19]. Figs. 8(a) and 8(b) show the amount of change in EC in soil before and after spraying of (a) CC and (b) MMC on farmland. With regard to CC, the EC level in the 10 soil samples was 46~369 uS/cm before spraying and 262~688 uS/cm after spraying. As for MMC, EC level ranged from 35 to 718 uS/cm before spraying and 258 to 745 uS/cm after spraying and there was no decrease in EC in all 10 sites

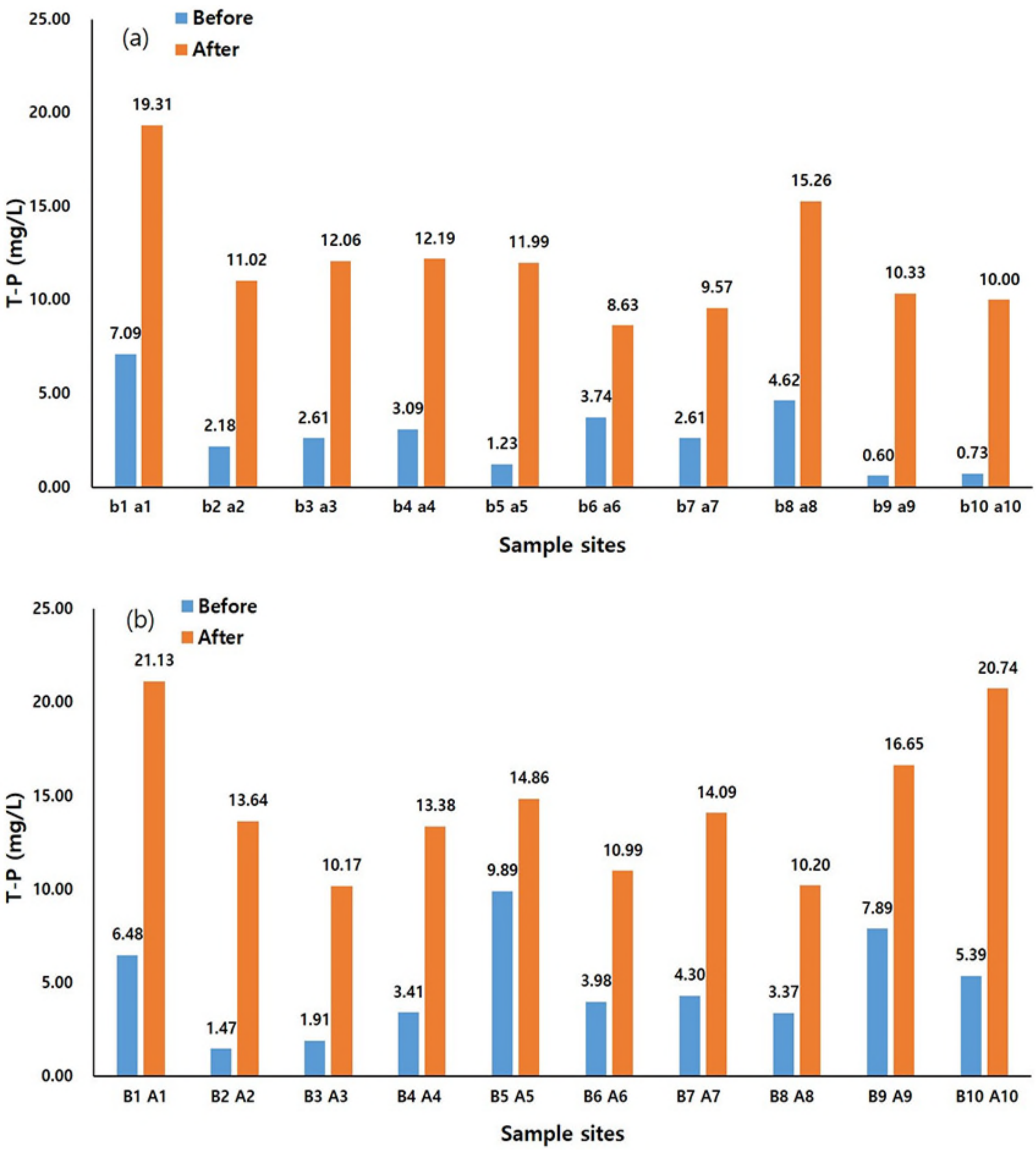

Fig. 7. Amount of change in the T-P concentration in water before and after spraying of (a) CC and (b) MMC on farmland.

under investigation after spraying. EC of the soil increased 1.89 times from 240.2 uS/cm before MMC spraying to 454.1 uS/cm after MMC spraying. Meanwhile, in the case of CC, the average level of EC increased from 170 uS/cm before spraying to 466.3 uS/cm after spraying, and its increase rate was 2.73 times. When comparing CC and MMC in relation to EC, the increase rate of EC was lower in the soil applied with MMC. This phenomenon stems from the fact that MMC is better matured than CC due to the addition of a maturity accelerator. When MMC, which has better maturity, is applied to the soil, the fertility of the soil increases, and the amount dissolved and lost by rainwater decreases.

pH

The pH of the soil has a close influence on the growth of the crop. If the pH is low, the elution amount of various mineral components from the soil increases, which is advantageous for crop growth, but the elution of excessive mineral components may act as a cause of water pollution. A low pH below 5 inhibits plant growth, so the pH should be arbitrarily adjusted. The higher the maturity degree of compost, the higher pH. At higher pH, the loss of inorganic nutrients contained in the

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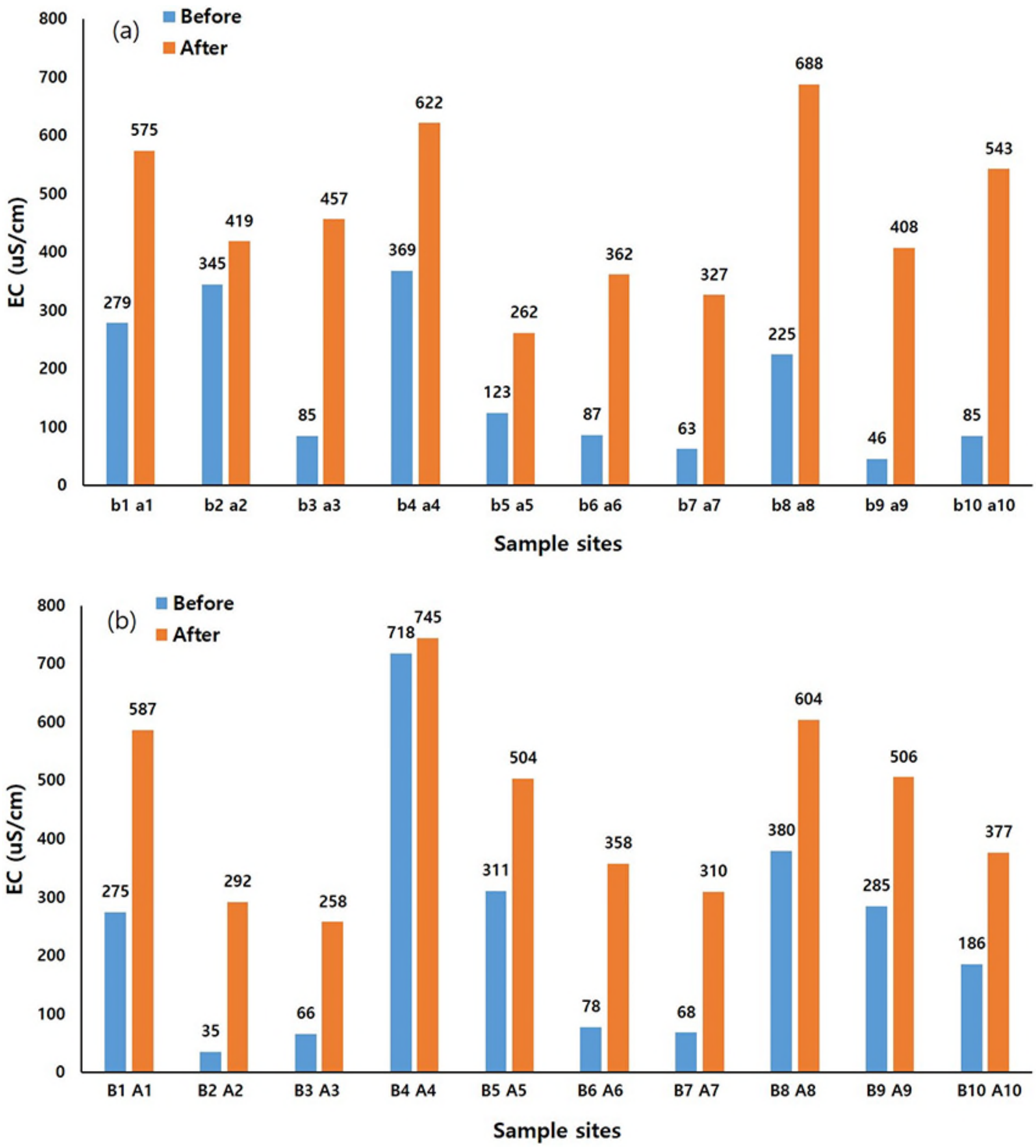

Fig. 8. Amount of change in EC in water before and after spraying of (a) CC and (b) MMC on farmland.

soil tends to decrease, thereby increasing the fertility of the soil. Figs. 9(a) and 9(b) represent the pH change in the soil before and after spraying of CC and MMC on farmland. As for CC, the pH ranged from 5.41 to 6.87 before spraying and from 6.33 to 7.27 after spraying. When comparing before and after CC spraying, there was no decrease in pH in all 10 sites. Out of 10 sites, the site where the pH increased the most was Dochon-ri (No. 2), where the pH increased by 26.8%. In the case of MMC, the pH distributed from 4.47 to 7.06 before spraying and from 6.21 to 7.45 after spraying, and there was no decrease in pH after spraying. The site where the pH increased the most was Gwangcheon-ri (No. 4), and pH increased by 38.93%. As a result, pH of the soil tended to increase slightly when MMC was sprayed than when CC was sprayed on farmland. It can be presumed that this is due to the improvement of the maturity of compost and the increase in the elution amount of minerals added to MMC. It is obvious that MMC has a better effect on increasing the pH of the soil, which is considered to be more efficient in increasing the fertility of the soil by reducing the loss of inorganic nutrients lost from the soil.

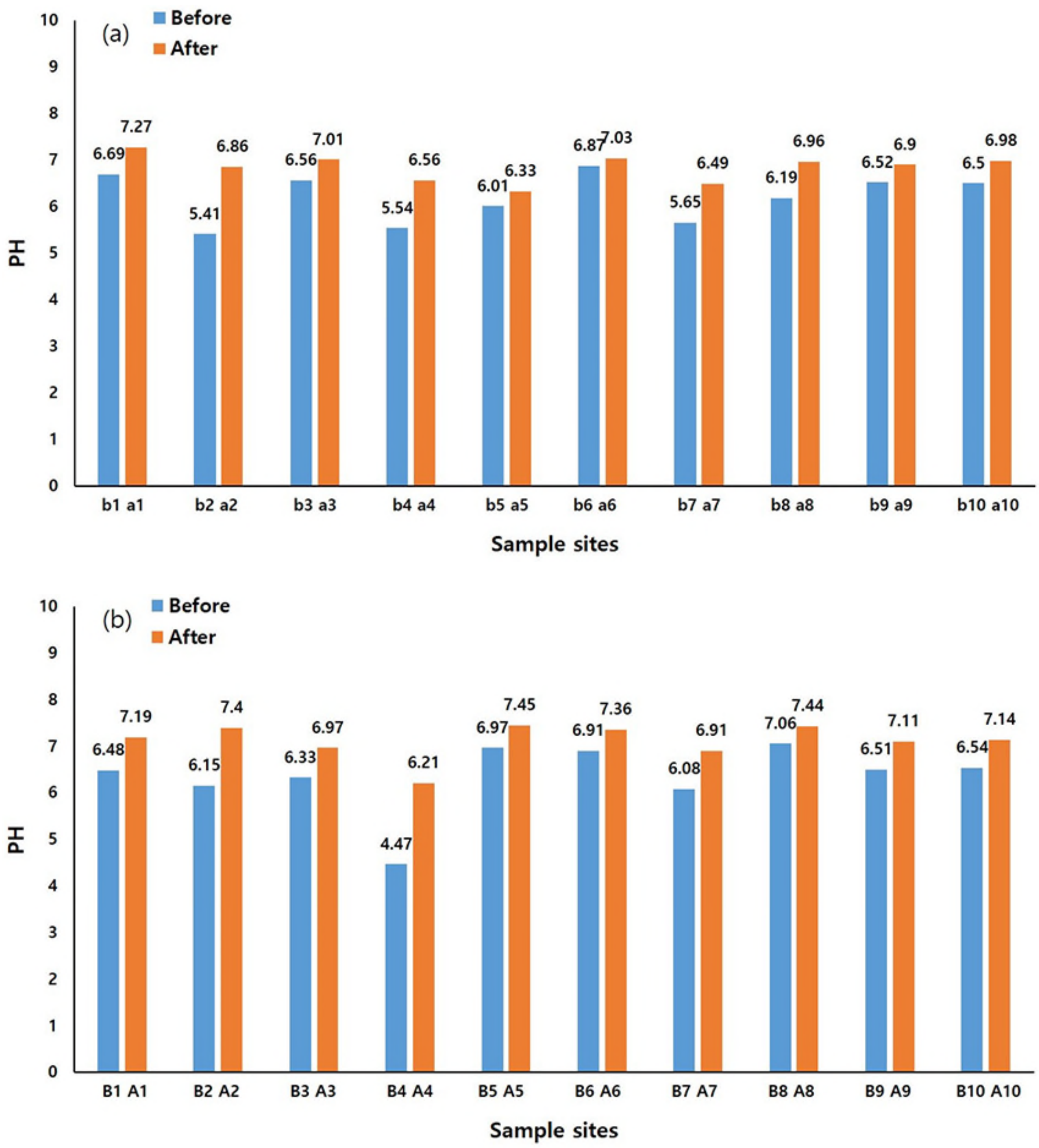

Fig. 9. Changes in pH in soil before and after spraying of (a) CC and (b) MMC on farmland.

Effective phosphoric acid

Effective phosphoric acid refers to phosphoric acid in the form that crops can absorb. Phosphoric acid has the closest relationship to plant growth, such as photosynthesis and respiration, and is an important factor acting on the circulation system between soil and crops. If phosphoric acid is deficient, root development becomes poor, terrestrial growth is also suppressed, resulting in smaller leaves and a grayish-colored color. Excessive accumulation of phosphoric acid in the soil does not affect plant growth disorders, but if it is lost by rainwater and flows into rivers, resulting in eutrophication or contamination of groundwater. It may also lead to a deficiency of trace elements in crops by combining them with micro nutrients and insolubilizing them. In general, compost, which can be continuously eluted in small amounts of effective phosphoric acid, is advantageous for crop cultivation [20]. Figs. 10(a) and 10(b) show the amount of change in the concentration of effective phosphoric acid on the farmland before and after spraying of CC and MMC on farmland. As regard with CC, the distribution of the effective phosphoric acid concentration was 25.42~324.04 mg/kg before spraying, and 147.48~422.27 mg/kg after spraying. When comparing before and after CC spraying, there was no decrease in the concentration of effective phosphoric acid in all 10 sites. The

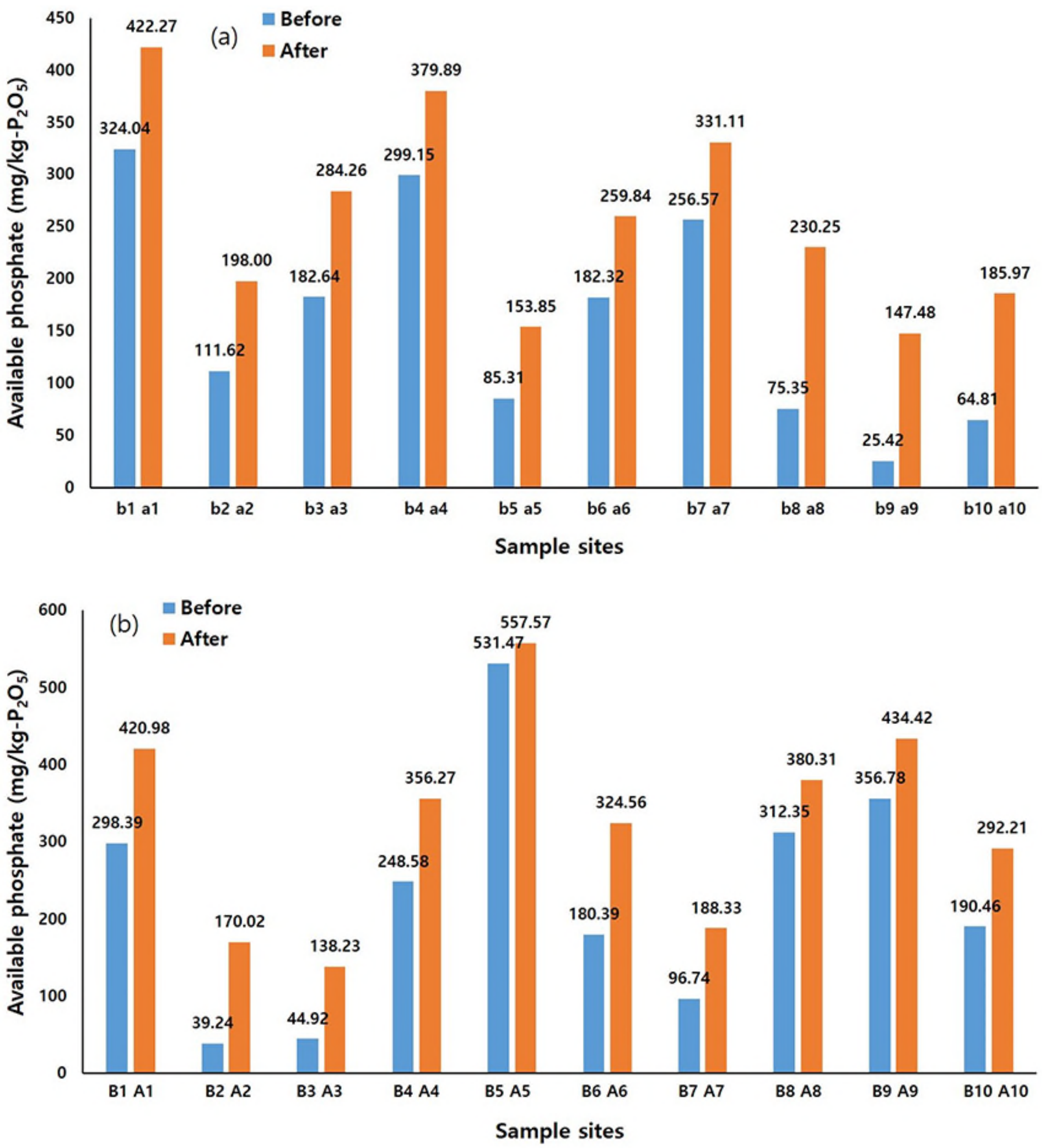

Fig. 10. Amount of change in the concentration of effective phosphoric acid in soil before and after spraying of (a) CC and (b) MMC on farmland.

site with the highest increase in effective phosphoric acid was the Jeojeon-ri (No. 8), and its increase rate was 4.8 times from 25.42 to 147.48 mg/kg. In the case of MMC, the concentration of the effective phosphoric acid ranged from 39.24 to 531.47 mg/kg before spraying and 138.23 to 557.57 mg/kg after spraying. No site was observed decrease in the effective phosphoric acid after spraying. The site where the effective phosphoric acid increased the most was Dochon-ri (No. 2), and its increase rate was 3.33 times from 39.24 to 170.02 mg/kg. For the 10 test sites sprayed with MMC, the average concentration of effective phosphoric acid eluted from the soil increased 1.42 times from 229.9 mg/kg before spraying to 326.3 mg/kg after spraying. While, in the case of CC, the average concentration of effective phosphoric acid increased 1.61 times from 160.7 mg/kg before spraying and 259.3 mg/kg after spraying. Resultingly, it was found that the elution amount of effective phosphoric acid by MMC was reduced by 12.04% compared to that of CC. It is assumed that the fertility of the soil can be increased slightly because MMC has relatively higher phosphoric acid remaining in the soil than CC. In addition, as the amount of effective phosphoric acid that can be lost to rainwater is also reduced, water pollution can be reduced.

Organic matter

Organic matter softens the soil and provides nutrients to help crops grow. Lack of organic matter in soil deteriorates physical properties and lowers the growth of crop roots, resulting in poor quality of agricultural products. Therefore, the higher the content of organic matter, the better the role of compost. Organic matter made of fibers such as cellulose is not well decomposed in water, which does not affect water pollution, but the higher the content of organic matter, which dissolves well in water or is easily decomposed by microorganisms, the more it affects water pollution. Organic matter such as livestock excreted by biological activities is easily decomposed in water and has a high content of organic matter that increases the impact on water pollution. In the case of compost consisting of livestock manure, organic matter that is well matured is not easily dissolved or decomposed in water, so the higher the content, the better [21]. Figs. 11(a) and 11(b) show the amount of change in organic matter before and after spraying of CC and MMC. In relation with CC, the amount of change in organic matter in the test sites ranged from 0.02 to 1.0 % and 0.06 to 2.32% before and after spraying, respectively. There were no sites where organic matter decreased after spraying. The site where organic matter increased the most was Dochon-ri (No. 3), which increased

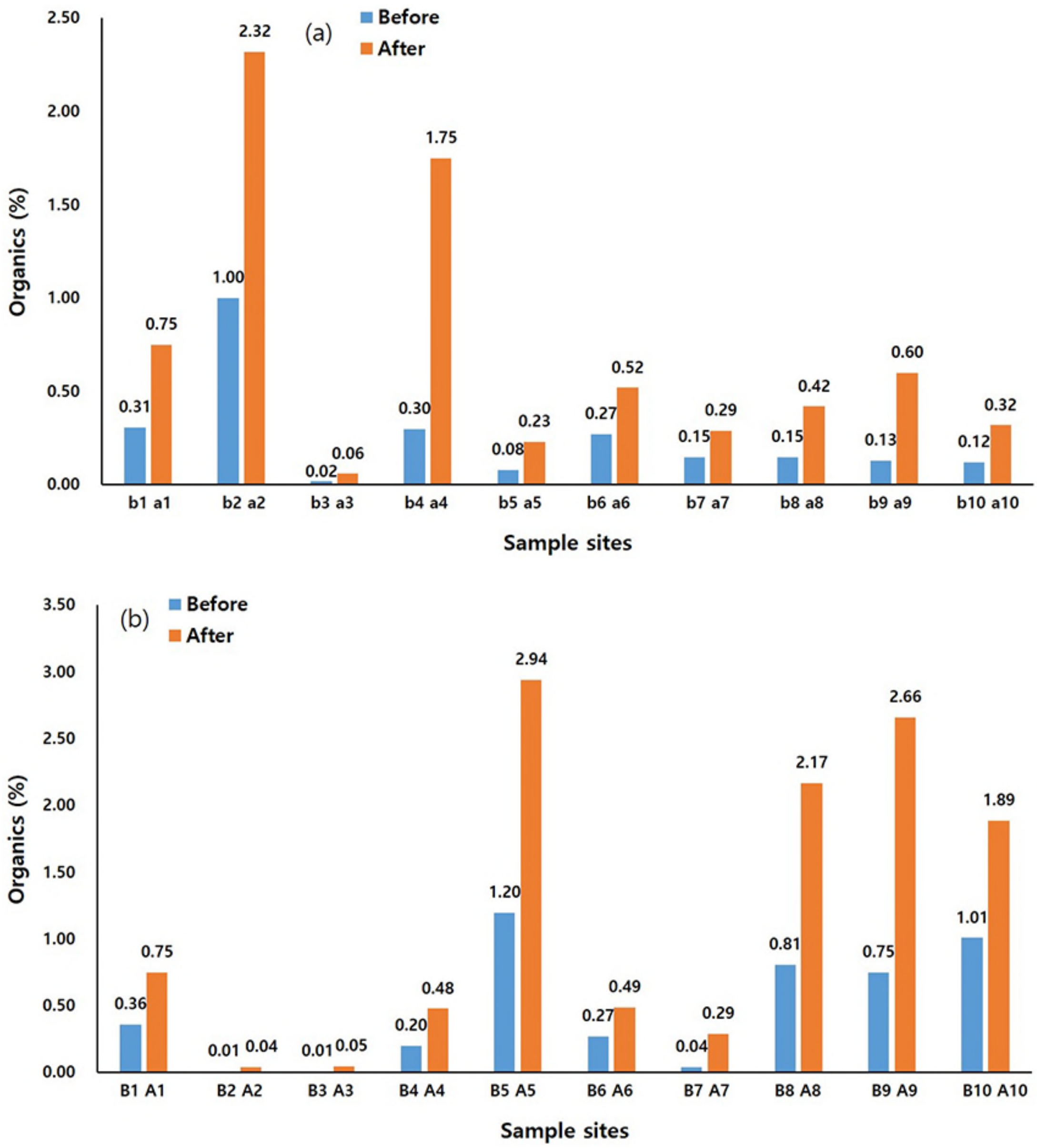

Fig. 11. Amount of change in organic matter in soil before and after spraying of (a) CF and (b) MMF on farmland.

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4.83 times. For MMC, the content of organic matter before spraying ranged from 0.01 to 1.2%, and from 0.04 to 2.94% after spraying. In all sites, the content of organic matter after spraying increased compared to before spraying, and the site with the largest increase was Songcheon-ri (No. 9). In relation with MMC, the average content of organic matter in the 10 test sites increased 2.53 times from 0.47% before spraying to 1.18% after spraying. In the case of CC, it increased 2.88 times from 0.25% before spraying to 0.73% after spraying. When comparing the difference in organic matter content for CC and MMC, there was no significant difference in the rate of increase in organic matter.

CEC

CEC states the total amount of substitutable cations that a certain amount of soil can hold. Ions related to CEC are exchangeable basic cations such as calcium ions (Ca^{2+}), magnesium ions (Mg^{2+}), sodium ions (Na^{+}), and potassium (K^{+}) ions. CEC not only gives the soil the ability to retain nutrients, but also becomes a very important factor in determining how the soil

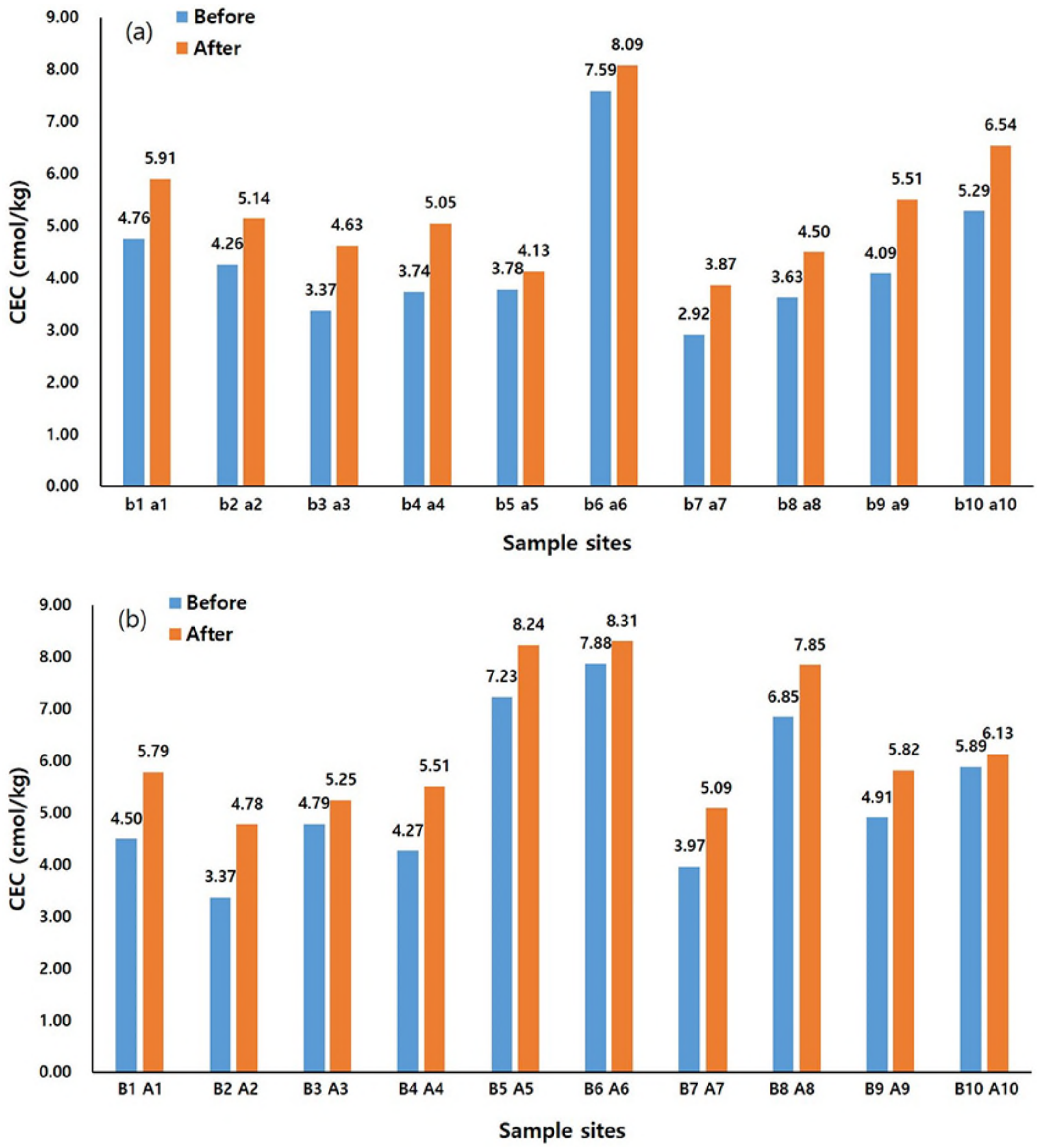

Fig. 12. The amount of change in CEC in soil before and after spraying of (a) CC and (b) MMC on farmland.

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reacts when fertilizer or soil conditioner is injected. Since the surface of the minerals or organic substances that make up the soil is negatively charged, positively charged cations are attached by electrostatic attraction. In general, soil with more negative charges becomes more fertile because it can hold more cations. CEC is closely related to pH. The soil is defined as fertile when the pH of the soil is high, resulting in retaining a lot of basic cations. In fertile soil, the amount of substituted Ca is an indicator of soil fertility because the amount of base decreases in the order of Ca > Mg > K > Na [22]. The amount of change in CEC before and after spraying of CC and MMC is shown in Figs. 12(a) and 12(b). Regarding CC, CEC ranged from 2.92 to 7.59 cmol/kg before spraying and from 3.87 to 8.09 cmol/kg after spraying. In all sites, no sites were observed decrease in CEC before and after spraying. The site where CEC increased the most was Dochon-ri (No. 3), and its increase rate increased by 37.4%. In the case of MMC, CECs before and after spraying were 3.37 to 7.88 cmol/kg and 4.78 to 8.31 cmol/kg, respectively. CEC increased slightly in each test site, and the site where CEC increased the most was Dochon-ri (No. 2). The CEC average for the 10 test sites sprayed with MMC increased 1.17 times from 5.37 cmol/kg before spraying to 6.28 cmol/kg after spraying. While, for CC, the average of CEC increased 1.23 times from 4.34 cmol/kg before spraying to 5.34 cmol/kg after spraying. Considering the analysis results of CEC, both CC and MMC showed almost similar trends in terms of soil fertility.

Conclusion

This research was conducted to improve water pollution and recover soil through field test using MMC. For field test, 20 farmland sites in 5 areas near Songya stream were selected, and CC as a contrast role and MMC manufactured in this study were sprayed on farmland, respectively. After that, various items of water and soil before and after spraying were analyzed and compared. The water items surveyed were BOD, TOC, TSS, T-N, and T-P, and the soil items were pH, EC, effective phosphoric acid, organic matter, and CEC. They were all analyzed according to the Korean Agricultural Environment Resource Analysis Act. MMC was a compost manufactured through the maturity process for 4 weeks after adding magnesia and mineral supplier (called as maturity accelerator in this study) to the Korean cattle compost. The main components that make up MMC were MgO, SiO_2, P_2O_5, K_2O, and CaO and contained about three times more MgO than CC (commercial compost). MMC met the process standards for livestock composting related to heavy metals. From analysis results of the maturity inspection, the maturity accelerator-treated compost showed the ammonia gas removal rate of 85% or more compared to the maturity accelerator-untreated compost. Furthermore, the maturity degree appeared from the early stage of maturity to the mid and late of maturity four weeks later. It was proved that the addition of maturity accelerator to Korean cattle compost was very effective in promoting the decomposition of the Korean cattle compost. By mineral elution test, MMC-treated compost increased 1.51 times in Ca, 1.57 times in Mg, and 2.75 times in S, which are major mineral elements, compared to the MMC-untreated compost. When spraying MMC on farmlands, TOC, BOD, T-N, and T-P in water were reduced by 19.1% and 28.0%, 30.9%, and 27.5% respectively, compared to those of CC. MMC tended to slightly increase the pH of the soil than CC. MMC decreased in effective phosphoric acid by 12.04% compared to CC. It is judged that MMC can increase the fertility of the soil and at the same time reduce the pollution of water as the amount of phosphoric acid that can be lost to rainwater decreases. Through the analysis items of water and soil, it can be seen that MMC is more effective in improving water pollution and recovering soil than CC.

Data Availability: All data are available in the main text or in the Supplementary Information.

Author Contributions: K.-S.R. conceived and designed the research; K.-S.R. collected the data; K.-S.R. performed the analysis; K.-S.R. wrote the first manuscript.

Notes: The authors declare no conflict of interest.

Additional Information:
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