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Derivation of Monitoring Factors to Produce Liquid Manure Fertilizers from the Aerobic Liquid Fertilization Process of Pig Slurries

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In this study, 150 liquid fertilizers in 2012 and 70 liquid fertilizers in 2015 were sampled and analyzed to derive the process monitoring factors for the production of stabilized liquid fertilizer during the liquid composting of pig slurry. Dissolved oxygen (DO) and oxidation–reduction potential (ORP), which are major operating factors of the liquid composting process, tend to increase with the improvement of organic stabilization degree in the liquid composting of pig slurry, but pH and suspended solid (SS) did not show any significant difference regardless of the organic stabilization degree of liquid fertilizer. Electric conductivity (EC), soluble chemical oxygen demand ($SCOD_{Cr}$), total nitrogen (TN), and ammonium nitrogen (NH_4^+–N) showed a significant decreasing tendency, and nitrate nitrogen (NO_3^-–N) and total phosphorus (TP) showed no significant differences with the improvement of organic stabilization degree in the liquid composting of pig slurry. And there was a significant correlation between the EC, TN, and NH_4^+–N parameters in the correlation analysis of the chemical properties of the stabilized liquid fertilizer. Therefore, EC, $SCOD_{Cr}$, TN, and NH_4^+–N were derived as chemical parameters that could distinguish the characteristics of stabilized liquid fertilizer. Especially, the EC parameter was evaluated as an useful indicator for the quality control of liquid fertilizer in the monitoring of overall liquid composting process of the pig slurry.

Key words: Liquid composting, Pig slurry, Liquid fertilizer, Organic stabilization degree, Monitoring parameter

INTRODUCTION

Livestock manure contains both major and minor vegetative nourishment such as nitrogen (N), phosphorus acid (P_2O_5), and potassium (K_2O) in addition to humic organic matter. Thus, it can increase the organic matter, cation exchange capacity and the supply of nutrients in soils for crops during farm restoration. Thus, it can both supply various nutrients and growth stimulating agents to crops and increase the soil aggregation formation, buffer capacity, chelation functions, and the effect of soil biota (Lee *et al.*, 2011).

Crop–livestock farming that utilizes livestock manure generated in farms and/or in field husbandry and supplies feedstuffs to livestock that were produced in field husbandry can achieve eco–friendly farming status based on the natural circulation principle for substances. However, the use of non–stabilized livestock liquid manure fertilizer that does not meet quality criteria and the excessive application of fertilizers become the main disturbance in the soil's crop cultivation function and water pollution problems can arise due to non–point pollution sources in agricultural lands. Thus, quality control in livestock manure for compost and liquid manure fertilizer and the appropriate application of fertilizers are highly important in terms of agricultural environment conservation and the prevention of water pollution. In particular, the government has strengthened the management of non–point pollution sources that are generated in agricultural lands while operating a total water pollution load management system to preserve water quality in environments against degradation due to livestock manure. In addition, the government plans to adopt a total maximum nutrient load management system to prevent the excessive use of fertilizer ingredients in agricultural lands and preserve a sustainable agricultural environment, indicating the growing need for quality control in livestock manure compost and liquid manure fertilizer and their appropriate use.

When livestock manures are neglected in barns or grounds and the surrounding areas or when livestock manure compost and liquid manure fertilizers are used excessively, they run off as non–point pollution sources during rainfall (Lee *et al.*, 2009; Lee and Lee, 2009; Han and Lee, 2013). The rainfall effluent generated around barns reportedly contains 7–28 times more nutrient salts than the water quality criteria for effluence from public treatment facilities, which is then discharged to a river (Hwang *et al.*, 2012). As described in the above, non–point pollution sources from livestock manures degrade the self–purification function of streams due to the excessive loads of pollutants introduced into the water environment. In addition, as the paradigm of food production has changed in recent years from quantity and quality priority to safety and functionality, Korea, CODEX, and EU nations have extended regulation standards for harmful substances such as heavy metals in agricultural products and the environment such as soils in agricultural land (Go *et al.*, 2012). Consequently, much atten-

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tion has been paid to safety management such as heavy metals in composts and liquid manure fertilizer as employed in agricultural production.

The livestock manure generated in Korea amounted to 46,489,000 tons in 2002, of this, 37,656,000 tons (81.0%) was composted, 3,580,000 tons (7.7%) was turned into liquid fertilizer, and 4,210,000 tons (9.1%) was treated using purification (MAFRA, 2013). In particular, around 74% of pig farms in Korea adopted a slurry pigsty structure, which is characterized by the discharge of the mixed feces and urine of pigs with cleansing water that is used by farmers as a form of slurry with greater than 95% moisture content. Pig slurries require a large amount of a moisture control agent (sawdust) for composting treatment due to their high moisture content, which carries the problem of high cost. Thus, much attention has been paid to liquid fertilization as a measure for the economic utilization of pig slurries. In this regard, the Ministry of Agriculture, Food and Rural Affairs has planned and started a policy of promoting liquid manure fertilization through strengthening the quality of livestock manure fertilizers and continuous stabilization management in "the Mid– to Long–term Livestock Manure Recycling Measure" (MAFRA, 2013). The main quality control problems for livestock manure fertilizers are: the lack of quality criteria for liquid manure fertilizer in individual farms, avoidance of use in agriculture farmhouse due to the non–stabilized nature of the liquid manure fertilizer spray, and complaints regarding odor.

The quality standard for livestock manure liquid fertilizer is managed through the Notification of the Rural Development Administration. The current quality standards for livestock manure liquid fertilizer has set amounts for the fertilizer ingredients (nitrogen, phosporus, and potassium) and harmful substances (heavy metals and pathogenic microorganisms) that are included in liquid fertilizers. A mechanical stabilization index for liquid fertilizer products is used for stabilizing liquid fertilizers for color and odor substances.

Furthermore, several studies have focused on quality control for livestock manure liquid fertilizer products such as studies that compare the physico–chemical characteristics in livestock manure liquid fertilizers (Jeon *et al.*, 2012a), main level–grading factors for the establishment of a Liquid Fertilizer Quality Certification (LFQC) system for livestock manure in Korea (Jeon *et al.*, 2012b), a comparative study on correlation through a physiochemical property comparison for livestock liquid fertilizer (Jeon *et al.*, 2013), and a study with which to draw a plan of liquid fertilizer quality certification standards for livestock manure management (Jeon *et al.*, 2013) for the appropriate use and promotion of livestock manure liquid fertilizers and to strengthen quality standards for livestock manure liquid fertilizers. However, the quality control–centered system of manufactured products is limited to managing the prevention of distribution for non–stabilized liquid fertilizers that have already been manufactured. Thus, a study has started on the installation of measuring and monitoring equipment for use in production processes (liquid fertilization processes) by utilizing information and communication technology (ICT) and monitoring liquid fertilization processes to prevent the manufacture of non–stabilized liquid fertilizers during the production phase of livestock manure liquid fertilizers for the quality control of livestock manure liquid fertilizer products.

The present study aims to compare and analyze the chemical characteristics of stabilized liquid livestock manure fertilizers and derive the management factors for stabilization in the liquid fertilizer manufacturing process to derive factors for the management of the operation index in the manufacturing process for liquid livestock manure fertilizers. It also aims to analyze the quality status of livestock manure liquid fertilizers that are distributed locally, thereby utilizing the analysis result for the quality control of livestock manure liquid fertilizers and manage the nutrients.

MATERIALS AND METHODS

Test materials

The livestock manure liquid fertilizers used in this study were collected from storage tanks in the Livestock Manure Public Resourcing Center (LMPRC) and Livestock Liquid Fertilizer Supply Center (LLFSC) around the nation, and 150 samples and 70 samples of stabilized liquid fertilizers were collected and analyzed in May–June in 2012 and 2015, respectively.

Analysis

The collected livestock manure liquid fertilizer samples were measured three times iteratively according to the standard analysis method (APAH, 1998), The measured items were the hydrogen ion concentration (pH), electrical conductivity (EC), suspended solid (SS), total nitrogen (TN), ammonia nitrogen (NH_4^+–N), nitrate nitrogen (NO_3^-–N), total phosphorus (TP), and potassium (K). The heavy metal content (As, Cd, Cu, Cr, Ni, Pb, and Zn) was measured using ICP–MS (GBC Optimass–8000, Australia), and the mercury (Hg) content was analyzed using an automatic mercury analyzer (Direct Mercury Analyzer, DMA80, Milestone, Italy) based on the US EPA method 7476 (US EPA, 1998). Furthermore, the stabilization level of the collected livestock manure liquid fertilizers was analyzed using a mechanical stabilization analyzer (LMQ2000, Korea Spectral Products, Seoul, Korea). SPSS (Version 13.0, SPSS Inc., Chicago, Illinois, USA) was used to analyze the statistical correlation between items through Pearson Correlation Coefficient analysis.

RESULTS AND DISCUSSION

Chemical distribution

The chemical characteristics were analyzed by collecting the samples from LMPRC and LLFSC in 2012. The analysis results for the liquid fertilizer showed that the distribution of liquid fertilizer types was as follows: 55 stabilized (matured), 70 semi–stabilized (semi–matured), and 25 non–stabilized (immature) liquid fertilizers.

The measurement method for the mechanical stabilization level analyzes the stabilization level by measuring the color of the liquid livestock manure fertilizer and the hydrogen sulfide (H_2S) and ammonia (NH_3) content, which are sources of bad odor. In general, humic substances are generated as stabilization progresses, so the color changes to black–brown, and ammonia and hydrogen sulfide change to nitrate ion (NO_3^-) and sulfate ion (SO_4^{2-}) in the aerobic condition.

Table 1, Table 2, and Table 3 present the chemical characteristics of stabilized, semi–stabilized, and non–stabilized liquid fertilizers, respectively. The pH, DO, and EC of stabilized liquid fertilizer were 7.8, 3.7 mg·L^{-1}, and 10.3 dS·m^{-1}, and $SCOD_{Cr}$ 1,205 mg·L^{-1}, SS 7,543 mg·L^{-1}, TN 827 mg·L^{-1}, NH_4^+–N 517 mg·L^{-1}, NO_3^-–N 151 mg·L^{-1}, and TP 285 mg·L^{-1} were revealed. The pHs of semi–stabilized and non–stabilized liquid fertilizers were 8.5 and 8.0, respectively, and their DO were 1.3 and 1.2 mg·L^{-1}, which showed a trend of slight reduction compared to those of stabilized liquid fertilizer (Table 1). The EC of semi–stabilized and non–stabilized liquid fertilizers were 19.0 and 19.8 dS·m^{-1}, which are considerable increases compared to that of stabilized liquid fertilizer. The $SCOD_{Cr}$ contents were 2,106 and 2,215 mg·L^{-1} respectively, which were significant increases compared to that of stabilized liquid fertilizer. Furthermore, the contents of TN and NH_4^+–N were respectively 2,140 and 1,830 mg·L^{-1} in semi–stabilized liquid fertilizer and 2,543 and 2,285 mg·L^{-1} in non–stabilized liquid fertilizer, which were significantly increases compared to those of stabilized liquid fertilizer. The NO_3^- –N content were respectively 83 and 60 mg·L^{-1} in semi–stabilized and non–stabilized liquid fertilizers, which showed a slight decreasing

Table 1. Chemical properties of stabilized liquid fertilizer by the liquid composting of pig slurry in 2012 (Number of samples = 55)

Parameter	pH (–)	DO[a] (mg·L^{-1})	EC[b] (dS·m^{-1})	ORP[c] (mV)	$SCOD_{Cr}$[d]	SS[e]	TN[f]	NH_4^+–N	NO_3^-–N	TP[g]
					(mg·L^{-1})					
Mean	7.8	3.7	10.3	–117	1,205	7,543	827	517	151	285
SD[h]	0.9	3.0	5.6	128	828	7,830	669	662	215	227
Median	7.8	3.3	9.8	–71	919	5,500	693	350	70	227
Max.[i]	9.4	12.3	43.0	199	3,993	34,440	4,159	4,130	805	1,175
Min.[j]	4.4	0.2	3.5	–416	303	340	165	21	0	14

a) Dissolved oxygen, b) Electrical conductivity, c) Oxidation reduction potential, d) Soluble chemical oxygen demand, e) Suspended solid, f) Total nitrogen, g) Total phosphorus, h) Standard deviation, i) Maximum value, j) Minimum value.

Table 2. Chemical properties of semi–stabilized liquid fertilizer by the liquid composting of pig slurry in 2012 (Number of samples = 70)

Parameter	pH (–)	DO[a] (mg·L^{-1})	EC[b] (dS·m^{-1})	ORP[c] (mV)	$SCOD_{Cr}$[d]	SS[e]	TN[f]	NH_4^+–N	NO_3^-–N	TP[g]
					(mg·L^{-1})					
Mean	8.5	1.3	19.0	–247	2,106	6,850	2,140	1,830	83	276
SD[h]	0.6	1.9	6.4	147	1,694	5,278	988	868	119	201
Median	9.6	10.9	37.9	–11	14,123	32,020	5,093	3,780	490	1,197
Max.[i]	8.6	0.6	18.0	–254	1,751	5,880	2,011	1750	35	230
Min.[j]	7.2	0.1	2.6	–443	333	280	272	245	0	26

a) Dissolved oxygen, b) Electrical conductivity, c) Oxidation reduction potential, d) Soluble chemical oxygen demand, e) Suspended solid, f) Total nitrogen, g) Total phosphorus, h) Standard deviation, i) Maximum value, j) Minimum value.

Table 3. Chemical properties of non–stabilized liquid fertilizer by the liquid composting of pig slurry in 2012 (Number of samples = 25)

Parameter	pH (–)	DO[a] (mg·L^{-1})	EC[b] (dS·m^{-1})	ORP[c] (mV)	$SCOD_{Cr}$[d]	SS[e]	TN[f]	NH_4^+–N	NO_3^-–N	TP[g]
					(mg·L^{-1})					
Mean	8.0	1.2	19.8	–291	2,215	5,939	2,543	2,285	60	370
SD[h]	0.6	1.8	9.0	119	1,387	9,063	1,446	1,438	112	385
Median	8.0	0.7	19.4	–297	1,656	2,400	2,205	1,820	0	246
Max.[i]	9.0	9.2	37.1	–64	5,908	41,640	5,433	5,250	420	1,264
Min.[j]	6.5	0.0	5.8	–451	517	240	274	560	0	25

a) Dissolved oxygen, b) Electrical conductivity, c) Oxidation reduction potential, d) Soluble chemical oxygen demand, e) Suspended solid, f) Total nitrogen, g) Total phosphorus, h) Standard deviation, i) Maximum value, j) Minimum value.

trend (Table 2 and Table 3).

Table 4 presents the chemical properties of livestock manure liquid fertilizer as investigated in 2015. The pH and EC of the livestock manure liquid fertilizer investigated in 2015 were 8.1 and 13.1 dS·m^{-1} and SS 5,188 mg·L^{-1}, TN 1,109 mg·L^{-1}, NH_4^+–N 317 mg·L^{-1}, NO_3^-–N 170 mg·L^{-1}, and TP 239 mg·L^{-1} were revealed. The heavy metal content contained in the livestock manure stabilized liquid fertilizer investigated in 2015 (Table 5) met the standards for heavy metal content as specified in the livestock manure fermentation liquid in the specification and designation of the fertilizer process specification (Notification 2016–26 from the Rural Development Administration). Only a single case was revealed in which zinc (Zn; Max: 131.30 mg·kg^{-1}) exceeded the content standard.

Fig.1 shows the comparison of distribution for the main physiochemical items from livestock manure stabilized liquid fertilizer as investigated in 2012 and 2015. A similar property distribution was revealed for pH between 2012 and 2015, and the distribution range of item values was widened for EC and TN but no difference was found for the mean values. In contrast, a significant reduction was revealed in the distribution range for TP in 2015. The Ministry of Agriculture, Food and Rural Affairs supervises solid–liquid separation through vibrating screens in farming households to improve the quality of liquid fertilizer produced at the LMPRC and LLFSC (MAFRA, 2012). It also supports the renovation and repair of solid–liquid separation devices at existing and new facilities. Thus, the decrease in the distribution value for TP in 2015 was caused by the decrease in the amount of solid matter introduced in the fertilization tank.

Characteristic factors of the stabilized liquid fertilizer

Fig. 2 and Fig. 3 compare the distributions of the fertilization process operation factors and chemical property factors among stabilized, semi–stabilized, and non–stabilized liquid fertilizers in livestock manure liquid fertilizers collected in 2012. DO and ORP, which were two of the main operating factors in the fertilization process, showed an increasing trend as the stabilization of liquid fertilizers progressed, whereas pH and SS did not show a clear difference between stabilized, semi–stabilized, and non–stabilized liquid fertilizers. Furthermore, EC, $SCOD_{Cr}$, TN, and NH_4^+–N showed a clear decreasing trend in stabilized liquid fertilizer among chemical factors in liquid fertilizer, whereas NO_3^-–N and TP did not show any distinguished difference among stabilized, semi–stabilized, and non–stabilized liquid fertilizers. Accordingly, EC, $SCOD_{Cr}$, TN, and NH_4^+–N were found as chemically characteristic factors that could distinguish the characteristics of stabilized liquid fertilizer.

The liquid fertilization process for pig slurries can largely be divided into anaerobic and aerobic liquid fertilizations. Anaerobic liquid fertilization refers to the process of decomposition for organic matter via anaerobic microorganisms in the condition of withholding oxygen, which generates both various types of organic acids and

Table 4. Chemical properties of stabilized liquid fertilizer by the liquid composting of pig slurry in 2015 (Number of samples = 70)

Parameter	pH (–)	EC[a] (dS·m^{-1})	SS[b]	TN[c]	NH_4^+–N	NO_3^-–N	TP[d]	K
			(mg·L^{-1})					
Mean	8.1	13.1	5,188	1,109	317	170	239	1,681
SD[e]	0.5	6.2	6,115	982	323	256	377	730
Median	8	11.8	5,608	764	243	75	89	1,558
Max.[f]	9.4	32.4	36,400	4,511	1,260	1,190	2,000	3,516
Min.[g]	6.1	6.2	460	0	0	0	0	115

a) Electrical conductivity, b) Suspended solid, c) Total nitrogen, d) Total phosphorus, e) Standard deviation, f) Maximum value, g) Minimum value.

Table 5. Heavy metal contents of stabilized liquid fertilizer by the liquid composting of pig slurry in 2015 (Number of samples = 70)

Parameters	As	Cd	Hg	Pb	Cr	Cu	Zn	Ni
	(mg·kg^{-1})							
Mean	0.04	0.002	0	0.04	3.69	4.01	14.72	3.39
SD[a]	0.06	0.005	0	0.06	0.82	4.86	19.85	0.72
Median	0.03	0	0	0.02	3.83	2.50	8.18	3.49
Max.[b]	0.44	0.03	0	0.36	5.60	30.20	131.30	5.07
Min.[c]	0	0	0	0	1.73	0.13	0.31	1.60
Korean criteria[d]	5	0.5	0.2	15	30	50	130	5

a) Standard deviation, b) Maximum value, c) Minimum value, d) Announced by RDA (No.2016–26).

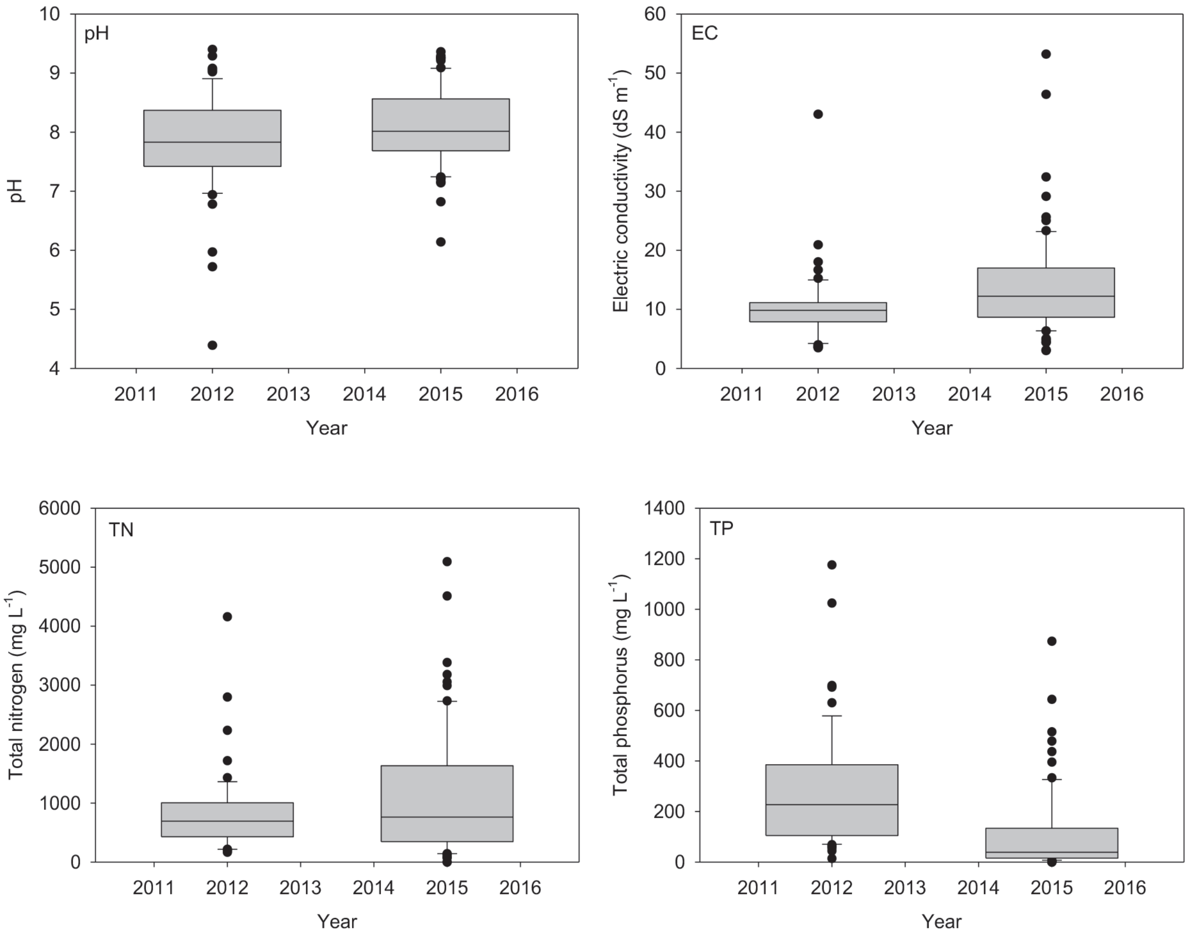

Fig. 1. Comparison of chemical parameters distribution at the stabilized liquid fertilizer in 2012 and 2015 (Number of samples collected in 2012 and 2015 was 150 and 70, respectively. Line within the box marks the median, Boundary of the box indicates from the 25th percentile to 75th percentile, Vertical bars indicate the 90th and 10th percentiles).

methane gases and various odor substances such as ammonia (NH_3) and hydrogen sulfide (H_2S). In contrast, aerobic liquid fertilization refers to a process of transition from biodegradable organic matter into physically, chemically, and biologically stabilized corrosive materials using aerobic microorganisms, in which odor substances such as ammonia or hydrogen sulfide are changed into nitrate nitrogen and sulfur oxides (Jung *et al*., 1998). In Korea, aerobic liquid fertilization facilities are usually constructed in consideration of the safety of organic matter in soils when returning lands for agriculture and civil complaints due to bad odors. Anaerobic digestion facilities also spray an anaerobic digester liquid that is produced after completing bio–gas production via aerobic liquid fertilization.

Basically, a liquid fertilization reaction tank maintains an oxidation state because aerobic liquid fertilization is progressed via long–term or intermittent aeration. Thus, DO, ORP, and NO_3^-–N were expected to increase in stabilized liquid fertilizer. However, the present study result showed that no significant difference was exhibited for semi–stabilized and non–stabilized liquid fertilizers. Furthermore, although a significant increase in pH has been reported in the liquid fertilization process using aeration compared to the liquid fertilization process of stirring and storing in the aerobic liquid fertilization process (Jung *et al*., 1998; Shin *et al*., 1998), no significant difference in pH was revealed in this study among stabilized, semi–stabilized, and non–stabilized liquid fertilizers. The reason for this is that the oxidation of residual organic matter (Biochemical Oxygen Demand (BOD)) continued during the storage of produced liquid fertilizer and the liquid fertilizer storage tank was characterized by the transition into an anoxic state so that aspects that influenced conditions such as pH, DO, ORP, and NO_3^-–N fluctuated. Hence, although pH, DO, ORP, and NO_3^-–N items were utilized as an operation index during the operation circumstances in the liquid fertilization process, they did not specify the characteristics of the stabilized liquid fertilizer. In contrast, $SCOD_{Cr}$, TN, and NH_4^+–N items were quantitative items that were reduced through decomposition and volatilization in the aerobic liquid fertilization process (Westerman *et al*., 2000; Kirchmann, 1985; Kirchmann and Witter, 1989), which can be utilized as an index that specifies the characteristics of the produced stabilized liquid fertilizer.

A study reported that EC was reduced as stabilization progressed in the pig slurry liquid fertilization process (Lee *et al*. 2011). The liquid fertilization process of pig slurries decomposes carbohydrates, fats and proteins,

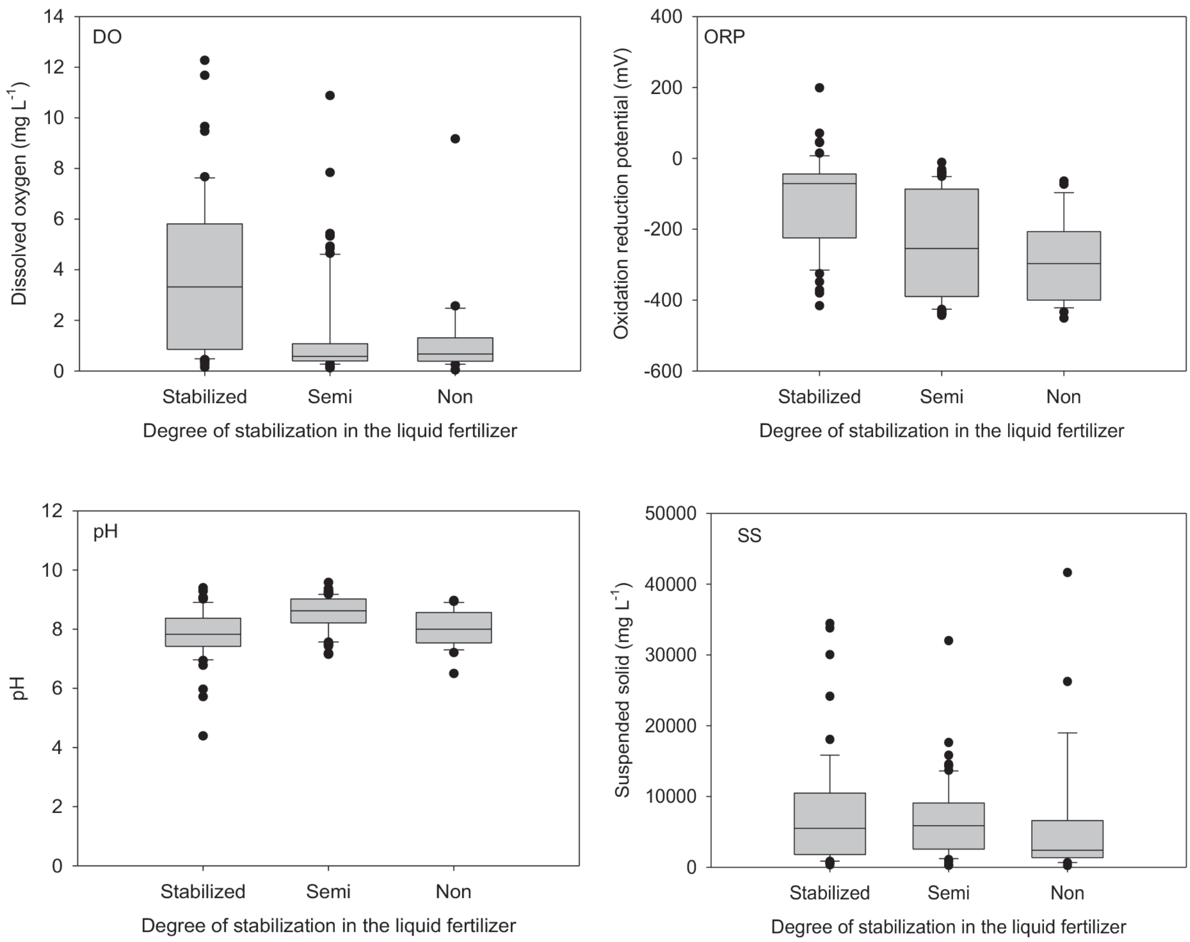

Fig. 2. Distribution plots of operational parameters in the stabilized, semi–stabilized, and non–stabilized liquid fertilizers pig slurry (Samples was collected in 2012 and number of samples was 170, Line within the box marks the median, Boundary of the box indicates from the 25th percentile to 75th percentile, Vertical bars indicate the 90th and 10th percentiles).

and turns them into biologically, chemically, and physically stable corrosive organic matter. Thus, various organic acids and volatile fatty acids are generated and decomposed due to the biological reactions of microorganisms during the liquid fertilization process. Thus, the conversion of ion species such as NH_4^+/NH_3, $CO_2/HCO_3^-/CO_3^{2-}$, and CH_3COOH/CH_3COO^- occurs along with the variation of pH, and $CaCO_3$ (calcite) or $MgNH_4PO_4$. $6H_2O$ (struvite) that is formed from Ca_2^+, Mg_2^+, and $PO_4^{3-}/HPO_4^{2-}/H_2PO_4^-$. The chemical reaction during the liquid fertilization process weakens the ionic strength and reduces the EC (Griffin and Jurinak, 1973; Aceves–Lara *et al.*, 2012). Consequently, Sommer and Husted (2009) reported that there was a strong correlation between EC and the ionic strength in their study on the anaerobic digestion of pig slurries. Thus, EC can become an index that represents a change in the overall liquid during pig slurry liquid fertilization, and can thus be utilized as an item that specifies the characteristics of stabilized liquid fertilizers. However, the mechanism of EC reduction during the liquid fertilization process for pig slurries has not yet been disclosed. Thus, additional studies on the mechanism of EC reduction during the stabilization process for liquid fertilizers made from pig slurries are needed to utilize the EC item as a management index of the stabilization level during the liquid fertilization process for pig slurries.

Correlation between the characteristic factors of stabilized liquid fertilizers

Table 6 outlines the analysis results for the correlation between the chemical characteristic factors of stabilized liquid livestock manure fertilizers. The pH of stabilized liquid fertilizers showed a significant correlation with TN at the 95% confidence level, and with NH_4^+–N at the 99% confidence level. The EC of stabilized liquid fertilizers showed a significant correlation with TN, NH_4^+–N, and K at the 99% confidence level, and with NO_3^-–N at the 95% confidence level. Furthermore, the SS of stabilized liquid fertilizers showed a significant correlation with TN, NO_3^-–N, and TP at the 99% confidence level, and TN showed a significant correlation with NH_4^+–N, NO_3^-–N, and TP at the 99% confidence level.

Thus, a high correlation was found among EC, TN, and NH_4^+–N, which can be chemical factors that specify the characteristics of stabilized liquid fertilizers as investigated above. The above study results indicate that only one of EC, TN, or NH_4^+–N can determine the stabili-

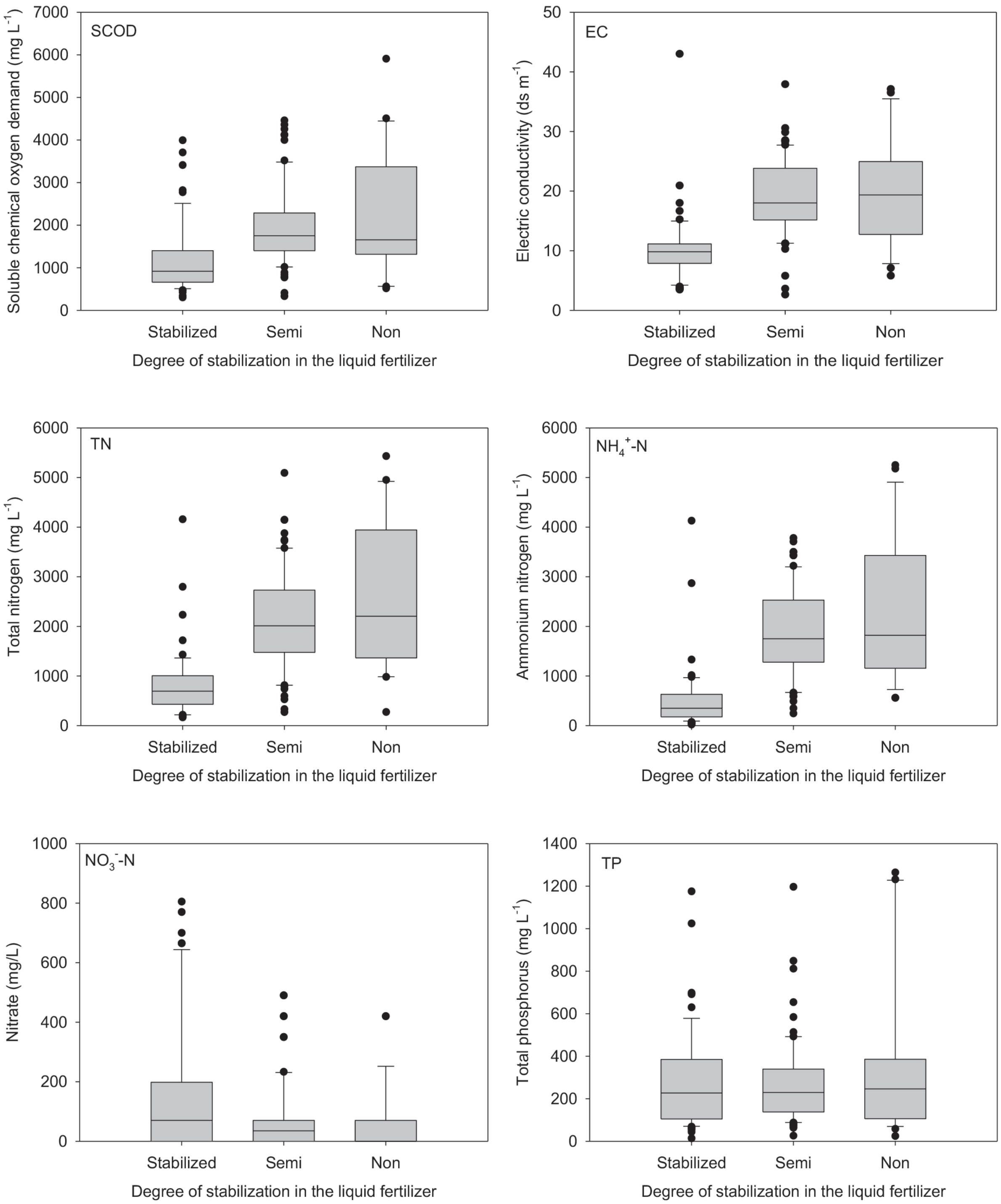

Fig. 3. Distribution plots of chemical parameters in the stabilized, semi–stabilized, and non–stabilized liquid fertilizers pig slurry (Line within the box marks the median, Boundary of the box indicates from the 25th percentile to 75th percentile, Vertical bars indicate the 90th and 10th percentiles).

zation level of liquid fertilizers. In particular, EC can be an efficient management factor that manages the stabilization level of liquid fertilizers, as the liquid fertilization process can be monitored with rather simple and inexpensive measurement tools.

HALDER *et al*. (2017) analyzed 22 stabilized liquid fertilizers, 25 semi–stabilized liquid fertilizers, and 19 non–stabilized liquid fertilizers (66 samples in total) from Korean livestock manures and conducted a correlation analysis between the chemical factors of liquid fertilizers. They verified a significant correlation among EC, NH_4^+–N, Org–N, and NO_3^-–N in stabilized, semi–stabilized, and non–stabilized liquid fertilizers. Their study report showed a similar result with ours, in that a high correlation was discovered among the EC, TN, and NH_4^+–N of stabilized liquid fertilizers. The results derived from all 70 types of stabilized liquid fertilizer in Korea in this study are regarded as reliable results in terms of the

Table 6. Linear correlation coefficients between chemical parameters in the stabilized liquid fertilizers by liquid composting of pig slurry (Number of samples = 70)

Parameters	pH	EC[a)]	SS[b)]	TN[c)]	NH_4^+–N	NO_3^-–N	TP[e)]	K
pH	1.000							
EC	0.260	1.000						
SS	–0.082	0.052	1.000					
TN	0.357*[f)]	0.475**	0.643**	1.000				
NH_4^+–N	0.720**[g)]	0.412**	0.053	0.673**	1.000			
NO_3^-–N	–0.115	0.345*	0.512**	0.711**	0.114	1.000		
TP	–0.079	0.082	0.933**	0.610**	0.013	0.588**	1.000	
K	0.095	0.464**	0.253	0.260	–0.006	0.214	0.216	1.000

a) Electric conductivity, b) Suspended solid, c) Total nitrogen, d) Organic nitrogen, e) Total phosphorus, f) Significant at $p<0.05$, g) Significant at $p<0.01$.

statistical perspective.

CONCLUSION

This study collected 150 livestock manure liquid fertilizers in 2012 and 70 stabilized liquid livestock manure fertilizers in 2015 from the manufacturing phase of livestock manure liquid fertilizers to derive process monitoring factors and analyze their chemical factors.

DO and ORP, which were two of the primary operating factors in the fertilization process, showed an increasing trend as the stabilization of the liquid fertilizers progressed, whereas pH and SS did not exhibit any clear difference among stabilized, semi–stabilized, and non–stabilized liquid fertilizers. Furthermore, among the chemical growth factors in liquid fertilizer, EC, $SCOD_{Cr}$, TN, and NH_4^+–N showed clear decreasing trends in the stabilized liquid fertilizer, whereas NO_3^-–N and TP did not show any distinguished difference among stabilized, semi–stabilized, and non–stabilized liquid fertilizers. Accordingly, EC, $SCOD_{Cr}$, TN, and NH_4^+–N were derived as chemically characteristic factors that can distinguish the characteristics of stabilized liquid fertilizer. Correlation analysis among the chemical factors of stabilized liquid fertilizers displayed a significant correlation among EC, TN, and NH_4^+–N.

In particular, EC was an index that represented the overall changes in liquid properties during pig slurry liquid fertilization. Thus, it can represent the characteristics of stabilized liquid fertilizers as a monitoring item.

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AUTHOR CONTRIBUTIONS

Y. M. Yoon designed the study and performed analytical experiments and wrote the first draft of the manuscript. J. N. Halder analyzed the data statistically and performed literature search. T. W. Kang contributed to perform analytical experiments and gathered field samples. S. R. Kim performed to write and editing the manuscript and literature search. Mitsuyasu YABE and M. G. Lee has supervised and helped to design the total work and collaborate information and ideas for this study and contribute to writing the paper. All authors assisted in the editing of the manuscript and approved the final version.

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