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The Application of Liquid Fertilizer Quality Certification (LFQC) for Liquid Manure Fertilizers and Probability of Implementation as a Quality Specification for Business Purposes in South Korea

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Liquid manure could be a valuable source of plant nutrition, if well treated. However, well–treated manure should have to follow some quality control protocol to reduce its adverse effects on the environment. Liquid Fertilizer Quality Certification (LFQC) is an established quality certification system that ensures the production of environmentally friendly liquid manure fertilizer. This study uses LFQC_1 and LFQC_2 to check the quality status of 18 liquid pig manure samples by examining their nutrient contents, harmful contents such as heavy metals and microorganisms, stability, and maturity according to their physiochemical properties. The TN, TP and TK have been tested to determine their nutrient contents and As, Cd, Cu, Cr, Ni, Pb, Zn, Hg, pathogens, and antibiotics were tested to measure their harmfulness. EC, pH, TS, LFGI, and mechanical stability analysis has been done to ensure these liquid manures' stability and maturity. Finally, all 18 samples were ranked by their score according to LFQC_1 and LFQC_2.

Key words: Livestock manure, Manure maturity, Manure nutrients, Liquid Fertilizer Quality Certification (LFQC)

INTRODUCTION

The livestock manure is a confirmed valuable source for plant nutrition. Livestock manure can provide nutrients for plants and improve the buffer capacity, total formation, and soil biota (Lee *et al.*, 2011), the raw manure could have to be treated and recycled into a hygienic, stable, and odor–free product (Mhaibes and Heinonen–tanski, 2004) that could fulfill the fertilization criteria (Skjelhaugen, 1997). However, untreated or poorly treated manure/slurry has potential risks for the environment and humans (Heinonen–tanski *et al.*, 1998). Furthermore, crop cultivations based on manure reduce the use of chemical fertilizers and increase the flow of nutrients between manure, soil, and plants (Zhang *et al.*, 2006; Fowler *et al.*, 2004). Meanwhile, manure becomes a significant source of pollution when management systems are deficient (AAFC 1980) instead of a highly valuable fertilizer and amendment for soil–crop if the manure is not properly managed (Laguë *et al.*, 2005).

The frequent and reasonable use of manure can improve the physical and chemical properties of nearly all types of soil, and the potential for degradation in the quality of soil, air, and water resources are greatly reduced. Manure adds organic matter, improves soil structure and gradient, and increases the soil's ability to hold water and nutrients and resist compaction and crusting (Madison *et al.*, 1986). Manure returns nutrients and organic matter to the soil and carries on the ancient natural cycle of nutrition on which all life depends (NAC 1993). Soil's ability to provide nutrients for plant growth is enhanced by such sensible returns of nutrients. Simply disposing of manure as a waste product can lead to serious degradation of both surface water and groundwater. Likely sources of surface water and groundwater contamination include runoffs and leaching from manure and wastewater applied to land, open and unpaved feedlots, runoff from holding ponds, manure treatment and storage lagoons, and manure stockpiles.

Nitrogen, phosphorus, and potassium are the major plant nutrients available in liquid manure. However, they also have some limitations. Nitrogen among other nutrients is taken up and can disappear easily from crop production systems (Barrena *et al.*, 2011). Most nitrogen forms in manure are organic (Da Silva *et al.*, 2016) and must be mineralized before they can be used by plants, or it could face nitrogen volatilization. Phosphorus in manure is generally conceded to be as effective as acid–treated forms of inorganic phosphorus (Azevedo and Stout, 1974). The nutrient content of manure is directly reduced significantly by nitrogen volatilization, phosphorus leaching, and potassium runoff. These happen because the nutrient contents of different manures can vary significantly, which is why it is vital to measure and control the quality and quantity of manure and its nutrients before, during, and after treatment and application. The uncertainty in estimating the quality, quantity, and availability of nutrients in manures can lead to their over–application or to the use of unnecessary supplemental nutrient sources for crop growth.

Applying untreated or unstable non–standardized liquid livestock manure on crop land can cause non–point pollution, which may create a nutrient imbalance in soil for crop cultivation and soil erosion and thus cause surface water and ground water pollution (Hugo *et al.*,

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2012). Therefore, quality control protocols and standardization for livestock manure and liquid manure fertilizer are vital for agricultural and environmental conservation. If livestock manure compost and liquid manure fertilizers are used excessively or deposited on the ground for a long time run off may occur during rainfall (Lee and Lee, 2009; Han and Lee, 2013). Thus, non–point pollution sources from livestock manures can damage the self–purification of water streams due to unwarranted loads of pollutants being discharged into water bodies (Hwang *et al.*, 2012).

In Korea, the key problems of quality control for livestock manure or liquid manure fertilizers are "the lack of quality standards for liquid manure fertilizer in individual farms, using non–stabilized liquid manure fertilizer in agriculture farmhouses, and complaints regarding odor" as reported by Yoon (Yoon *et al.*, 2016).

Some previous studies have sought to promote the applicable use of liquid manure fertilizers and to make stronger quality standards to improve livestock manure liquid fertilizers quality by comparing the physico–chemical characteristics of livestock manure liquid fertilizers (Jeon *et al.*, 2012a) or the main level–grading factors for establishing a Liquid Fertilizer Quality Certification (LFQC) system for livestock manure in Korea (Jeon *et al.*, 2012b). However, a 2013 study successfully outlined quality control standards for recycled livestock manure as a renewable resource of crop nutrients and reduced the environmental problems of applying manure to land as a Liquid Fertilizer Quality Certification or LFQC (Jeon *et al.*, 2013).

The LFQC system is a certification tool that ensures the quality and value of recycled liquid livestock manure to reduce non–point pollution sources and maximize the liquid manure–based crop production. The most recent version of the LFQC system has been divided into LFQC_1 and LFQC_2 as Premium Liquid Fertilizer rankings. The properties of LFQC_1 and LFQC_2 have been divided into four categories: Nutrient content, Hazardous content including heavy metals and pathogenic microorganisms, Maturity, stability and Physical properties include 30 checklist items. LFQC_1 determines whether a liquid fertilizer is fit or unfit and LFQC_2 scores the performance based on the presence of the maximum/minimum amount of various physiochemical parameters.

This study aims to apply and justify this LFQC system for various different collected liquid manure fertilizers as the final product from 18 different Livestock Manure Public Resource Centers (LMPRC) around the country and then rank them according to their properties based on LFQC_1 and LFQC_2.

MATERIALS AND METHODS

Materials

The liquid manure samples were collected from the after–treatment storage tanks of Livestock Manure Public Resource Centers (LMPRC). These were collected from eight cities and 18 different sites, specifically one in Gang–won (GW1), three in Gyeong–gi (GG1, GG2, and GG3), two in Chungbuk (CB1 and CB2), three in Chungnam (CN1, CN2, and CN3), one in Jeonbuk (JB1), four in Jeonnam (JN1, JN2, JN3, and JN4), one in Gyeongbuk (GB1), and three in Jeju (JJ1, JJ2, and JJ3) in 2017.

Physiochemical analysis

The physiochemical analyses of pH, EC, NaCl, TN, NH_4^+–N, nitrate–nitrogen (NO_3^-–N), organic nitrogen (Org–N), TP, K, and total sulfur (TS) in the samples were performed according to the standard analysis method (APAH, 1998). The pH and EC were measured using an YSI–556MPS (xylem Inc. USA) handheld meter and NaCl was measured by the silver nitrate titration method. The heavy metal content (As, Cd, Cu, Cr, Ni, Pb, and Zn) was measured using Spectroblue IPS–OES (FMX36, GERMANY), and the mercury (Hg) content was analyzed using a CVAAS mercury analyzer (NIC, RA–5, CVAAS Mercury Analyzer NIC, Japan) based on the US EPA method 7476 (US EPA, 1998). Furthermore, the stabilization of samples was tested by a mechanical stabilization analyzer (LMQ2000, Korea Spectral Products, Seoul, Korea) and maturity was determined by LFGI (Halder *et al.*, 2016).

Statistical analysis

SPSS software was used for statistical analysis and Microsoft Office Excel 2017 was used to plotting graphs and charts. However, LFQC_1 and LFQC_2 were used to determine the quality and scoring of the samples shown in Table 1.

RESULTS AND DISCUSSION

NPK total and N, P, K

Table 2 and Figure 1 show the total NPK (%), N (mg/L), P (mg/L) and K (mg/L) of 18 samples where JB1, JN4, and GG3 showed the highest total NPK as 0.74%, 0.73%, and 0.72%, respectively (Figure 1a). GG2 showed N 3,643 mg/L, P 380 mg/L, and K 3,138 mg/L; JB1 showed N 3,138 mg/L, P 283 mg/L, and K 3,956 mg/L; and JN4 showed N 672 mg/L, P 217 mg/L, and K 6,430 mg/L. Therefore, according to LFQC_1, they are "fit" and according to LFQC_2 they get "five points". However, the lowest total NPK was found in CB2 0.27% and JJ2 0.28%. Whereas, their individual N, P, and K were 420 mg/L, 61 mg/L, and 2,193 mg/L for the CB2 sample and 701 mg/L, 279 mg/L, and 1,830 mg/L for JJ2.

Heavy metals and microorganisms

The Heavy metals As, Cd, Hg, Pb, Cr, Cu, Zn, and Ni were analyzed as harmful components (Table 2), and As and Hg were absent from all samples. Although in the LFQC system and official standard of commercial fertilizer, As should be < 5 mg/kg and Hg should be < 0.2 mg/kg (Table 1). Cd was only found in CN3, JB1, JN1, JB2, JB3, and JB4 samples at 0.01 mg/kg, 0.004 mg/kg, 0.004 mg/kg, 0.01 mg/kg, 0.01 mg/kg, and 0.01 mg/kg, respectively, where the LFQC standard is 0.5 mg/kg. Pb was only found only in GW1 at 0.02 mg/kg, GG1 at

Table 1. Standard criteria of official standard of commercial fertilizer and Proposed LFQC_1 and LFQC_2 check list for inspection of liquid manure fertilizer's quality

Category		Items		Official standard of commercial fertilizer	Premium Liquid Fertilizer (LFQC_1)	Premium Liquid Fertilizer scoring system (LFQC_2), Total 25 point				
						1 point	2 point	3 point	4 point	5 point
Nutrient contents	1	NPK (Total)	%	0.3% (or more)	0.3 (or more)	<0.35	0.35~ 0.40	0.40~ 0.45	0.45~ 0.50	0.50>
	2	N	mg/L	–	Components	<500	500~ 1000	1000~ 1500	1500~ 2000	2000>
	3	P	mg/L	–	Components					
	4	K	mg/L	–	Components					
Hazardous contents: heavy metals	5	As	mg/kg	5	5					
	6	Cd	mg/kg	0.5	0.5					
	7	Hg	mg/kg	0.2	0.2					
	8	Pb	mg/kg	15	15					
	9	Cr	mg/kg	30	30					
	10	Cu	mg/kg	50	50					
	11	Zn	mg/kg	130	130					
	12	Ni	mg/kg	5	5					
Hazardous contents: pathogens	13	E. coli O157:H7		N/D	N/D					
	14	Salmonella		N/D	N/D					
	15	Staphylococcus Aureus		–	N/D					
	16	Listeria Monocytogenes		–	N/D					
	17	Bacillus Cereus		–	N/D					
Antibiotics	18	Tetracycline		–	N/D					
	19	Beta–Lactam		–	N/D					
	20	Sulfamide		–	N/D					
	21	Macrolide		–	N/D					
	22	Aminoglycoside		–	N/D					
Maturity & stability	23	Mechanical Stability Analysis		–	Matured					
	24	*LFGI		–	70>	<80	80~85	85~90	90~95	↑95
Physical properties	25	NaCl	%	↓0.3%	↓0.3%					
	26	Moisture content	%	95%>	95%>					
	27	Total solids (TS)	%	–	Component	↑2.0	2.0~1.5	1.5~1.0	1.0~0.5	<0.5
	28	Electrical Conductivity (EC)	mS/cm	–	Component	↑25	25~20	20~15	15~10	<10
	29	pH		–	Component					
	30	Odor		–	Odor intensity <1					

↓: below, ↑: over, <: less than, >; more than, ∧: above, ∨: under, *LFGI= Liquid Fertilizer Germination Index

0.05 mg/kg, CB1 at 0.03 mg/kg, CN1 at 0.05 mg/kg, CN2 at 0.03 mg/kg, JJ1 at 0.03 mg/kg, and JJ2 at 0.02 mg/kg. Cr was present in GG1 at 0.08 mg/kg, GG2 at 0.02 mg/kg, CB1 at 0.03 mg/kg, CN1 at 0.17 mg/kg, CN3 at 1.33 mg/kg, JB1 at 1.18 mg/kg, JN1 at 0.96 mg/kg, JN2 at 1.41 mg/kg, JN3 at 0.84 mg/kg, JN4 at 1.57 mg/kg, and GB1 at 1.22 mg/kg where the standard is 30 mg/kg. Cu was present in all samples, but highest in CN2 at 46.97 mg/kg and lowest in CB2 at 0.79 mg/kg, where the standard is 50 mg/kg (Table 2).

The LFQC standard of Zn is 130 mg/kg, but the highest amount of Zn was 174.50 mg/kg in CN 2 sample and the lowest 2.01 mg/kg in CB 2. The highest amount of Ni 1.70 mg/kg was found in CN 1 and the lowest in CB 2 and JJ 3 0.01 mg/kg (LFQC standard is 5 mg/kg). These 18 samples were tested to identify the presence of any pathogenic microorganisms, but none were found (Table 2).

EC, pH, NaCl, TS and moisture

The standard range of pH to maintains an ideal condition for liquid manure should be pH 6–9 (Eklind *et al.*, 2000; Michel *et al.*, 1998). The lowest and highest EC were 8.4 mS/cm for JJ2 and 25.1 for CN1, respectively (Table 2) (Figure 2b). The highest scored sample accord-

Table 2. Application of improved Liquid Fertilizer Quality Certification (draft) Premium Liquid Fertilizer (LFQC_1) and Premium Liquid Fertilizer scoring (LFQC_2) to 18 surveyed livestock manure samples

Category	Items		Units	GW1	GG1	GG2	GG3	CB1	CB2	CN1	CN2	CN3
Nutrients contents	1	NPK (total)	%	0.43	0.37	0.72	0.54	0.4	0.27	0.64	0.66	0.49
	2	N	mg/L	560	1,541	3,643	1,684	847	420	1,051	3,503	532
	3	P	mg/L	847	192	380	191	953	61	1,465	522	420
	4	K	mg/L	2,936	1,966	3,138	3,554	2,238	2,193	3,867	2,566	3,948
Hazardous contents: heavy metals	5	As	mg/ kg	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	6	Cd	mg/ kg	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	0.01
	7	Hg	mg/ kg	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	8	Pb	mg/ kg	0.02	0.05	N/D	N/D	0.03	N/D	0.05	0.03	N/D
	9	Cr	mg/ kg	N/D	0.08	0.02	N/D	0.03	N/D	0.17	N/D	1.33
	10	Cu	mg/ kg	24.58	15.84	3.13	2.19	19.98	0.79	39.72	46.97	23.91
	11	Zn	mg/ kg	58.14	54.41	6.32	9.36	93.36	2.01	82.13	174.5	99.11
	12	Ni	mg/ kg	0.24	0.17	0.03	0.02	0.21	0.01	1.7	0.32	1.38
Hazardous contents: pathogen	13	E. coli O157:H7		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	14	Salmonella		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	15	Staphylococcus Aureus		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	16	Listeria Monocytogenes		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	17	Bacillus Cereus		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Antibiotics	18	Tetracycline		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	19	Beta–Lactam		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	20	Sulfamide		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	21	Macrolide		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	22	Aminoglycoside		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Stability & Maturity	23	Mechanical Stability Analysis		#m	#im	#im	#s–m	#im	#s–m	#s–m	#s–m	#im
	24	*LFGI		82.8	31.5	98.6	72.8	83.4	0	64.6	0.1	85.5
Physical properties	25	NaCl	%	0.18	0.12	0.19	0.23	0.17	0.13	0.03	0.17	0.21
	26	Moisture	%	97.6	98.3	98.8	97.9	98	97.5	95.7	97.8	98
	27	TS	%	2.4	1.7	1.2	2.2	2	2.5	4.3	2.2	2.1
	28	EC	mS/cm	15.3	14.1	12.2	20	10.6	21.4	25.8	18.5	12.5
	29	pH		7.1	8.6	6.9	9	8.2	9.6	5.3	9	8.4
	30	odor		–	–	–	–	–	–	–	–	–
Official standard of commercial fertilizer				Fit	Fit	Fit	Fit	Fit	Unfit	Fit	Unfit	Fit
Premium Liquid Fertilizer (LFQC_1)				Fit	Unfit	Fit	Unfit	Fit	Unfit	Unfit	Unfit	Fit
Premium Liquid Fertilizer scoring (LFQC_2)				11	(13)	22	(14)	13	(6)	(11)	(15)	14

*LFGI= Liquid Fertilizer Germination Index; #im= immature, s–m= semi–matured, m= matured

Category	Items		Units	JB1	JN1	JN2	JN3	JN4	GB1	JJ1	JJ2	JJ3
Nutrients contents	1	NPK (total)	%	0.74	0.47	0.59	0.47	0.73	0.51	0.33	0.28	0.33
	2	N	mg/L	3,138	476	1,373	2,401	672	796	980	701	1,121
	3	P	mg/L	283	416	913	159	217	102	351	279	259
	4	K	mg/L	3,956	3,770	3,572	2,103	6,430	4,226	2,003	1,830	1,888
Hazardous contents: heavy metals	5	As	mg /kg	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	6	Cd	mg/ kg	0.004	0.004	0.01	0.01	0.01	N/D	N/D	N/D	N/D
	7	Hg	mg/ kg	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	8	Pb	mg/ kg	N/D	N/D	N/D	N/D	N/D	N/D	0.03	0.02	N/D
	9	Cr	mg/ kg	1.18	0.96	1.41	0.84	1.57	1.22	N/D	N/D	N/D
	10	Cu	mg/ kg	14.44	10.56	20.18	3.12	18.5	6.37	17.85	20.2	1.62
	11	Zn	mg/ kg	69.07	38.1	81.83	28.57	55.87	29.29	72.93	63.61	8.7
	12	Ni	mg/ kg	1.09	1.01	1.24	0.82	1.51	1.03	0.15	0.13	0.01
Hazardous contents: pathogen	13	E. coli O157:H7		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	14	Salmonella		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	15	Staphylococcus Aureus		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	16	Listeria Monocytogenes		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	17	Bacillus Cereus		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Antibiotics	18	Tetracycline		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	19	Beta–Lactam		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	20	Sulfamide		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	21	Macrolide		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
	22	Aminoglycoside		N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D	N/D
Stability & Maturity	23	Mechanical Stability Analysis		#s–m	#m	#m	#s–m	#m	#m	#m	#m	#m
	24	*LFGI		0	101.5	0	41	77.3	72.2	81.3	117	112.2
Physical properties	25	NaCl	%	0.18	0.2	0.17	0.12	0.36	0.23	0.11	0.11	0.11
	26	Moisture	%	97.6	98.2	97.2	99	97.1	98.3	98.2	98.5	98.4
	27	TS	%	2.4	1.8	2.8	1	2.9	1.7	1.8	1.5	1.6
	28	EC	mS/cm	24.4	11.4	15.7	12.7	19.2	15.2	9.6	8.4	9.6
	29	pH		8.3	7.8	6.5	8.7	9.2	7.9	8.1	9.2	8.3
	30	odor		–	–	–	–	–	–	–	–	–
Official standard of commercial fertilizer				Fit	Fit	Fit	Fit	Unfit	Fit	Fit	Unfit	Fit
Premium Liquid Fertilizer (LFQC_1)				Unfit	Fit	Unfit	Unfit	Unfit	Fit	Fit	Unfit	Fit
Premium Liquid Fertilizer scoring (LFQC_2)				(14)	16	(13)	(18)	(12)	13	12	(16)	16

*LFGI= Liquid Fertilizer Germination Index; #im= immature, s–m= semi–matured, m= matured

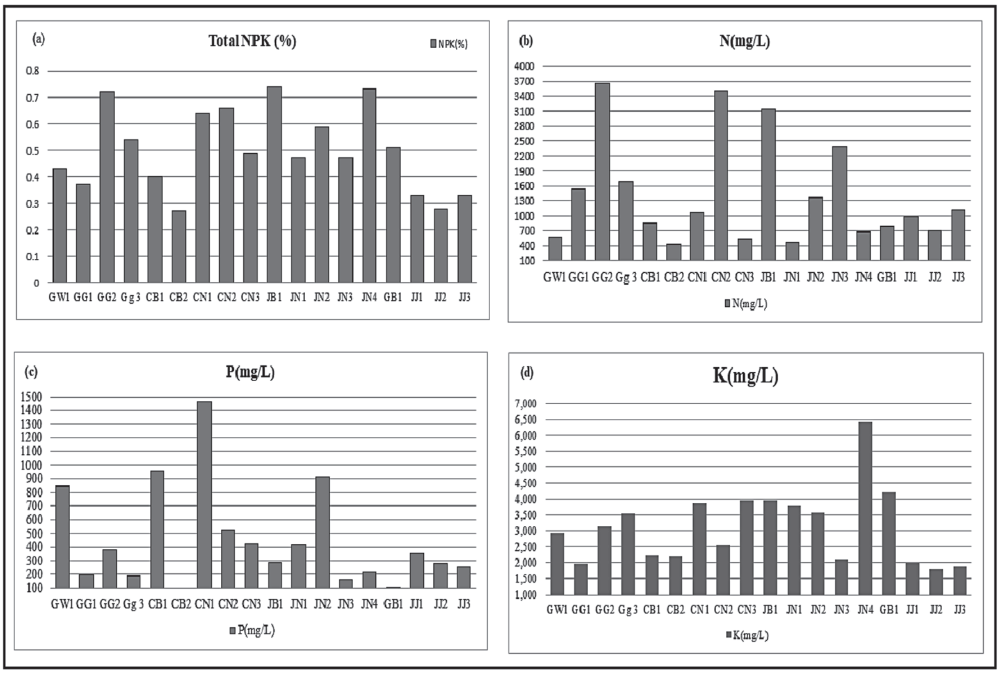

Fig. 1. Comparing the total NPK and N, P, K of samples with LFQC_2 standards.

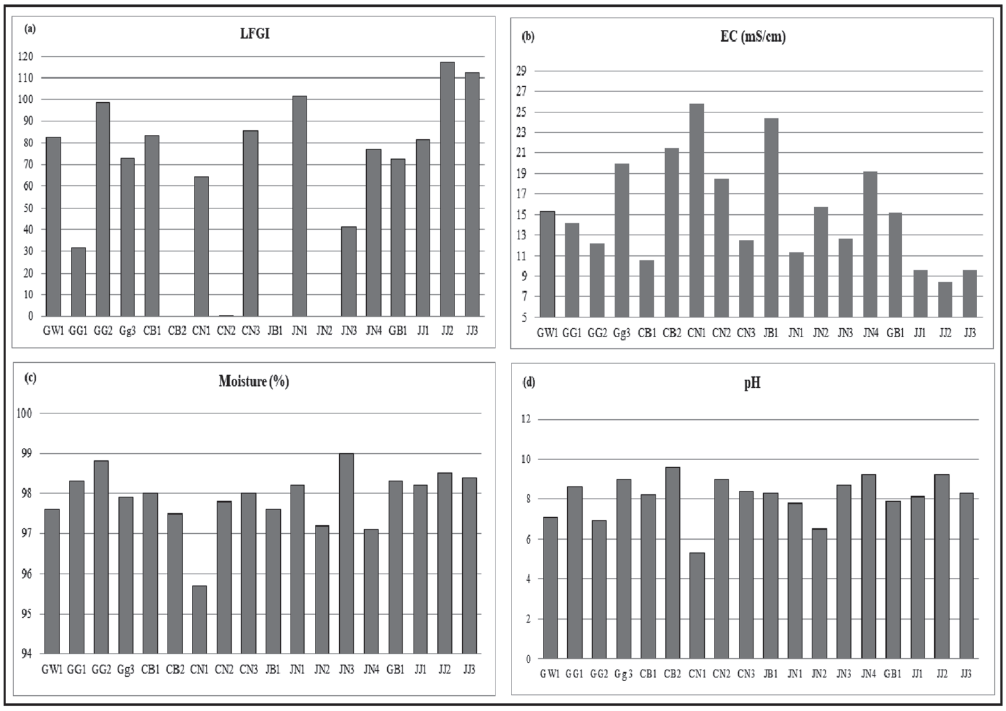

Fig. 2. Physiochemical (Moisture, EC and pH) and biological (LFGI) properties of 18 samples.

ing to LFQC was GG2, which had an EC reading of 12.2 mS/cm, and the lowest scored samples were CB2, at 21.4 mS/cm. CN1 had the highest pH, 9.2, and GW1 had the lowest pH, 5.3 (Table 2) (Figure 2d). GW1 had a maximum TS of 4.3% (moisture 95.7%) and minimum TS was 1.0% (moisture 99.0%), of JB1 (Table 2).

Maturity and stability (mechanical compost stability and LFGI)

According to mechanical compost stability test, JN3, CN1, CN2, GG3, and JB1 were semi–matured, GG1 was immature and the rest of the samples were matured (Table 2) (Figure 2a). However, the LFGI test shown the maturity of 18 samples, with JJ2 the highest (117) GI count, followed by JJ3 had (112.2); the lowest GI counts were 0, for JB1 and JN2. Therefore, JJ2 and JJ3 score more than 5 points (Table 2).

Relation between EC, LFGI

Seed germination has a close relation with salt stress (Mahmoodzadeh *et al*., 2013). The high phytotoxicity level of manure is caused by the slow breakdown of mineral salts (Zaha, 2013). Therefore, EC and LFGI had a negative co–relation (Halder, *et al*., 2016). This is also reflected in the present findings. Here, JJ2 had the highest LFGI count (117), and its EC was measured as 8.4 mS/cm; the lowest LFGI counts were from JB1 and JN2 (each 0), and their EC value were 24.4 mS/cm and 15.7 mS/cm, respectively. On the other hand, the highest–ranked sample was GG2, with an LFGI count of 98.6 has EC value of 12.2 mS/cm, and the lowest–ranked sample, CN1, had EC value of 25.8 mS/cm.

The scoring and ranking of the samples

According LFQC_2 some samples got fair scores but was marked as unfit by LFQC_1. This is simply because some of their properties or compositions did not meet the LFQC standard. Mostly, it was due to their LFGI results, because the ideal germination count starts from 70 (Jeon *et al*., 2013). As seen in Tables 2 and 3, GG1 scored 13 but was marked as unfit because mechanical stability test was immature and it had a lower LFGI count, at 31.5. GG3 scored 14 but mechanical stability test was semi–matured and LFGI was highly marginal; CB2 scored only 6 and its total NPK was 0.27%, mechanical stability test was semi–matured and LFGI was 0; for CN1, its LFGI was 64.6 and mechanical stability test was semi–matured; CN2 had a score of 15 but it had 0.1 LFGI and mechanical stability test was semi–matured along with high amount of Zn (175 mg/kg); JB1 had 0 LFGI and mechanical stability test was semi matured, despite scoring 14; JN2 had 0 LFGI, though it scored 13; JN3 has semi–matured mechanical stability test and 41 LFGI, with a score of 18; JN4 has higher salinity stress 0.36% NaCl (Khan *et al*., 2000); and JJ2 had total NPK of 028% with LFQC_2 score of 16.

Table 3. Scoring of 18 samples according to current official standard of commercial fertilizer, LFQC_1 and LFQC_2

Site	Official standard of commercial fertilizer	LFQC_1	LFQC_2 (scoring)	Ranking
GG2	Fit	Fit	22	1
JJ3	Fit	Fit	16	2
JN1	Fit	Fit	16	3
CN3	Fit	Fit	14	4
CB1	Fit	Fit	13	5
GB1	Fit	Fit	13	6
JJ1	Fit	Fit	12	7
GW1	Fit	Fit	11	8
JN3	Fit	Unfit	(18)	9
JJ2	Fit	Unfit	(16)	10
CN2	Unfit	Unfit	(15)	11
GG3	Fit	Unfit	(14)	12
JB1	Fit	Unfit	(14)	13
GG1	Fit	Unfit	(13)	14
JN2	Fit	Unfit	(13)	15
JN4	Unfit	Unfit	(12)	16
CN1	Fit	Unfit	(11)	17
CB2	Unfit	Unfit	(6)	18

Those samples which are declared "unfit" by LFQC_1 and have semi– matured or immature status from mechanical stabilization analysis, showed LFGI below 70. However, only examine by mechanical stabilization analysis is not enough (like GG3) to determine the condition of liquid manure fertilizers. Because this stabilization analysis done based on sample's color and NH_3 and H_2S gas (Yoon *et al*., 2018) in other hand LFGI showed the biological evidence of the maturity of liquid fertilizers (Halder *et al*., 2016).

CONCLUSION

The main purpose of analyzing and standardizing manure fertilizers is to assess their quality. This standardization and examination depended on their physical and chemical composition according to their nutrient contents, harmful and hazardous properties, and stability and maturity.

In this study 18 different post–treatment liquid manure samples from 18 different sites were analyzed according to their physical and chemical composition and classified based on LFQC_1 and LFQC_2. N, P, and K were analyzed to determine their nutrient content. The JN4 sample showed highest total NPK at 0.73%, and CB1 samples showed the lowest, at 0.4%.

Heavy metals as As, Cd, Hg, Pb, Cr, Cu, Zn, and Ni were analyzed as harmful components. As and Hg were absent in all samples. Cd was found only in CN3, JB1, JN1, JN2, JN3, and JN4 samples; Pb was found only in GW1, GG1, CB1, CN1 and 2, and JJ1 and 2. Cr was absent in only seven samples: GW1, GG3, CB2, Cn2, and JJ1, 2, and 3. Cu was present in all samples; the highest was CN2 and the lowest was CB2. The highest amount of Zn was in CN 2 and the lowest in CB2. The highest amount of Ni was found in CN 1 and the lowest in CB2 and JJ3. The EC and LFGI showed a significant negative relation maturity and stability in all 18 samples.

The LFGI_2 scored samples were marked unfit by LFGI_1 because in most of these samples one or a few check items failed to meet the LFQC standard. Based on the physiochemical components and standard parameters of LFGI_1 and LFGI_2, the 18 samples were ranked as follows: GG2, JJ3, JN1, CN3, CB1, JJ1, GW1, GB1, JN3, JJ2, CN2, GG3, JB1, GG1, JN2, JN4, CN1 and CB2 (Table 3).

This study has fulfilled its objective of proving the LFQC system could be used to ensure the highest quality of liquid manure fertilizer and produce premium quality fertilizers by inspecting most vital compositions of liquid manure fertilizers. The LFQC system might also indicate the lack of proper technological use of manure treatment processes as well. In addition, it could be helpful to warn and improve awareness about the proper quality of liquid manure fertilizers.

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AUTHOR CONTRIBUTIONS

J. N. Halder designed the study, performed analytical experiments and literature review, and wrote the manuscript. T. W. Kang contributed to performing analytical experiments and gathered field samples. S. R. Kim performed statistical analysis, editing the manuscript and literature review. Mitsuyasu YABE and M.G. Lee supervised and helped to design the work, collaborated by providing 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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