Byproducts from Piggery Wastewater Treatment for the Sustainable Soil Amendment and Crop Production

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Livestock manure is generally beneficial to soil and crop production when appropriate amount is applied, but excessive application may be detrimental to soil and water environments. A proper protocol of livestock waste treatment is required to manage the quality of soil and water. A trickling filter system using rice straw media was employed to treat piggery wastewater from small-scaled livestock farms as an alternative to the currently available methods. Batches of piggery wastewater were treated with this system, and the byproducts of rice straw media and trickling filtrate were applied to the soil with cultivating rye (*Secale cereale* L.). Objective of this research was to characterize these byproducts for the sustainable soil amendments and rye production. Both the treated straw medium and filtrate were proven to be effective organic fertilizers for rye plant development, with the enhanced but balanced absorption of nutrients. The synergistic effects of filtrate in addition to straw application did not show, but the filtrate appeared to lead to a higher water content of the plant. No specific nutrient deficiency or toxicity symptom was shown due to the salts derived from the byproducts applied. Chemical parameters of the soil quality were significantly improved with the application of straw medium either with or without the filtrate. Judging from parameters relating to the salt accumulations, such as sodium adsorption ratio (SAR), electrical conductivity (EC), exchangeable sodium percentage (ESP), potassium adsorption ratio (KAR), and residual P concentrations, the byproducts from piggery wastewater exhibited no detrimental effects on soil quality within the ranges of treatments used. In addition to the effectiveness of the rice straw trickling filter system for the small-scaled swine farms, both rice straw medium and filtrate could be recycled for the sustainable soil amendment and plant nutrition.

Key words : *trickling filter, rice straw, filtrate, rye plant, livestock farm wastewater.*

There have been many successful treatments and disposal methods developed for industrial wastes. These may be less successful with agricultural wastes unless modified to accomodate the characteristics of specific agricultural wastes, such as livestock wastewater which varies in quantity and quality. Livestock wastes may mean fresh excrement including both the solid and liquid portions.[1]

The characteristics of livestock wastes depend on the digestibility and composition of the feed. Undigested cellular fiber protein and other nutrients are excreted in the feces. The excess nitrogen from digested protein is excreted in urine as urea by animals. Residues from the digestive fluids, waste mineral matter, worn-out cells from the intestinal linings, mucous bacteria, and others such as dirt consumed along with the food are contained in the feces.

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Abbreviations: BOD, biological oxygen demand; CEC, cation exchange capacity; COD, chemical oxygen demand; EC, electrical conductivity; ESP exchangable sodium percentage; KAR, potassium adsorption ratio; SAR, sodium adsorption ratio; SS, suspended solids.

The waste production per day from pig farm is a function of the type and the size of the animal, the feed, the temperature and humidity within the feedlot, and the amount of water supplied in washing and leakage. The production of feces and urine in quantity increases with the weight and feed consumption of the livestock. The portion of the feed converted to body tissue is approximately 30% of the consumed, and the remainder is excreted as urine and manure. The average of feed conversion efficiency ranges from 2.6 to 3.8 kg of feed per 1 kg of weight gain. Nutrients in the wastes, therefore, are of great interest as the land is the ultimate accepter of the wastes.[1]

The residues from agricultural production operations are associated with potential environmental quality problems. Animal waste at animal production facilities is one of them. Animal production also represents an alteration of a natural cycle and the resultant environmental effects. The land is the primary component of the cycle, which provides feed for the animals whose waste is returned to the land to help produce more feed. Animal wastes can be processed and reutilized as part of the ration of other animals and for other purposes. Environmental problems related to waste management are kept to minimal as long as the resultant animal wastes are utilized in the cycle.

Improper application of the waste to the land can result in nutrient accumulation, and surface water and groundwater pollutions. Operations of large and intensive livestock feedlots have certainly increased the efficiency of animal protein production, but they can accumulate large quantities of waste, weaken the waste-land link, and be a cause of serious environmental problems. The extent of water pollution from farm animal production units has been more dependent on waste management methods than on the quantity of the waste involved.[2-6]

Livestock manure has been spread on the land for many centuries, at first, perhaps, as a method of disposal but later as fertilizer for crop production. Before the advent of inorganic fertilizers, it was the principal source of plant nutrients added to the soil. Livestock waste is a valuable resource in increasing and maintaining soil fertility. It supplies nutrients for crop growth and organic matter for improving and maintaining soil physical properties.[7] When applied in quantities that supply adequate but not excessive nutrients for crop requirements, animal waste is generally beneficial to the soil environment. However, excessive quantities may be at least temporarily detrimental to the soil and water qualities. Nitrogen, P, organic matter, pathogen, and salts are components that degrade the soil and water qualities. Thus, use of the soil for disposal of animal waste and for crop production requires a proper management.

Though concerns for environmental protection were brought up in Korea in the 1970s, livestock farm facilities have come under legal constraints only since 1981 primarily aimed at somewhat large-scaled animal production operations. Medium- to small-scaled animal production farms are exempt from these regulations. Waste disposal of small livestock feeding facilities raises serious questions about its detrimental effects on environmental quality of the area.

Trickling filters are aerobic oxidation units designed to treat diluted waste, which absorb and oxidize the organic matter in the wastes passing over the filter support media. The most common support media employed in trickling filters are crushed stones, large size rocks, or plastic materials of various configurations. The largest population of microorganisms in a trickling filter consists of heterotrophic facultative bacteria. Other microbes such as protozoa and higher forms of animal life can be found in filters. Algae grow on the surface of filters but not below the surface because sunlight cannot penetrate the media. Growth of microbes on the surface of the media is stimulated by the organic matter in the waste.[8]

In place of more commonly used materials, rice straw was employed as a trickling filter support medium.[9-11] Rice crop is one of the staple food plants widely harvested in Southeast Asian countries including Korea, but the straw, which was one of the most useful raw materials for daily home commodities, became a mere crop residue to be disposed of or recycled. Application of animal waste combined with the crop residue used as a trickling filter medium and the resultant filtrate to soil will serve as a step forward to the establishment of ecologically sustainable agriculture. Objective of this research was to characterize the byproducts from piggery wastewater treatment for the sustainable soil amendments and rye production.

Materials and Methods

Trickling filter system using rice straw medium. Rice straw was cut in 3 to 5 cm in length and evenly stacked into a trickling filter column ($9\times0.5\times120$ cm ; $D\times W\times H$). Wastewater effluent from the swine farm was sprayed over the support medium with operational parameters of 0.846 m^3/m^2/day and 1.148 kg BOD/m^3/day for hydraulic and organic loading, respectively. Table 1 shows the treatment efficiency of the straw trickling filter system for the piggery wastewater. The removal efficiencies of this system were 53.4%, 54.3%, and 70.9% for BOD, COD, and SS, respectively. Removal efficiencies for BOD and COD were similar to those reported by Eckenfelder.[12] pH of the trickling filtrate did not change compared to that of the raw piggery wastewater. The rice straw trickling filter system

Table 1. Treatment efficiency of rice straw trickling filter system for piggery wastewater.

Chemical parameters	Raw piggery wastewater	Straw column effluent
pH	8.19	8.16
DO, mg/L	0.12	0.32
BOD, mg/L	1,628	758
COD, mg/L	3,435	1,569
SS, mg/L	1,681	490
Total nitrogen (T-N), mg/L	407	319
NH_4-N, mg/L	332	294
NO_3-N, mg/L	0.347	0.151
NO_2-N, mg/L	0.008	0.006
Total phosphorus (T-P), mg/L	46.7	23.8

Table 2. Chemical composition of treated rice straw and filtrate as compared to farm compost.

	Total Nitrogen	Total P_2O_5	K_2O	Na_2O	CaO	MgO
Treated ricestraw (%)	4.80	3.52	0.86	0.27	2.27	0.58
Trickling filtrate(mg/kg)	15	52.9	735.2	184.7	82.0	21.6
Farm compost(%)	4.08*	3.64	0.87	0.26	1.73	0.86

Table 3. Development and chemical composition of rye plant (*Secale cereale* L.) grown on soils fertilized with straw medium and filtrate of a trickling filter.

Treatment	Fwt[a]	Dwt[a]	T-N	P_2O_5	K_2O	CaO	Na_2O	MgO
	--- g ---		%					
N,P,K (Control)	30.4	16.6	2.07	0.21	2.36	0.15	0.12	0.76
N,P,K + RSM[b] 0.5	32.5	13.3	1.93	0.23	2.48	0.20	0.06	1.34
N,P,K + RSM 1.0	32.0	13.0	2.17	0.27	2.68	0.23	0.05	1.47
N,P,K + RSM 1.5	35.8	14.6	2.10	0.34	3.10	0.24	0.02	1.87
N,P,K + RSM 2.0	33.6	13.0	2.10	0.30	2.91	0.24	0.03	2.30
N,P,K + CO[c] 0.7	34.4	13.5	2.17	0.28	2.76	0.21	0.15	1.08
LSD (0.05)	5.1	2.0	0.09	0.05	0.60	0.06	0.12	0.33
N,P,K + RSM 0.0 + F[d]	28.6	9.2	2.63	0.19	4.02	0.15	0.16	1.02
N,P,K + RSM 0.5 + F	32.2	13.3	2.37	0.22	3.35	0.14	0.07	1.01
N,P,K + RSM 1.0 + F	34.5	13.3	2.63	0.25	3.62	0.17	0.07	1.09
N,P,K + RSM 1.5 + F	34.8	12.3	2.60	0.27	2.82	0.20	0.03	1.17
N,P,K + RSM 2.0 + F	33.7	13.0	2.57	0.34	3.90	0.30	0.03	1.31
N,P,K + CO 0.7 + F	35.9	12.4	2.60	0.23	3.67	0.16	0.02	1.02
LSD (0.05)	5.1	2.0	0.09	0.05	0.60	0.06	0.11	0.32

[a]Fwt = Fresh weight; Dwt = Dry weight
[b]RSM = Rice straw medium of the trickling filter (unit = ton/10a)
[c]CO = Commercially available compost (unit = ton/10a)
[d]F = Filtrate after passing through the column

was not very efficient for the removal of nitrogen. At the end of the wastewater treatment, the straw was taken out of the column, dried, and crushed into small fragments for easy storage and application. Trickling filtrate was collected at the bottom of the column and stored for amendments at 4°C. Table 2 shows the chemical properties of the rice straw media and filtrate after treatment of the wastewater. These properties were compared with those of the commercially available compost utilizing weeds. The contents of total nitrogen and CaO were higher in the straw medium than in the compost, but those of total P_2O_5 and MgO were higher in the compost than in the support medium.

Greenhouse study. Greenhouse study was conducted to evaluate the fertility values of the treated rice straw and the

Table 4. Chemical parameters of soil quality as affected by the treated rice straw medium and filtrate from the piggery wastewater trickling filter.

Treatment	pH (1:5)	EC (dS/m)	Exchangeable Cations K	Ca	Na	Mg	CEC	P_2O_5	OM
			cmol(+)/kg					mg/kg	%
N,P,K (Control)	6.58	0.070	2.19	1.83	0.32	2.19	9.39	75.2	1.76
N,P,K + RSM[a] 0.5	6.59	0.076	2.01	1.90	0.34	3.17	10.21	82.5	1.88
N,P,K + RSM 1.0	6.48	0.083	1.83	2.36	0.52	4.07	11.94	102.6	2.26
N,P,K + RSM 1.5	6.60	0.100	2.15	3.10	0.40	5.03	13.62	146.5	2.45
N,P,K + RSM 2.0	6.24	0.083	1.80	3.85	0.51	5.31	14.29	128.9	2.43
N,P,K + CO[b] 0.7	6.43	0.073	2.07	2.36	0.37	2.63	9.77	104.7	1.95
LSD (0.05)	0.23	0.018	0.40	0.62	0.12	1.04	1.29	16.8	0.22
N,P,K + RSM 0.0 + F[c]	6.53	0.077	1.87	1.87	0.42	2.78		91.63	2.07
N,P,K + RSM 0.5 + F	6.55	0.083	2.00	1.55	0.48	1.89		97.45	2.17
N,P,K + RSM 1.0 + F	6.49	0.087	2.32	1.90	0.55	2.20		98.85	2.31
N,P,K + RSM 1.5 + F	6.12	0.073	1.47	1.70	0.54	1.59		114.74	2.41
N,P,K + RSM 2.0 + F	6.09	0.073	1.26	2.31	0.58	1.67		138.81	2.68
N,P,K + CO 0.7 + F	6.50	0.070	1.75	1.84	0.46	1.97		115.97	2.06
LSD (0.05)	0.31	0.012	0.41	0.35	0.10	0.48		14.7	0.24

[a]RSM = Rice straw medium of the trickling filter (unit = ton/10a)
[b]CO = Commercially available compost (unit = ton/10a)
[c]F = Filtrate after passing through the column

trickling filtrate for soil and crop. Soil treated with the crushed straw and filtrates at various levels was put into the Wagner pot (1/5000a). Contents of soil treatments are shown in Tables 3 and 4. The experimental soil was a Jungdong series of coarse loamy, mixed, mesic typic Udifluvents, a type of soil with low natural fertility and low organic matter content. Some of the important chemical properties of the soil were reported previously.[13] The control plot received chemical fertilizers at ratios of $N : P_2O_5 : K_2O = 12 : 9 : 7$ kg/10a. Nitrogen and potassium fertilizers were applied to soil four times as split side dressings. Soils of other plots were applied with the treated straw medium with or without filtrate (Tables 3 and 4). These plots were also fertilized with the same $N : P_2O_5 : K_2O$ levels with the control. The background fertilizers used were in forms of urea, fused superphosphate, and potassium chloride. All plots received CaO as much as the lime requirement of the soil determined by Rural Development Administration method.[14] The trickling filtrate was applied twice, with 30 days interval, to the surface of the plot soil in an amount equivalent to 4 tons/10a (100 m*l*/pot). The first application of the filtrate was made at three months after the seeding of rye plant (*Secale cereale* L.). At each pot, 15 rye plants were grown for 6 months. Growth parameters and yield were measured at every 30 days. Experiments were conducted based on a completely randomized design with four replications.

Assessment of sustainable soil amendments. Since piggery manure contains high concentrations of organic matter and soluble salts,[1,7] excessive application of these resources may at least temporarily be detrimental to the soil. Thus, it is necessary to assess the changes of soil quality driven by the rice straw medium and filtrate from piggery wastewater treatment. In this paper, the sustainability of these byproducts for soil amendments and crop growth was characterized by yield, salt content uptake, SAR, ESP, and EC. The criteria of the sustainability were based on the reported threshold values of the respective parameters.

Results

Development of rye plant. Table 3 shows the treatment effects of the rice straw medium and filtrate, the byproducts obtained from the piggery wastewater trickling filter system. Rye plant exhibited a normal development and growth, showing neither nutrient deficiency nor toxicity symptoms in all plots within the treatment levels employed in this research.

In general, fertilization of straw medium and filtrate resulted in the enhanced development of the rye. This result was similar to the effects on the growth of lettuce and orchard grass as previously reported.[9-11] Addition of the filtrate led to an increase in plant height but not necessarily dry weight, partly because water content of the plant grown with the addition of the filtrate tended to be higher by 2 to 6% than that of the plant grown without added filtrate. There

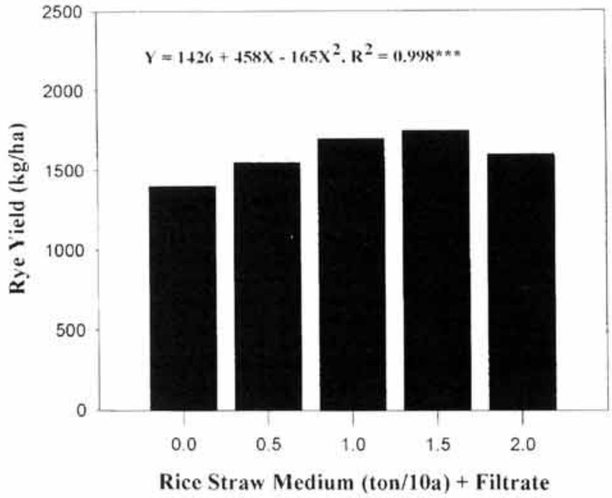

Fig. 1. Response curve of rye yield to rice straw and filtrate treatments.

was no significant synergistic effect of filtrate treatment on rye growth and nutrient uptake as compared to the single straw treatment.

Figure 1 shows a highly significant correlation between rye yield and the rice straw medium and filtrate treatments, showing the general yield response curve. Yield reached maximum at 1.5 ton/10a treatment. The content of phosphorus in the plant was dependent upon the rate of application of the straw medium. The highest value was obtained when the application rate was 1500 kg/10a. Nitrogen content, however, was independent of the rate of fertilization.

The amounts of K, Ca, and Mg absorbed by the plant were higher in plots with added straw medium and filtrate, while the content of Na was lower in those plots. Addition of the filtrate appeared to reinforce the absorption of K in particular by the plant. Figure 2 shows that balance of the cations taken up by rye was slightly decreased with

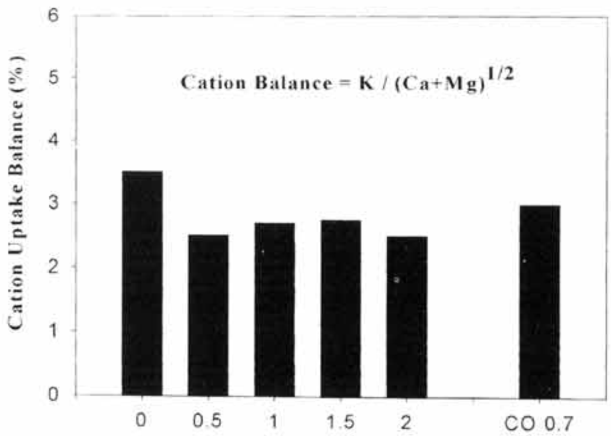

Fig. 2. Cation uptake balance as affected by rice straw medium and filtrate treatments.

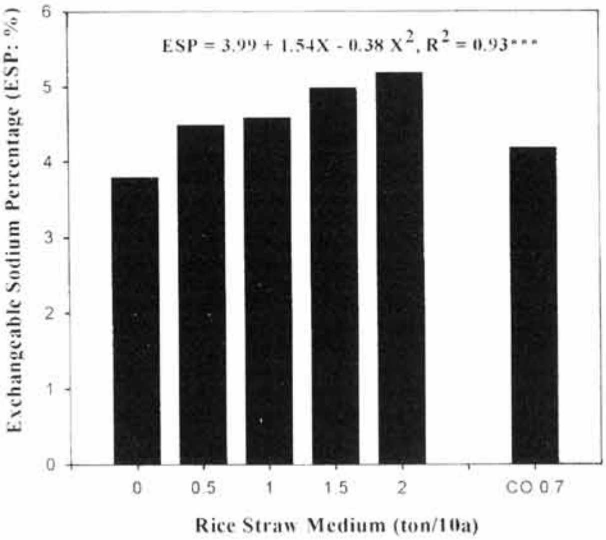

Fig. 3. Changes of exchangeable sodium percentage (ESP: %) as affected by rice straw medium treatment.

treatments, but did not significantly change with the levels of treatments.

Results indicated that the byproducts from the piggery wastewater treatment exhibited no harmful effects on rye growth, and both rice straw medium and filtrate could be utilized for the plant nutritional sources.

Sustainable soil amendment. Chemical parameters of the soil quality were enhanced significantly by the treatments of rice straw and filtrate, as compared to the control soil (Table 4). Soil pH remained almost invariable within statistical significance regardless of the additions of filtrate and straw medium in various ratios.

EC of the soil was measured and found to follow the general trend of increase with the addition of mineral fertilizer (N : P : K). In the present experiment, application of straw medium with or without the filtrate also increased the ECs of the soil. The increment was greater with the addition of the straw medium only than with the medium plus the filtrate. The values of EC, nevertheless, were far lower than those commonly found under field conditions that salinity problems could not occur, as the defined value of EC for soil salinity is over 4 dS/m.[15] With an exception of Ca, the concentrations of exchangeable K, Na, and Mg increased as a result of treatment. Addition of the filtrate seemed to depress the residual soil exchangeable K as a result of increased absorption by the plant.

KAR is defined as Exc. K/(Exc. Ca + Mg)$^{1/2}$, which is a measure of ionic balance between K^+, Ca^{2+} and Mg^{2+} in soil.[15] KAR value ranged from 0.6 to 1.2. The highest value was obtained with addition of NPK only, and the value decreased with increasing amount of the straw medium with or without the filtrate, which indicates the increase in relative concentrations of divalent cations, Ca^{2+} and Mg^{2+}. As shown in Table 4, increase in the concentration of Mg^{2+} was noticeable. And there was a close correlation between soil exchangeable Mg content and Mg uptake by the plant.

Sodium adsorption ratio[15] [SAR = Exc. Na/(Exc. Ca + Mg)$^{1/2}$] had values between 0.18 and 0.42. These values could be considered as low, indicating the byproducts from piggery wastewater treatment contribute little Na to the soil environment. The exchangeable sodium percentage[15] [ESP = (Exc. Na/CEC) $\times$ 100] ranged from 2.5 to 6.1%, which increased proportional to the treatments as shown in Figure 3. However, these values are well below 15%, which is the threshold value for a soil to be classified as sodic or saline.[15] These results demonstrate that a concern on salt accumulation due to the treatment could be avoidable within the ranges applied.

Concentrations of the soil available phosphorus were intensified by the addition of fertilizing materials. A very close relationship was found between concentrations of soil available phosphorus and the phosphorus contents of the plant. As anticipated, the increase in the soil organic matter content was proportional to the amount of the straw medium applied to soil. The increase was augmented in general by the addition of the filtrate.

Discussion

Environmental problems associated with intensive agricultural practices have been a continuously debated subject of social issues. The wastewater from livestock farms, irrespective of management scales, must be drawn to attention and should be properly treated to reduce the hazard of environmental pollution of surface and ground waters. Direct utilization of the wastewater or use of byproducts of treatment processes is obviously the best solution because it has been well known that livestock wastewater can be used as an organic fertilizer with very high nutritional values. In Korea a considerable portion of livestock feeds is imported from abroad and so will be in the future. The degree of self sufficiency of food in Korea is so low that the utilization of agricultural waste products is desirable in terms of easing the national economic status at the same time maintaining environmental quality of the country.

There have been many procedures of treatment for livestock wastewater. Utilization of plant residue such as rice straw, livestock wastewater, and even the filtrate through trickling filter should be considered in the view points of ecological and economic advantages. Results indicated that the byproducts from the piggery wastewater treatment exhibited no adverse effects on rye growth and soil quality. Both rice straw medium and filtrate could be recycled for the plant nutritional sources and soil amendment from the viewpoint of sustainability.

References

1. Loehr, R. C. (1984) In *Pollution Control for Agriculture*,

(2nd ed.) Academic Press, New York, USA.
2. Howells, D. H., Kriz, G. J. and Robbins, J. W. D. (1971) In *Role of Animal Waste in Agricultural Land Runoff*, Final Rep. Proj. 13020 DGX U. S. Environmental Protection Agency, Washington, D.C., USA.
3. Lim, D. K., Shin, J. S., Choi, D. H. and Park, Y. D. (1987) Utilization of liquid waste from methane fermentation as a source of organic fertilizer. *J. Kor. Soc. Soil. Sci. Fer.* **20**, 333-336.
4. Shin, J. S., Lim, D. K., Kim, J. G. and Park, Y. D. (1986) Utilization of liquid waste from methane fermentation as a source of organic fertilizer. I. The effect of liquid waste from methane fermentation on grass yields. *J. Kor. Soc. Soil Sci. Fert.* **19**, 133-137.
5. Shin, J. S., Kim, J. G., Lim, D. K. and Han, K. H. (1987) Utilization of liquid waste from methane fermentation as a source of organic fertilizer. II. Effect of liquid waste on chemical components, digestible dry matter and net energy of pasture mixtures. *J. Kor. Soc. Soil Sci. Fert.* **20**, 147-151.
6. Shin, J. S. (1984) In *Agricultural Environmental Chemistry*, Han, K. H. and Park, C. K. (ed.) Donghwa Publishing Co., Seoul, Korea.
7. Eck, H. V. and Stewart, B. A. (1995) In *Soil Amendments and Environmental Quality*, J. E. Rechcigl (ed.) Lewis Publishers, Boca Raton, FL, USA.
8. Coleman, D. C. and Crossley Jr., D. A. (1996) In *Fundamentals of Soil Ecology*. Academic Press, New York, USA.
9. Kim, J. J., Yang, J. E. and Shin, Y. O. (1996a) Effect of humified straw used as a medium of trickling filter with livestock wastewater on the growth of bunching lettuce (*Lactuca sativa*., var. crispa) and soil chemical properties. *J. Kor. Soc. Soil Sci. Fert.* **29**, 137-144.
10. Kim, J. J., Yang, J. E. and Shin, Y. O. (1996b) Effect of straw used as a medium of trickling filter with livestock wastewater on the growth of bunching lettuce (*Lactuca sativa* L., var. crispa) and soil chemical properties. *J. Kor. Soc. Soil Sci. Fert.* **29**, 371-377.
11. Kim, J. J., Yang, J. E., Shin, Y. O. and Shin, M. K. (1997) Application of the trickling rice straw filter medium for livestock wastewater enhanced soil chemical properties and the growth of Orchard grass (*Dactylis glomerata*, L.). *J. Kor. Soc. Soil Sci. Fert.* **30**, 334-340.
12. Eckenfelder Jr., W. W. (1998) In *Encyclopedia of Environmental Analysis and Remediation*, Meyer, R. A. (ed.) pp. 5147-5169, John Wiley & Sons, Inc., New York.
13. Yang, J. E., Kim, J. J., Shin, Y. O., Shin, M. K. and Park, Y. H. (1999) Fertility assessment of the piggery wastewater trickling filtrate for Orchard grass (*Dactylis glomerata*, L.) and soil. *Agric. Chem. Biotechnol.* **42**, 34-39.
14. Rural Development Administration (1988) In *Methods of Soil Chemical Analysis*, Suwon, Korea.
15. USDA (1954) *Diagnosis and Improvement of Saline and Alkaline Soils*, Handbook No. 60, US Salinity Lab. Staff.