Agric. Chem. Biotechnol. **42**(1), 34-39 (1999)

Articles

Fertility Assessment of the Piggery Wastewater Trickling Filtrate for Orchard Grass (*Dactylis glomerata* L.) and Soil

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Received March 12, 1999

In search of a method to achieve sustainable agricultural practices, a trickling filter was employed for the piggery wastewater treatment, where rice straw was the support medium in place of more commonly used materials. The filtrate from the trickling filter were applied to a soil, on which orchard grass (*Dactylis glomerata* L.) was grown followed by amendment of the treated straw medium. Orchard grass was cut twice, and growth parameters and yields were measured. Soil chemical properties before and after harvesting orchard grass were analyzed. Development of the forage crop was greatly enhanced by the application of the filtrate in terms of fresh weight, dry weight, and the absorption of nutrients. Better growth and higher nutrient uptake were found in the second cutting of the orchard grass. Organic matter content, ionic intensity, exchangeable cations, and phosphate of the soil increased with the application of the filtrate. The relative high concentrations of salts in the piggery trickling filtrate, expressed in electrical conductivity and content of sodium, exerted no detrimental effect on the crop and soil.

Key words: *trickling filter, filtrate, orchard grass, piggery wastewater.*

Quality of soil and water environments has degenerated due to the intensive agricultural activities. Some of the examples of adverse effects attributed to agriculture are (i) excessive nutrient loads to water body from lands used for crop production or waste disposal, (ii) microorganisms in waste discharges that may impair the use of surface waters for recreation, (iii) impurities in groundwater from land disposal of wastes, (iv) contaminants that complicates water treatment, (v) depletion of dissolved oxygen in surface waters causing fish-kills, and (vi) septic conditions and odors from concentrated waste storage and land disposal.[1,2]

Agricultural production bec more intensive in recent decades. Some of the most dramatic changes in agricultural production are increases in animal production.[3] Farm animals, such as chickens and pigs, are mostly confined within small pen and controlled to produce the greatest weight gain in the shortest period of time with the least amount of feed.[2]

In some areas of the country, water pollution problems have resulted from the concentrated animal feeding and wastes.[4,5] Land application has been a traditional way of agricultural waste disposal and will remain as one of the best approaches. But in some cases, the quantity of wastes from the intensive animal operations exceeds the capacity of the available land to assimilate the wastes. Many potential problems in environmental quality are associated with the residues from such farmstead. Residues of this nature have merited attention because the natural cycles associated with agriculture have been altered or even broken in some situations. The relative adverse effect of manure disposal, however, was found to be dependent more on waste management methods than on the quantity of the waste involved.[6]

Livestock wastes are semisolid or semiliquid in nature. The waste production from pig is dependent on the type and size of animal, the type of feed, the amount of water added in washing and leakage, and the condition of the feedlot. Nutrients in the wastes are of utmost interest because land is the ultimate acceptor of the piggery wastes.

The most common processes used for the treatment, stabilization, or disposal of livestock wastes are of biological attenuation.[4,5,7] Biological treatment processes can be exemplified by oxidation ponds, aerated lagoons, oxidation ditches, anaerobic lagoons, anaerobic digesters, compositing, and land treatment.[2]

A conventional trickling filter in a fixed-film reactor is a packed bed, usually plastic, on which a biofilm grows. As wastewater passes over the film, organics and oxygen

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Abbreviations: BOD, biological oxygen demand; CEC, caton exchange capacity; COD chemical oxygen demand; EC, electrical conductivity; SS, supended solid.

diffuse into the film where they undergo biodegradation.[8] The variables affecting performance are the organic loading rate, the hydraulic loading rate, temperature, and the degradability of the wastewater. For industrial wastewaters, a trickling filter is considered a pretreatment process usually designed to remove about 50% of the BOD.

The media more commonly used in trickling filters are crushed stone, rock of various size or plastic material of different configurations.[9] As an alternative to the common support media, rice straw was employed for the filter medium in the previous studies.[10,11] Rice straw used as a filter medium proved to be beneficial to crop and soil chemical properties. Application of animal wastes to soil, combined with this crop residue, is supposed to serve as a forward step toward an ecologically desirable practice to achieve sustainable agriculture. In this paper the nutritional potential of the trickling filtrate of piggery wastewater, where rice straw was employed as the filter medium, was assessed for the growth of orchard grass and soil chemical properties.

Materials and Methods

Soil and plant. A soil sample of Jungdong series, coarse loamy, mixed, mesic, Typic Udifluvent, taken from the outskirts of Chunchon, Kangwondo, was used in the experiment. Some of the selected chemical properties of the experimental soil are shown in Table 1. Chemical analysis of the soil was done following the procedures suggested by the Rural Development Administration of Korea.[12] Orchard grass (*Dactylis glomerata* L.) was grown for the assessment of nutritional potentials of the trickling filtrate of piggery wastewater.

Operation of trickling filter using rice straw medium. Rice straw used for trickling filter support medium was collected from the farmhouse and cut in 3 to 5 cm in length and evenly packed into a trickling filter column (plexiglass; 9×0.5×120 cm; D×W×H). Wastewater effluent from a swine farm feedlot was sprayed over the medium using peristaltic pump, with the operational parameters of 0.846 m^3/m^2/day and 1.148 kg BOD/m^3/day for hydraulic loading and organic loading, respectively. The removal efficiencies of the trickling filter system employed were 53.4, 54.3, and 70.9%, for BOD, COD, and SS, respectively. Treatment efficiency of this trickling filter system for BOD and COD was in similar ranges to those reported by Eckenfelder, Jr.[8] Filtrate passed through the trickling filter was collected at the bottom of the column.

Fertility assessment of the trickling filter filtrate. Some of the plant nutritional properties of the filtrate are shown in Table 2. The straw medium was taken out of the column after wastewater treatment was completed, then dried and crushed into small fragments for easy storage and application to soil. Table 2 compares the chemical properties of the treated straw medium with those of a commercial compost. The treated rice straw medium was superior to an ordinary compost in term of total nitrogen and CaO contents. The soil sample for this experiment was divided into six experimental plots. Each plot received a determined amount of fertilizers. The background fertilizers (NPK) were urea, fused superphosphate and potassium chloride, applied at equivalent rates of 28 kg/10a of N, 20 kg/10a of P_2O_5, 24 kg/10a of K_2O, 8 kg/10a of MgO, 0.4 kg/10a of B, and lime requirement of CaO. Nitrogen and potassium fertilizers were applied to the soil four times as split side dressings. Wagner pots (1/5000a) were used with treated straw media and soil, where 15 of orchard grass seeds were planted and allowed to develop under greenhouse conditions. The trickling filtrate was applied to the surface of the pot or injected into the pot at depths of 10 cm and 20 cm. The amount of the filtrate applied or injected was equivalent to 4 tons/10a (100 mL/pot). The application of the filtrate was repeated 4 times with an interval of every two weeks. The pots were laid out following the randomized complete block design with three replications for each treatment. The forage crop was cut in 62 days after planting for the first analysis, and 42 days after the first cutting for the second analysis of plant. At each cutting, soil samples were taken at the same time. Growth parameters and yields of orchard grass were measured, and soil chemical properties were analyzed.

Table 1. Selected chemical properties of the the experimental soil (Jungdong series, coarse loamy, mixed, mesic typic udifluvent).

pH (1:5)	Ava. P_2O_5 (mg/kg)	OM (%)	Exc. cations [cmol(+)/kg] K	Ca	Mg	Na	Texture
5.9	57.14	1.17	0.411	2.490	0.213	0.012	Silt loam

Table 2. Plant nutritional properties of the filtrate, treated straw medium and a commercial farm compost.

Material	Composition (%) T-N	Total P_2O_5	K_2O	CaO	Na_2O	MgO
Filtrate	0.002	0.011	0.148	0.008	0.037	0.002
Straw medium[a]	4.800	3.521	0.859	2.267	0.265	0.583
Compost[a]	4.080	3.642	0.872	1.732	0.260	0.862

[a] % dry matter

Results

Growth and yield of orchard grass. It has been well visualized that the addition of treated rice straw media from trickling filter with swine farm wastewater enhanced the growth of plants resulting in the increase of yield, in which rice straw was used as an alternative support medium to more common support media such as stones or plastic materials of various configurations.[10,11] Results of this experiment clearly demonstrated that application of the filtrate of trickling filter in addition to the treated straw media resulted in a drastic increase in yield (Table 3). The

Table 3. Development of orchard grass (*Dactylis glomerata* L.) grown on soils amended with rice straw medium and filtrates at different depths.

Treatment	Injection depth (cm)		Height (cm)	Fresh weight (g)	Dry weight (g)	T-N (%)	P_2O_5 (%)	K_2O (%)	CaO (%)	Na_2O (%)	MgO (%)
1. N.P.K. (Control)	0	1st cutting	41.37	18.8	2.67	4.1	0.35	3.79	0.28	0.07	0.66
+ Filtrate		2nd cutting	37.73	28.6	7.27	3.8	0.20	3.27	0.30	0.22	0.86
	10	1st cutting	43.97	15.2	2.23	3.4	0.52	3.57	0.19	0.07	0.55
		2nd cutting	43.40	27.6	6.13	3.1	0.26	3.24	0.21	0.30	0.83
	20	1st cutting	44.43	21.8	3.73	3.8	0.38	3.24	0.45	0.12	0.78
		2nd cutting	40.13	33.9	7.93	3.5	0.28	4.16	0.21	0..23	0.83
2. N.P.K	0	1st cutting	29.37	13.1	2.20	4.4	0.51	3.74	0.32	0.10	0.72
+compost		2nd cutting	36.70	39.7	8.53	3.2	0.36	4.05	0.13	0.43	0.69
2000 kg/10a	10	1st cutting	44.43	23.4	4.43	3.6	0.58	3.86	0.37	0.98	0.68
+ Filtrate		2nd cutting	50.40	34.5	10.60	2.9	0.27	3.61	0.21	0.25	0.78
	20	1st cutting	36.73	22.2	3.70	3.4	0.55	3.73	0.22	0.11	0.62
		2nd cutting	35.80	29.4	7.77	3.2	0.35	4.46	0.17	0.15	0.73
3. N.P.K +	0	1st cutting	34.30	21.8	2.83	3.9	0.54	3.43	0.27	0.14	0.76
Rice straw medium		2nd cutting	41.87	40.3	9.33	3.2	0.19	3.36	0.15	0.43	0.77
1000 kg/10a	10	1st cutting	39.60	22.5	3.87	3.9	0.60	2.88	0.40	0.20	0.84
+ Filtrate		2nd cutting	42.27	31.7	8.57	2.7	0.70	3.65	0.15	0.21	0.79
	20	1st cutting	39.33	22.5	3.87	3.8	0.52	2.81	0.40	0.23	0.83
		2nd cutting	41.33	34.8	8.10	3.6	0.30	3.94	0.45	0.23	0.79
4. N.P.K+	0	1st cutting	33.73	22.1	2.80	4.1	0.68	2.79	0.20	0.19	0.67
Rice straw medium		2nd cutting	35.60	37.9	8.57	3.2	0.24	3.54	0.24	0.47	0.83
2000 kg/10a	10	1st cutting	34.10	22.7	4.07	3.9	0.76	3.02	0.27	0.20	0.77
+ Filtrate		2nd cutting	45.53	37.7	10.07	3.1	0.24	3.56	0.18	0.24	0.88
	20	1st cutting	30.10	23.6	3.87	3.7	0.90	3.6	0.32	0.26	0.80
		2nd cutting	47.00	29.5	8.63	2.9	0.53	4.48	0.27	0.27	0.63
5. N.P.K+	0	1st cutting	29.93	24.9	4.30	3.9	0.45	3.53	0.27	0.21	0.81
Rice straw medium		2nd cutting	39.87	25.0	8.33	3.1	0.36	3.59	0.21	0.44	0.75
3000 kg/10a	10	1st cutting	34.33	21.6	3.77	3.9	0.80	4.05	0.43	0.24	0.93
+ Filtrate		2nd cutting	40.93	37.6	9.87	3.2	0.42	3.32	0.13	0.31	0.78
	20	1st cutting	35.00	22.8	3.73	3.8	0.77	2.92	0.30	0.31	0.74
		2nd cutting	47.73	29.3	10.67	3.0	0.38	3.74	0.13	0.34	0.70
6. N.P.K+	0	1st cutting	54.20	27.4	5.03	4.3	0.43	4.37	0.24	0.29	0.77
Rice straw medium		2nd cutting	40.00	25.6	8.93	3.2	0.29	3.46	0.15	0.60	0.79
4000 kg/10a	10	1st cutting	43.37	20.6	3.20	4.1	0.9	3.88	0.25	0.26	0.71
+ Filtrate		2nd cutting	41.00	37.5	11.07	3.7	0.25	3.61	0.36	0.57	0.89
	20	1st cutting	34.54	29.6	5.27	3.9	1.02	3.74	0.28	0.21	0.78
		2nd cutting	42.27	27.1	9.57	2.9	0.42	4.23	0.37	0.22	0.68

trickling filtrate treatment increased the yield to more than double when estimated on dry weight basis. The same trend was amply shown in plant height, fresh weight, and contents of total nitrogen, phosphorus, potassium, calcium, and magnesium. The content of sodium was also increased in the plants with the filtrate treatment.

As shown in Table 3, height of the forage crop was taller with the filtrate injected into the soil at depths of 10 cm and 20 cm than with the filtrate sprayed over the soil surface. There was no significant difference between depths of injection regarding the plant height. The average plant height of the second cutting was greater than that of the first, even though the required time for growth of the first cutting was longer than that of the second cutting. An increase in the amount of treated straw medium applied to the soil, along with the filtrate, was accompanied by the increment of yield.

Nutrient uptake. Average content of nitrogen in the plant was not significantly different among various treatments. The higher content of nitrogen in the first cutting than in the second cutting was attributed to the fact that plants in an early stage of development have a great demand for nitrogen sources.[13] The depth of injection of the filtrate exerted no effect on the absorption of nitrogen. The content of phosphorus in the plant was also higher in the first cuttings than in the second as in case of nitrogen, because phosphorus is an essential plant nutrient required in a high concentration for normal development in the early period of growth.[13] However, as compared to N, the increase in injection depth of the filtrate into the rhizosphere enhanced the phosphorus uptake by the plant.

Concentration of potassium in orchard grass shows no difference between the first and the second cuttings or among depths of the filtrate injection. Filtrate treatment increased the potassium uptake by about 3%. Absorption of calcium by orchard grass from the soil appeared to be a function of the growth stage, as the content of calcium of the first cutting is higher than that of the second, irrespective of depths of the application of the filtrate. The absorption of sodium by the plant was, in general, greatly enhanced with the application of the filtrate to the soil. Depths of the application of the filtrate scarcely affected the absorption. The differences in time of cuttings, amounts of the fertilizing materials, or depths of the application of the filtrate had no significant effects on the content of magnesium absorbed by the plant.

Changes in chemical properties of the soil. Table 4 shows the effects of trickling filtrate and rice straw on the soil fertility parameters. pH of the soil increased by 0.3~0.6 unit toward neutrality with the treatment of the treated straw medium and the filtrate, as previously reported.[10,11] The concentrations of calcium, magnesium, potassium and

Table 4. Effects of treated straw medium and the filtrate on the soil chemical properties after the cultivation of orchard grass

Treatment	Injection depth (cm)		pH	EC (dS/m)	Exc Cations [cmol(+)/kg]				P_2O_5[a] (ppm)	OM (%)
					K	Ca	Na	Mg		
1. N.P.K. (Control) + Filtrate	0	1st cutting	6.17	1.63	0.41	2.99	0.14	1.02	67.4	1.44
		2nd cutting	6.57	0.95	0.41	2.61	0.10	0.53	73.3	1.48
	10	1st cutting	6.23	1.12	0.55	8.43	0.33	2.99	96.6	1.42
		2nd cutting	6.50	0.85	0.41	2.34	0.03	0.46	184.8	1.50
	20	1st cutting	6.17	2.16	0.36	2.50	0.11	0.75	77.8	1.48
		2nd cutting	6.23	0.96	0.41	3.00	0.06	0.58	66.7	1.51
2. N.P.K + compost 2000 kg/10a +Filtrate	0	1st cutting	6.27	1.33	0.38	2.53	0.03	1.03	120.4	1.71
		2nd cutting	6.50	1.01	0.45	4.57	0.09	0.80	64.0	1.76
	10	1st cutting	6.27	1.53	0.43	2.39	0.20	0.72	121.1	1.71
		2nd cutting	6.53	0.83	0.41	4.30	0.04	0.69	68.6	1.79
	20	1st cutting	6.27	1.52	0.41	3.21	0.20	0.77	112.6	1.68
		2nd cutting	6.27	1.00	0.42	3.48	0.05	0.83	150.5	1.77
3. N.P.K+ Rice straw medium 1000 kg/10a +Filtrate	0	1st cutting	6.10	2.39	0.43	4.19	0.06	0.81	124.1	1.73
		2nd cutting	6.50	0.90	0.39	3.16	0.56	0.62	98.1	1.78
	10	1st cutting	6.27	1.81	0.42	2.12	0.14	0.92	127.8	1.79
		2nd cutting	6.47	1.07	0.37	3.16	0.01	0.80	178.1	1.78
	20	1st cutting	6.10	2.82	0.39	2.82	0.19	0.97	98.9	1.80
		2nd cutting	6.23	2.27	0.41	2.61	0.04	0.93	125.7	1.75
4. N.P.K+ Rice straw medium 2000 kg/10a +Filtrate	0	1st cutting	6.17	2.22	0.38	2.56	0.06	0.68	146.9	1.92
		2nd cutting	6.37	1.13	0.40	4.08	0.05	1.13	57.1	1.84
	10	1st cutting	6.20	2.31	0.39	2.45	0.17	1.18	160.7	1.97
		2nd cutting	6.43	1.09	0.42	3.92	0.05	1.06	97.1	2.04
	20	1st cutting	6.17	1.55	0.45	3.48	0.24	1.04	136.5	2.16
		2nd cutting	6.23	1.44	0.3	2.72	0.07	1.17	118.1	1.84
5. N.P.K+ Rice straw medium 3000 kg/10a +Filtrate	0	1st cutting	6.20	2.40	0.45	3.92	0.21	1.25	150.3	2.32
		2nd cutting	6.30	1.40	0.41	5.88	0.07	1.50	133.3	2.67
	10	1st cutting	6.20	3.08	0.44	3.15	0.25	1.37	211.6	2.36
		2nd cutting	6.33	1.44	0.42	6.59	0.05	1.34	163.8	2.28
	20	1st cutting	6.10	2.52	0.43	3.32	0.21	1.40	144.9	2.22
		2nd cutting	6.30	1.17	0.42	3.49	0.06	1.33	136.2	2.32
6. N.P.K+ Rice straw medium 4000 kg/10a +Filtrate	0	1st cutting	6.20	2.13	0.51	6.31	0.27	2.65	167.4	2.56
		2nd cutting	6.40	1.20	0.41	3.32	0.10	1.11	152.4	2.31
	10	1st cutting	6.13	3.66	0.46	4.62	0.21	1.71	176.4	2.94
		2nd cutting	6.40	1.68	0.47	5.72	0.06	1.86	158.1	2.76
	20	1st cutting	6.23	1.49	0.43	3.48	0.22	1.08	146.3	2.35
		2nd cutting	6.30	1.50	0.42	2.94	0.11	1.30	127.6	2.33

[a] Available P_2O_5

sodium in the fertilizing materials might be in part responsible for the changes in pH.

The values of EC reflecting the ionic intensity of the soil solution increased with treating the fertilizing materials. Since the ionic intensity of the soil solution is also a function of soluble salt concentration, the increase in EC reveals a positive effect exerting on the growth of the plant. The levels of the EC of the soil measured just after the first cutting of the plant were higher than those after the second cutting, which is in good agreement with the fact that much more plant nutrients were absorbed in ionic forms by the forage crop as shown by the yield increase of the second cutting. However, in-creases in EC did not reach to the critical level which may cause the salt injury of the crop.[14]

The content of soil organic matter increased significantly (r^2=0.98**, p<0.001) following the addition of the amendments. The highest increase in soil organic matter content was reached by the largest amount of the materials applied to the soil which more than doubled the soil organic matter. The effect of continuous application of the fertilizing materials to the field and their accumulation in the field merits further investigation. Within a given treatment of straw medium and filtrate, there was no significant difference in soil organic matter among the depths of application of the filtrate.

In most soils the organic matter contributes greatly to CEC of soil as expressed in part by the amount of exchangeable cations.[15] While the exchangeable potassium appeared to be independent of the level of amendment treatments and depths of injection of the filtrate, the concentration of exchangeable calcium exhibited a tendency of increase with the addition of the fertilizing materials.

Exchangeable sodium was increased drastically with an increase in the levels of treatment, possibly due to the salts in the piggery wastewater. Far less exchangeable sodium remained in the soil after the second cutting of the crop than after the first. Therefore, an increase in the amount of trickling filtrates led to the increase in sodium content of the plant. The concentration of the exchangeable magnesium increased with an increase in the amount of filtrate and straw, but within a given treatment, the depths of the injection of the filtrate affected very little the changes of the respective concentration in the soil. The largest amount of the exchangeable cations was found in calcium, followed by magnesium, potassium, and sodium.

The available phosphorus expressed by P_2O_5 was the most distinguished plant nutrient which accumulated in the soil in a great amount when the soil was treated with the trickling filtrate and straw. It was inadequate to draw any definite trend from the present study for the amount of available phosphorus in the soil due primarily to the fact that the availability of phosphorus is largely governed by a function of solubility-fixation ratio, which is a very intrinsic phenomenon to numerate or even to estimate when its procedure occurs in the soil environment.[16]

Discussion

As an alternative means of the treatment of livestock farm wastewater and its utilization as soil amendments, the feasibility of a trickling filter, in which rice straw was the substituted support medium for the crushed stone or rock, was proven adequate to be introduced. The trickling filtrate enhanced significantly the development and growth of orchard grass with no harmful effects when added to soil. This effect was synergistic with the rice straw support medium that was dried and crushed into small fragments after being sprayed over with the piggery wastewater. Results of this study confirmed a strong potentiality of rice straw as a support medium of trickling filter and a good source of plant nutrient material for an ecologically recommendable cultivation practice. It was also suggested that the filtrate from the trickling filter should be given serious attention because it is, in general, a source of environmental pollution of surface and ground water. A beneficial effect of the application of the filtrate should not be ignored when considering plant nutrient sources and irrigation water economy in terms of achieving ecologically sustainable agriculture practice.

References

1. Elliott, L. F. and Stevenson, F. J. (1986) In *Soils for Management of Organic Wastes and Waste Waters*, Soil Science Society America, Madison, USA.
2. Loehr, R. C. (1984) In *Pollution Control for Agriculture*, (2nd ed.) Academic Press, Inc., New York, USA.
3. Ministry of Agriculture & Forestry (1997) In *Statistical Yearbook of Agriculture & Forestry*, Agriculture Statistics Information Office, Kwachon, Korea.
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. Korean 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. Korean Soc. Soil Sci. Fert.* **20**, 147-151.
6. Howells, D. H., Kriz, G. J. and Robbins, J. W. D. (1971) Role of Animal Wastes in Agricultural Land Runoff. Final Rep. Proj. 13020 DGX. U.S. Environmental Protection Agency, Washington D. C..
7. 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. III. Effect of liquid waste from methane fermentation on Maize. *J. Korean Soc. Soil Sci. Fert.* **20**, 333-336.
8. Eckenfelder Jr., W. W. (1998) Wastes, industrial. In *Encyc-*

lopedia of Environmental Analysis and Remediation, Meyer R. A. (ed.) pp. 5147-5169, John Wiley & Sons, Inc., New York.

9. Manahan, S. E. (1994) In *Environmental Chemistry*, Lewis Publishers, Boca Raton, USA.
10. Kim, J. J., Yang, J. E. and Shin, Y. O. (1966) 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. Korean Soc. Soil Sci. Fert.* **29**, 137-144.
11. Kim, J. J., Yang, J. E. and Shin, Y. O. (1996) Effect of straw used as a medium of trickling filter with livestock wastwater on the growth of bunching lettuce (*Lactuca sativa* L., var. crispa) and soil chemical properties. *J. Korean Soc. Soil Sci. Fert.* **29**, 371-377.
12. Rural Development Administration (1988) Methods of Soil Chemical Analysis : Soil, Plant and Soil Microorganims, Suwon, Korea.
13. Marshner, H. (1986) In *Mineral Nutrition of Higher Plants*, Academic Press, New York, USA.
14. Killham, K. (1994) In *Soil Ecology*, Cambridge University Press, New York, USA.
15. Stevenson. F. J. (1982) In *Humus Chemistry: Genesis, Composition, Reactions*, John Wiley & Sons, New York, USA.
16. Russell, E. W. (1961) In *Soil Conditions and Plant Growth*, (9th ed.) Longman, London, Great Britain.