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Effect of Fertilization Practice on Nitrate Accumulation and Leaching in Vegetable Greenhouse System

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Abstract: A leaching experiment was conducted on three level of total N soils transplanted with lettuce in packed soil columns. Nitrate content in the surface soil layer increased to 52.6, 92.8 and 92.1 mg kg^{-1} when 30 t ha^{-1} poultry manure was used alone in the low, medium and high level of total N soils. Measured leachate data showed that more nitrate was leached in the chemical fertilized soils in the low and high level of total N soils. In conclusion, the study clearly demonstrated that the appropriate application rate of poultry manure and chemical fertilizer with minimized nitrate leaching loss. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Nitrate, Accumulation, Leaching, Greenhouse soil, Chemical fertilizer, Manure.

1. Instruction

Vegetable greenhouse systems in northern China contribute to vegetable yields and economic returns but may also cause accumulation of nitrate in soils and contamination of groundwater because vegetables are heavily fertilized to achieve high yields [1, 2]. Especially in vegetable greenhouse soils with high levels of nutrient elements, the potential risk of nitrate leaching is even higher.

In vegetable greenhouse agriculture, the level of nitrate is high partly due to long-term over fertilization practice. Yuan [3] conducted long-term field experiment and reported that the accumulation of nitrate significantly increased along with the increase of manure application. The concentration of nitrate in the 280-400 cm soil layer reached 40-50 mg kg^{-1} in vegetable soil, due to large incorporation of poultry manure [4]. In some dry land soil, the average nitrate concentration reached 200 kg hm^{-2} and peaked 600-900 kg hm^{-2} at the 90 cm depth of the soil in North China Plain [5].

Besides, the status of other nutritional substances may also play an import role in soil accumulation of nitrate. The values reflecting soil fertility such as total N, organic matter and available P and K in the surface layer of greenhouse soils are in a trend of gradual increase along with the years of vegetable cultivation [6]. Meanwhile, the content of nitrate in the 0-200 cm layer of greenhouse soil reached 377.3 mg kg^{-1} within 10 years. Similar increasing trends in content of nitrate in greenhouse soil along with the year of vegetable cultivation were also reported by other researchers [7-8]. The build-up of nitrate due to excessive N fertilization and soil fertility could increase the danger of underground water pollution with heavy irrigation practices [9].

Surface water and groundwater pollution caused by leaching loss of nitrate from intensive agricultural systems has caused public concern [10, 11]. In northern China, nitrate-N concentrations in shallow wells in the greenhouse vegetable systems ranged from 9 to 274 mg N L^{-1}. Shallow groundwater was particularly vulnerable to nitrate pollution in the greenhouse systems [12]. High rates of nitrate leached in greenhouse vegetable fields in southeastern China as well [13]. Excess use of N fertilizer contributes to subsurface water contamination [14, 15].

The significant increase of nitrate content in vegetable greenhouse soil and leachates are associated with the increase of N fertilization and soil fertility, available data is still limited about how to choose a proper fertilization strategy in vegetable greenhouse soils with different fertility levels. In this study, the influences soil fertility levels (specifically soil total N) and applications of chemical fertilizers and organic manure on mineral nitrogen accumulation and nitrate leaching were investigated in a greenhouse soil with different total N levels, aiming to lower the build-up of nitrate in soil.

2. Material and Methods

The experimental site of the packed soil column located at Shenyang Experimental Station (41°31′N and 123°41′E), Chinese Academy of Sciences. Soils used in the vegetable greenhouse cultivation were of the same type (Mollisols in US Soil Taxonomy) differed in total nitrogen, phosphorus and carbon levels, ranging from the low to high levels (Table 1). The packed soil columns were 50-cm high made of plexiglas, with an inner diameter of 24 cm. There were three water outlets at the bottom of the column for leachate collection. All the soils were sieved through a 2-mm sieve and mixed thoroughly prior to being packed into the columns. Altogether, 45 columns were packed with the sieved soil at a bulk density of 1.3 g cm^{-3}. The bottom layer was filled with soils from 20 to 40 cm soil layer, and the top layer of the column was packed with surface soil (0-20 cm). The leaching experiment was carried out in April 2011. The column was saturated with water for a day before the lettuce was transplanted in the column. Then the column was leached with 3 L distilled water each every three days. The leachates were collected with a plastic bottle and were stored at -20°C before analysis for NO_3^--N. The leaching experiment lasted for 49 days.

Table 1. Properties of 0-20 cm tested greenhouse soil with different nutrient status.

Tested Soil	**Total C** (g kg^{-1})	**Total N** (g kg^{-1})	**Total P** (g kg^{-1})
L soil	23.10 c	1.35 c	1.26 c
M soil	24.60 b	1.67 b	1.44 b
H soil	25.90 a	1.81 a	1.63 a

Different letters mean significant difference at P < 0.05. L represents the low level of total N soil; M represents the medium level of total N soil. H represents the high level of total N soil.

Experimental design: 1) A control with no fertilization applied (CK); 2) application of complex chemical fertilizer (NPK, 150 kg N ha^{-1}, 65 kg P ha^{-1} and 124 kg K ha^{-1}); 3) application of 30 t ha^{-1} of poultry manure (M, standard local application rate, 502 kg N ha^{-1}; 4) a combination of poultry manure and compound chemical fertilizer (M+NPK, 652 kg N ha^{-1}; and 5) a decreased combination of poultry manure and complex fertilizer (2/3 (M+NPK), 435 kg N ha^{-1}). Poultry manure contained 95.9 g kg^{-1} total carbon, 16.7 g kg^{-1} total nitrogen and 6.8 g kg^{-1} total phosphorus. Each treatment was repeated three times.

The soils samples were sampled from the soil column at two depths 0-20 cm and 20-40 cm at harvest maturity of lettuce. The soils were extracted with 100 mL 2 mol L^{-1} KCl for half an hour. Amounts of nitrate (NO_3^--N) were determined in the extract by MgO-Devarda alloy distillation method [16]. The leachates from the soil columns were stored at -20°C prior of analysis of NO_3^--N concentrations. Contents of NO_3^--N were measured by MgO-Devarda alloy distillation method. The loss amount of NO_3^--N at each sampling date is calculated as:

$$C_{NO_3^--N}\,(\text{mg kg}^{-1}\text{ soil}) = \frac{C_t \times V_t}{m},$$

where $C_{NO_3^--N}$ represents the content (mg kg^{-1} soil) of NO_3^--N at each sampling date; Ct represents the concentration (mg/L) of NO_3^--N in leachate at each sampling date. V_t is the volume (L) of the water leached out of every packed soil column. m represents the dry weight (kg) of soil samples in the packed leaching column.

All statistical analyses were performed with SPSS 16.0 (SPSS, Inc., 16.0). Significant differences were analyzed using ANOVA, followed by the least significant difference test (LSD, P < 0.05).

3. Results and Discussion

3.1. Nitrate-N Distribution in the 0-20 cm and 20-40 cm Depth

The concentrations of NO_3^--N in the top surface soil (0-20 cm depth) were in the range of 18.4 to 92.1 mg kg^{-1} (Fig. 1). With the increasing application of complex fertilizer or poultry manure, the content of NO_3^--N in the surface soil layer increased to 52.6, 92.8 and 92.1 mg kg^{-1} in the low, medium and high level of total N soil. The level of NO_3^--N under the application of 30 ha^{-1} poultry manure was significantly higher compared with other fertilization treatments (P < 0.05). However, NO_3^--N content had not always been proportionate to the increased application of fertilizer. NO_3^--N concentration dropped to 33.2, 65.2 and 71.9 mg kg^{-1} under the application of M+NPK treatment in these three levels of total N soils. Fertilization rate significantly affect the level of nitrate in the soil. The content of nitrate was highest with the application rate reaching

502 kg N ha^{-1}, more application of fertilizer decreased the level of nitrate in the soil. In the subsoil (20-40 cm soil depth), there was a similar variation of NO_3^--N under the fertilizer treatments. NO_3^--N content was significantly higher under the application of 30 t ha^{-1} poultry manure compared with other fertilization practices in the low and high level of total N soils ($P < 0.05$).

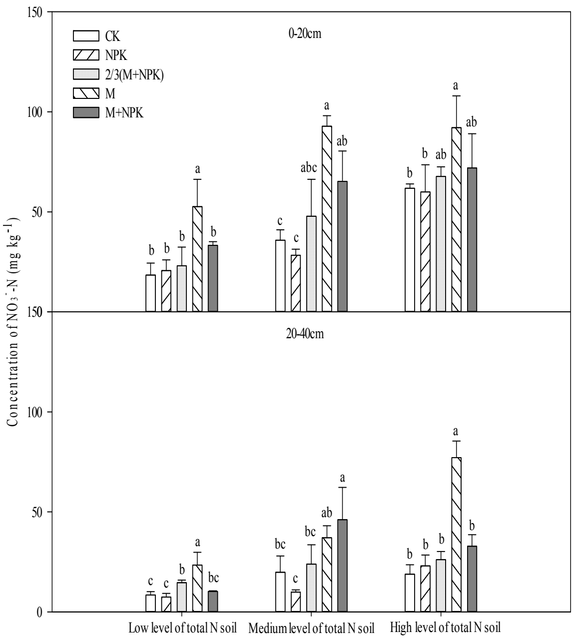

Fig. 1. Concentration of NO_3^--N in top surface soil and subsoil applied with 30 t ha^{-1} poultry manure (M), complex fertilizer (NPK), combination of poultry manure (M+NPK), decreased combination of poultry manure and complex fertilizer (2/3(M+NPK)) and no fertilizer applied control (CK).

Greenhouse vegetable cultivation is an intensive agricultural production system with high inputs of fertilizer. The continuous and excessive application of fertilizer leads to nutrients accumulation in greenhouse soil [9, 17, 18]. Total N, organic matter and available P and K in the surface soil layers of greenhouse soil tended to increase with the extension of using time, leading to the increase of soil fertility [6]. The results presented showed that applications of excessive fertilizer increased the level of NO_3^--N in greenhouse soil (Table 2). In the low level of total N soil, the application of 30 t ha^{-1} manure had a significant effect on increasing the content of nitrate in the soil. The highest content of NO_3^--N reached 52.6 mg kg^{-1} under the application of 30 t ha^{-1} poultry manure, with 46.9 % much more than the background level in the medium level of total N soil. In the medium level of total N soil, NO_3^--N content in the soil with application of 30 t ha^{-1} poultry manure was significantly higher than that in the background of the high level of total N soil (Table 3). There might be a leaching potential for NO_3^--N when massive of N accumulated in soil. Younie [19] reported that accumulation of inorganic N was major determinant of the potential N lost from the system via volatilization, denitrification or leaching. A high nitrate concentration in the root zone was one of the major concerns in extensively irrigated areas. There was potential for nitrate leaching with accumulative nitrate concentration in soil solution and high amount of leaching water [20].

Table 2. Comparison of content of NO_3^--N from different fertilization practices in the low level of total N soil with the content of NO_3^--N in the background level of the medium level of total N soil.

Fertilization practices	**NO_3^--N (mg kg^{-1})**
0-20 cm	
L NPK	20.7 b
L 2/3(M+NPK)	23.0 b
L M+NPK	33.2 b
M CK	35.8 b
L M	52.6 a
20-40cm	
L NPK	7.4 b
L M+NPK	10.2 b
L 2/3(M+NPK)	14.5 ab
M CK	19.8 a
L M	23.3 a

L represents the low level of total N soil; M represents the medium level of total N soil. Different letters mean significant difference at $P < 0.05$.

Table 3. Comparison of content of NO_3^--N from different fertilization practices in the medium level of total N soil with the content of NO_3^--N in the background level of the high level of total N soil.

Fertilization practices	**NO_3^--N (mg kg^{-1})**
0-20 cm	
M NPK	28.4 c
M 2/3(M+NPK)	47.8 bc
H CK	61.8 b
M M+NPK	65.2 b
M M	92.8 a
20-40cm	
M NPK	9.9 c
H CK	18.8 c
M 2/3(M+NPK)	23.8 bc
M M	37.0 ab
M M+NPK	46.1 a

M represents the medium level of total N soil; H represents the high level of total N soil. Different letters mean significant difference at $P < 0.05$.

3.2. Dynamic of NO_3^--N Content Through Leaching

As shown in Fig. 2, the content of NO_3^--N in the leachates was initially similar under all the fertilization practices. In the low level of total N soil, the content of NO_3^--N increased significant on April 25th in the treatment with no fertilizer applied control. In the NPK and M+NPK treatments, the contents of NO_3^--N significantly increased and peaked on May 1st. In the 2/3 (M+NPK) treatment, there was a significant increase of NO_3^--N on April 25th and a peaking value was showed on April 28th. In the M treatment, the content of NO_3^--N showed a fluctuate pattern and peaked on May 1st. The content of NO_3^--N decreased to low level after May 10th with the extension of leaching time. In the medium level of total N soil, intensity fluctuations of the concentration of NO_3^--N were observed in the leachates since the beginning of leaching experiment. NO_3^--N concentration significantly increased on April 25th, with a decrease on April 28th and peaked on May 1st significantly. The content of NO_3^--N dropped significantly on May 4th ($P < 0.05$). NO_3^--N concentration in the treatments with fertilizer showed a gradual decline trend after May 4th. With the extension of leaching time, the content of NO_3^--N decreased to 0.2 mg L^{-1} averagely on June 9th. While in the high level of total N soil, the content of NO_3^--N in the leachate from CK treatment increased on April 28th and peaked significantly on May 1st ($P < 0.05$). Under the application of NPK, NO_3^--N concentration significantly increased and peaked on May 4th ($P < 0.05$). NO_3^--N concentration showed a significant increase and peaked on Apr. 28th ($P < 0.05$) for the 2/3 (M+NPK) and M treatments. In the M+NPK treatment, the content of NO_3^--N was highest (39.4 mg L^{-1}) on April 25th and the leaching concentration of NO_3^--N decreased gradually to very low levels on June 9th.

The NO_3^--N concentrations in leachates fluctuated between 0.1 and 71.2 mg L^{-1} in the low level of total N soil, between 0.1 and 64.0 mg L^{-1} in the medium level of total N soil, and between 0.2 and 61.1 mg L^{-1} in the high level of total N soil.

Average content of NO_3^--N in leachates for the different fertilization practices mainly exceeded 50 mg NO_3^- L^{-1} recommended by the World Health Organization between April 25th and May 4th. High NO_3^--N losses through leaching might be illustrated by long term of excessive N application with intensive irrigation practice. There was environmental risk under high inputs in intensively managed agricultural systems, such as soil degradation, eutrophication and pollution of groundwater [21].

The fertilization treatment in present study was relatively common in intensively cultivated greenhouse soil (three or more cycles of vegetable planting in a year).

Chemical fertilizer was applied as basal in the NPK, 2/3(M+NPK) and M+NPK treatments, and poultry manure was applied as basal in the M, 2/3(M+NPK) and M+NPK treatments. According to the result reported by Maeda [22], intensive utilization of swine compost, coated urea or ammonium fertilizer for seven years can cause the leaching loss of nitrate ranging from 30 to 60 mg L^{-1} in soil water.

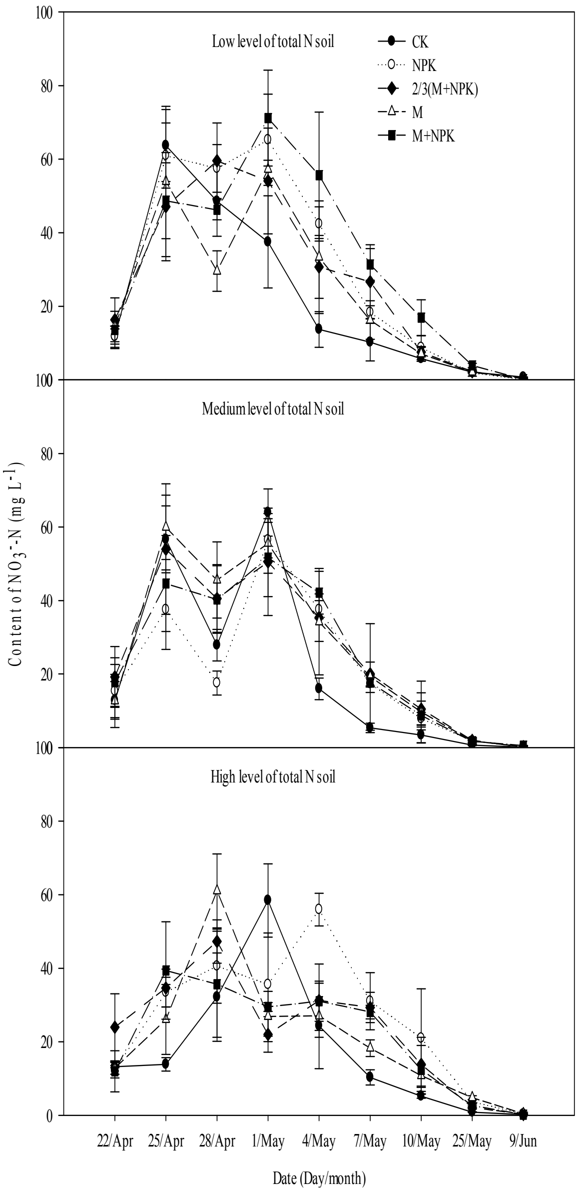

Fig. 2. Mean measured NO_3^--N concentration in leachates from treatments applied with 30 t ha^{-1} poultry manure (M), complex fertilizer (NPK), combination of poultry manure (M+NPK), decreased combination of poultry manure and complex fertilizer (2/3(M+NPK)) and no fertilizer applied control (CK).

3.3. Accumulative Leaching Loss of NO_3^--N

The 49-days accumulative leaching loss of NO_3^--N among the different fertilized soils ranged widely from 11.6 to 21.0 mg kg^{-1} for the five corresponding fertilization strategy (Fig. 3). In the low level of total N soil, the leaching loss of NO_3^--N ranged from 15.7 to 21.0 mg kg^{-1}. In the medium level total N soil, the leaching loss of NO_3^--N from the columns treated with 30 t ha^{-1} poultry manure was significantly higher than that from the no fertilizer applied control or NPK treatment (P < 0.05). In the high level of total N soil, the leaching losses of NO_3^--N was significantly higher under the treatment of NPK compared with CK control (P < 0.05).

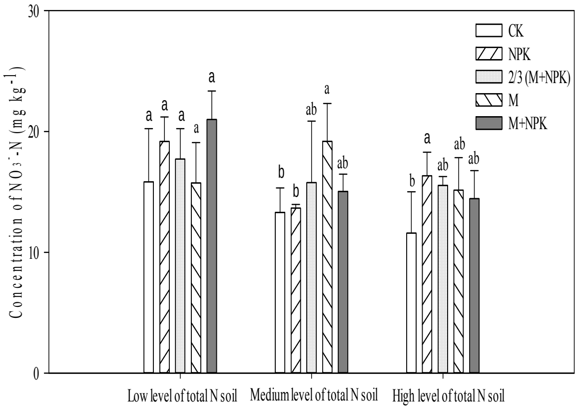

Fig. 3 Mass of NO_3^--N leached from columns applied with 30 t ha^{-1} poultry manure (M), complex fertilizer (NPK), combination of poultry manure (M+NPK), decreased combination of poultry manure and complex fertilizer (2/3(M+NPK)) and no fertilizer applied control (CK).

The utilization of organic manure increased the risk of nitrate leaching in dairy farming systems [23]. The application of poultry manure also increased the leaching potential of NO_3^--N in vegetable greenhouse soil. Manure contains mostly organic and ammonium nitrogen. Some soil microorganisms convert these compounds to nitrate, the easily mobile form of nitrogen in soils. Under some conditions, nitrate may leach below the root zone and eventually reach ground water. This result may be due to the enhancement of biological activities caused by organic manure, which including a large amount of living microorganisms and readily-utilizable carbon source on which microorganisms lived [24]. In addition, manure contains a great deal of organic matter, with the decomposition of which can add soluble N to the soil, increasing the amount of soil nitrate available to be leached [25]. The effect of increasing leaching loss was not significant under the combination of poultry manure and complex fertilizer. Report reflected that organic manure could reduce the leaching of NO_3^--N from KNO_3 addition in soil leachate [26]. However, manure application rates should not exceed the nitrogen requirement of the crop considering the risk of water environment caused by over accumulation of nitrate-N [27-29]. Therefore, it is important to quantify the appropriate application rate of organic fertilizer in vegetable greenhouse soil.

4. Conclusions

Increased inputs of chemical fertilizer and poultry manure to agriculture soil can lead to nitrate leaching to groundwater. The leaching loss potential of significant amounts of NO_3^--N in vegetable greenhouse has been enhanced under local common fertilization practice. Heavy leaching of NO_3^--N was observed after application of commercial fertilizer and poultry manure under intensive irrigation. Based on the findings, we recommended that combination of poultry manure and complex fertilizer (M+NPK) was appropriate fertilization practice in the low level of total N soil. While in the medium and high level of total N soil, the treatment of decreased combination of poultry manure and complex fertilizer (2/3(M+NPK)) was recommendable to decrease the accumulation of nitrate. In conclusion, it is important to use fertilizers at moderate quantity based on soil fertility tested in vegetable greenhouse. Additionally, irrigation frequency and rate should be taken into account according to the critical period when NO_3^--N loss is expected.

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References

[1]. Z. Y. Zhou, M. J. Wang, J. S. Wang, Nitrate and nitrite contamination in vegetables in China, *Food Reviews International*, Vol. 16, No. 1, 2000, pp. 61-76.

[2]. X. Ju, X. Liu, F. Zhang, M. Roelcke, Nitrogen fertilization, soil nitrate accumulation, and policy recommendations in several agricultural regions of China, *AMBIO: a Journal of the Human Environment*, Vol. 33, No. 6, 2004, pp. 300-305.

[3]. X. M. Yuan, Y. A. Tong, X. Y. Yang, X. L. Li, F. S. Zhang, Effect of organic manure on soil nitrate nitrogen accumulation, *Soil Environmental Science*, Vol. 9, No. 3, 2000, pp. 197-200.

[4]. L. X. Yao, X. C. Zhou, Impact of organic manure on the environment and its corresponding preventive researches, *Chinese Journal of Eco-Agriculture*, Vol. 13, No. 2, 2005, pp. 113-115.

[5]. Z. L. Zhu, Research on soil nitrogen in China, *Acta Pedologica Sinica*, Vol. 45, No. 5, 2008, pp. 778-783.

[6]. Q. Chen, X. Z. Zhang, H. Y. Zhang, P. Christie, X. L. Li, D. Horlacher, H. P. Liebig, Evaluation of current fertilizer practice and soil fertility in vegetable production in the Beijing region, *Nutrient Cycling in Agroecosystems*, Vol. 69, Issue 1, 2004, pp. 51-58.

[7]. L. J.Yuan, X. Ju, L. J. Zhang, Y. Wang, Z. X. Yang, NPK Accumulation in greenhouse soil and its effect on groundwater, *Chinese Journal of Eco-Agriculture*, Vol. 18, No. 1, 2010, pp. 14-19.

[8]. Q. F. Liu, J. L. Lv, S. L. Li, H. Y. Sheng, N. Li, Y. P. Wang, J. M. Wang, C. L. Zhu, The Spatio-temporal variation of nitric nitrogen in protected vegetable soils in different years of cultivation, *Agricultural Research in the Arid Areas*, Vol. 29, No. 2, 2011, pp. 159-163.

[9]. W. Yan, K. Yamamoto, K. I. Yakushido, Changes in nitrate N content in different soil layers after the application of livestock waste compost pellets in a sweet corn field, *Soil Science and Plant Nutrition*, Vol. 48, No. 2, 2002, pp. 165-170.

[10]. X. Z. Song, C. X. Zhao, X. L. Wang, J. Li, Study of nitrate leaching and nitrogen fate under intensive vegetable production pattern in northern China, *Comptes Rendus Biologies*, Vol. 332, No. 4, 2009, pp. 385-392.

[11]. Y. Zhao, J. Luo, X. Chen, X. Zhang, W. Zhang, Greenhouse tomato–cucumber yield and soil N leaching as affected by reducing N rate and adding manure: a case study in the Yellow River Irrigation Region China, *Nutrient Cycling in Agroecosystems*, Vol. 94, No. 2-3, 2012,pp. 221-235.

[12]. X. T. Ju, C. L. Kou, F. S. Zhang, P. Christie, Nitrogen balance and groundwater nitrate contamination: comparison among three intensive cropping systems on the North China Plain, *Environmental Pollution*, Vol. 143, No. 1, 2006, pp. 117-125.

[13]. J. Min, X. Zhao, W. M. Shi, G. X. Xing, Z. L. Zhu, Nitrogen balance and loss in a greenhouse vegetable system in southeastern China, *Pedosphere*, Vol. 21, No. 4, 2011, pp. 464-472.

[14]. M. E. Asadi, R. S. Clemente, A. D. Gupta, R. Loof, G. K. Hansen, Impacts of fertigation via sprinkler irrigation on nitrate leaching and corn yield in an acid-sulphate soil in Thailand, *Agricultural Water Management*, No. 52, 2002, pp. 197-213.

[15]. M. Jalali, Nitrates leaching from agricultural land in Hamadan, western Iran, *Agriculture, Ecosystems & Environment*, Vol. 110, No. 3-4, 2005, pp. 210-218.

[16]. D. R. Keeney, D. W. Nelson, Nitrogen-inorganic forms, in A. L. Page, R. H. Miller (Eds), Methods of Soil Analysis, Part 2, 2nd ed. Agron. Monogr. 9, *ASA and SSSA*, Madison, WI, pp. 643-698.

[17]. Y. Guo, J. Wang, R. Wu, M. Q. Zhao, X. Chen, Effect of organic manure on vertical distribution of NO_3^--N in protected cultivation soil depth profile, *Journal of Soil Science*, Vol. 40, No. 4, 2009, pp. 815-819.

[18]. L. Meng, W. Ding, Z. Cai, Long-term application of organic manure and nitrogen fertilizer on N2O emissions, soil quality and crop production in a sandy loam soil, *Soil Biology & Biochemistry*, Vol. 37, No. 11, 2005, pp. 2037-2045.

[19]. M. F. Younie, D. L. Bruton, R. G. Kachanoski, E. G. Beauchamp, R. W. Gillham, Impact of Livestock manure and Fertilizer application on nitrate contamination of groundwater, *Ministry of Environment and Energy*, Toronto, 1996, pp. 134-143.

[20]. T. Tamini, A. Mermoud, Water and nitrate dynamics under irrigated onion in a semi-arid area, *Irrigation & Drainage*, Vol. 51, No. 1, 2002, pp. 77-86.

[21]. J. Spiertz, Nitrogen, sustainable agriculture and food security. A review, *Agronomy for Sustainable Development*, Vol. 30, No. 1, 2010, pp. 43-55.

[22]. M. Maeda, M. Zhao, Y. Ozaki, T. Yoneyama, Nitrate leaching in an Andisol treated with different types of fertilizers, *Environmental Pollution*, No. 121, 2003, pp. 477-487.

[23]. J. Eriksen, M. Askegaard, K. Kristensen, Nitrate leaching in an organic dairy/crop rotation as affected by organic manure type, livestock density and crop, *Soil Use Management*, No. 15, 1999, pp. 176-182.

[24]. A. C. Luo, Effect of organic manure on the biological activities associated with insoluble phosphorus release in a blue purple paddy soil, *Communications in Soil Science and Plant Analysis*, Vol. 25, No. 13-14, 1994, pp. 2513-2522.

[25]. J. Clain, O. R. Kathrin, Crop and fertilizer management practices to minimize nitrate leaching, *Montana State University Extension Communications*, 2011, pp. 1-4.

[26]. S. L. Guo, C. Z. Yu, M. J. Dai, Simulated test of effects of organic manure on leaching of NO_3^--N in soil profile, *Research of Soil and Water Conservation*, Vol. 7, No. 4, 2000, pp. 123-126.

[27]. B. M. Olson, D. R. Bennett, R. H. McKenzie, T. D. Ormann, R. P. Atkins, Nitrate leaching in two irrigated soils with different rates of cattle manure, *Journal of Environmental Quality*, Vol. 38, No. 6, 2009, pp. 2218-2228.

[28]. S. P. Di, Magnetic force as source of electron attraction: a classical model and applications, *Journal of Mechatronics*, Vol. 1, No. 1, 2013, pp. 48-50.

[29]. S. K. Jain, S. S. K. Titus, Performance of a piezoelectric force actuator in low force measurement application, *Journal of Mechatronics*, Vol. 1, No.2, 2013, pp. 109-111.