Korean Journal of Environmental Agriculture

Korean J Environ Agric (2012) Online ISSN: 2233-4173
Vol. 31, No. 3, pp. 205-211 http://dx.doi.org/10.5338/KJEA.2012.31.3.205 Print ISSN: 1225-3537

Research Article Open Access

Effect of Nitrogen Application Rates on Nitrous Oxide Emission during Crop Cultivations in Upland Soil

Jong-Eun Lee,[1] Yeo-UK Yun,[1] Moon-Tae Choi,[1] Suck-Kee Jung,[1] Yun-Gyu Nam,[1]
Prabhat Pramanik[2] and Pil Joo Kim[2,3]*

[1]Chungcheongnam-do Agricultural Research and Extension Services, Yeasan 340-861, Korea
[2]Institute of Agriculture and Life Science, Gyeongsang National University, Jinju 660-701, South Korea
[3]Division of Applied Life Science (BK21 program), Gyeongsang National University, Jinju 660-701, South Korea

Received: 11 July 2012 / Accepted: 18 September 2012

Abstract

BACKGROUND: Generally, nitrogen (N) fertilization higher than the recommended dose is applied during vegetable cultivation to increase productivity. But higher N fertilization also increases the concentrations of nitrate ions and nitrous oxide in soil. In this experiment, the impact of N fertilization was studied on nitrous oxide (N_2O) emission to standardize the optimum fertilization level for minimizing N_2O emission as well as increasing crop productivity. Herein, we developed N_2O emission inventory for upland soil region during red pepper and Chinese milk vetch cultivation.

METHODS AND RESULTS: Nitrogen fertilizers were applied at different rates to study their effect on N_2O emission during red pepper and Chinese milk vetch cultivation. The gas samples were collected by static closed chamber method and N_2O concentration was measured by gas chromatography. The total N_2O flux was steadily increased due to increasing N fertilization level, though the overall pattern of N_2O emission dynamics was same. Application of N fertilization higher than the recommended dose increased the values of both seasonal N_2O flux (94.5% for Chinese cabbage and 30.7% for red pepper) and N_2O emission per unit crop yield (77.9% for Chinese cabbage and 23.2% for red pepper). Nitrous oxide inventory revealed that the N_2O emission due to unit amount of N application from short-duration vegetable field in fall (autumn) season (6.36 kg/ ha) was almost 70% higher than that during summer season.

CONCLUSION: Application of excess N-fertilizers increased seasonal N_2O flux especially the N_2O flux per unit yield during both Chinese cabbage and red pepper cultivation. This suggested that the higher N fertilization than the recommended dose actually facilitates N_2O emission than boosting plant productivity. The N_2O inventory for upland farming in temperate region like Korea revealed that N_2O flux due to unit amount of N-fertilizer application for Chinese cabbage in fall (autumn) season was comparatively higher than that of summer vegetables like red pepper. Therefore, the judicious N fertilization following recommended dose is required to suppress N_2O emission with high vegetable productivity in upland soils.

Key Words: N_2O emission inventory, N_2O flux, N fertilizer treatment, Vegetable cultivation

Introduction

Nitrous oxide (N_2O) is one of the key greenhouse gases emitted from soil and has a life time of about 170 years (Prinn*et al.*, 1990). This gas not only leads to the chemical destruction of ozone in stratosphere, but also is an important greenhouse gas with a global warming potential of 310 times higher than that of

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*교신저자(Corresponding author),
Phone: +82-55-772-1966; Fax: +82-55-772-1969;
E-mail: pjkim@gnu.ac.kr

carbon dioxide on per-molecule basis (Rodhe, 1990). Battle *et al.* (1996) reported that the contemporary atmospheric N_2O concentration measured at the South Pole was about 311 nmol/mol and is increasing at a rate of 0.74 nmol/mol/year. Nitrous oxide emitted due to anthropogenic factors account up to 64% of the total global N_2O emission. Though road transport, power generation and the preparation of acidic chemicals also produce notable releases, agriculture contributes almost 92% of the total anthropogenic N_2O emission (Duxbury *et al.*, 1993). Release of N_2O in the atmosphere is a microorganism-mediated process and several parameters like soil organic matter, temperature, forms of inorganic N (NO_3-N and NH_4-N) influence N_2O emission from soil. Soil organic matter acts as a carbon source for the soil microorganisms and an optimum temperature is required for maximum activity of these microorganisms (Sahrawat and Keeney, 1986). Nitrous oxide is generated due to both nitrification and denitrification in soil, and during these processes, microorganisms use NH_4^+ and NO_3^-ions as initial substrates, respectively. Urea is the major nitrogen fertilizer applied in today's agriculture and dissolution of urea releases both NH_4^+ and NO_3^-ions in soil solution (Biswas and Mukherjee, 2000). Therefore, application of N fertilizer to the agricultural field is one of the primary sources of N_2O and emission of this gas due to N fertilization may be estimated 0.01-6.84% of the applied fertilizers (Eichner, 1990).

In order to provide an estimate of current rates and to assess change in N_2O emissions, one of the obligations of signatory states to the United Nations Framework Convention on Climate Change (UNFCCC) is to establish a national emission inventory that fully reports all anthropogenic sources of greenhouse gases, using complete methodologies. In this study, the protocol of Intergovernmental Panel on Climate Change (IPCC, 1997) was modified to determine the inventory of N_2O emission from agricultural field as affected by different doses of N fertilizer. Among different vegetables, Chinese cabbage and red pepper, were selected as the study crop for this experiment. In case of vegetable cultivation in upland soil, N application rate was decided before only considering crop productivity. During this experiment, Chinese cabbage and red pepper were cultivated under optimum condition required for their growth, except the dose of N-fertilizer. For each crop, three doses of N-fertilizer [recommended dose (RD) and half and double of RD] were applied in soil to study their effect on N_2O gas emission and crop production and also to standardize the optimum N-fertilizer dose for these two crops. The objective of this study was to standardize the optimum N-fertilizer dose during upland cultivation of different vegetables in summer and fall (autumn) seasons through N_2O inventory methodology.

Materials and Methods

Experiment set up

The experiment was conducted at the Research Farm of Chungcheongnam-do Agricultural Research and Extension Services on 2010. Soils of this region belong to Yesan series having coarse loamy and mesic family of Dystrudepts (Red-Yellow soils, Table 1).

Table 1. Characteristics of soil used for the field tests, and cultivation background of two vegetables

Parameter		Crop plants	
		Chinese cabbage	Red pepper
Soil properties	pH (1:5, H_2O)	6.9	6.8
	Electrical conductivity (dS/m)	0.41	0.37
	Organic matter (g/kg)	27	18
	Available P_2O_5 (mg/ kg)	406	283
	Exchangeable cations (cmol$^+$/ kg)		
	K	0.56	0.61
	Ca	6.8	6.7
	Mg	1.1	1.2
Cultivation background	Transplanting date	September 15	May 24
	Transplanting interval (cm)	65×40	100×30
	Recommending fertilization (kg/ ha)		
	N	320	190
	P_2O_5	78	112
	K_2O	198	149
	Compost	15,000	20,000
	Harvesting date	November 25	August 4, 12, 20, 30

Climate condition	Cultivation period (day)	77	130
	Mean soil temperature (°C)	15.1	27.3
	Cumulative air temperature (°C)	1124	3484
	Mean soil moisture content (%)	22.6	18.8
	Total rainfall (mm)	262	739

Among the tested crops (Red pepper and Chinese cabbage), red pepper was cultivated in summer season, while Chinese cabbage was grown during fall (autumn) season. Information about cultivation background was presented in Table 1. During this study, compost was applied at 15 t/ ha and 20 t/ ha in each plot of Chinese cabbage and red pepper fields, respectively. The N content of compost was 1.17 g/kg; however, the effect of N application through compost could be nullified as it was applied in each treatment plot. The recommended chemical fertilizers for these crops are N-P_2O_5-K_2O =320-78-198 kg/ haand 190-112-149 kg/ ha, respectively. In this experiment, plant nutrients (N, P_2O_5 and K_2O) were supplied using urea, superphosphate and potassium chloride, respectively. The basal chemical fertilizers (N-P_2O_5-K_2O = 110-78-110 and 103-112-91 kg/ ha) were applied by broadcasting before transplantation of Chinese cabbage and red pepper, respectively. The remaining portions of N and K_2O were split as three side-dressing doses: in case of Chinese cabbage, split fertilizers were applied on 1st October (70-0 kg/ ha), 15th October (70-44 kg/ ha) and 30th October (70-44 kg/ ha), while split doses were applied on 24th June (29-19 kg/ ha), 26th July (29-19 kg/ ha) and 25th August (29-20 kg/ ha) for red pepper.All matured red pepper fruits were harvested (plucked) on 4th, 12th, 20th and 30th August following standard protocol, while Chinese cabbage was harvested on 25th November.

Nitrous oxide gas sampling and analysis

A closed-chamber method was used to estimate periodical N_2O emissions as well as total N_2O fluxes throughout the cultivation duration (Rolston, 1986). Three chambers were placed in each plot to collect the gas samples for N_2O analysis. The air gas samples from PVC chamber (diameter 27 cm and height 50 cm) were collected twice a week by air tight syringes 30 minutes after closing the lid of the chamber in each plot; however, the chamber was kept open except sampling time. Before starting the experiment, gas samples were collected after 15, 30, 45 and 60 minutes of closing the gas chamber to check the linearity and standardized that 30 minutes is the most optimum time to collect gas samples for studying greenhouse gas emission from soil. Gas samplings throughout the study period were conducted within 11:00-13:00 hours, since the daily mean N_2O emission was recorded within this time of a day (Buendia*et al.*, 1997). Nitrous oxide concentrations were determined with gas chromatography equipped with ^{63}Ni electron capture detector (ECD). The temperature of column, injection and detector were adjusted at 65°C, 150°C and 300°C, respectively with a carrier gas flow rate of 60m/min and 1 ml of gas sample was injected during analysis.

Estimation of nitrous oxide emissions

The rates of N_2O emission from soil were estimated by calculating the increase in N_2O concentration per unit surface area of the chamber in a specific time intervals. The closed-chamber equation was used to estimate N_2O flux from each treatment (Rolston, 1986):

$$F = \rho \times (V/A) \times (\triangle c/\triangle t) \times (273/T)$$

where, F was the N_2O flux (μg N_2O/ m^2/ hr); ρ was the gas density of N_2O under standardized state; mg/ cm^3; V was the volume of chamber (m^3); 'A' indicated the area from which N_2O emitted into the chamber (m^2); $\triangle c/\triangle t$ = rate of accumulation of N_2O gas concentration in the chamber (mg/ m^3/ hr) and T was the absolute temperature [273+mean temperature in chamber (⊞C)]. Total N_2O flux for the entire crop period was computed by the formula (Singh *et al.*, 1999); Total N_2O flux = $\sum_i^n (R_i \times D_i)$, where R_i was the rate of N_2O flux (g/ m^2/d) in the i^{th} sampling interval, D_i was the number of days in the i^{th} sampling interval, while 'n' was the number of sampling intervals.

Soil properties and statistical analyses

Soil temperature and moisture contents were recorded during every gas sample collections. Soil samples were collected from the surface layer (0-15 cm depth). The samples were air-dried, sieved (<2 mm) and analyzed for pH (1: 5 water extraction), organic matter content (Allison, 1965), exchangeable Ca^{2+}, Mg^{2+}, and K^+ (1 M NH_4-acetate extract at pH 7.0, atomic absorption spectrophotometer, Shimadzu 660), inorganic NO_3-N and NH_4-N (2M KCl extraction, Automatic analyzer, FIAstar 5000), available phosphate content using Lancaster method (Jackson, 1973; RDA, 1988).

N_2O emission inventory

The major potential sources of N_2O emission in arable soils are the N supplied for optimum plant growth. Therefore, N_2O inventory correlating total N_2O flux will provide the optimum N dose for sustainable crop production with reduced N_2O emission. Following the methodology described by Intergovernmental Panel on Climate Change (IPCC, 2006), the direct N_2O emission (N_2O_{Direct}) could be explained by equation:

$$N_2O_{Direct} \approx \Sigma i(F_{SN} + F_{ON})_i \text{ x } EF_i + (F_{CR} + F_{SOM}) \text{ x } EF_2 + F_{OS} + F_{PRP} \quad \cdots\cdots.. \text{ (i)}$$

In case of intensively managed upland cropping system, except synthetic N-fertilizers (F_{SN}) and applied compost (F_{ON}), the effects of other parameters like crop rotation (F_{CR}), N mineralization due to changes in land management practices (F_{SOM}) and effect of organic soil (F_{OS}) and animal grazing (F_{PRP}) are almost negligible. Therefore, equation (i) may be modified as

$$N_2O_{Direct} \approx \Sigma i(F_{SN} + F_{ON})_i \text{ x } EF_i$$
$$= \Sigma i \; F_{SN} \text{ x } EF_i + \text{constant} \quad \cdots\cdots.. \text{ (ii)}$$

Since, equal quantity compost was applied in all the treatments of same crop.

Statistical analysis

Statistical analyses were conducted using SAS software. Rice growth and yield, soil properties and N_2O emissions data were subjected to the analysis of variance and regression. Fisher's protected least significant difference (LSD) was calculatedat the 0.05 probability level to compare differences between treatment means.

Results and Discussion

Nitrous oxide (N_2O) emission from vegetable fields

The pattern of N_2O emission during Chinese cabbage and red pepper cultivation were different, though the emission pattern for different treatments in same crop field was similar in nature (Fig. 1). Seasonal N_2O flux during cabbage and red pepper cultivation increased proportionately with increasing N-fertilizer dose (Fig. 2). In case of both Chinese cabbage and red pepper cultivations, periodical N_2O emission was increased with increasing amount of N-fertilizer, especially just after fertilizer application. Periodical N_2O emission in N-fertilizer treated plots was higher than that of control treatment. During this study, 50% of the total N dose was applied as basal fertilizer and remaining portion of fertilizer was split in three top-dressing treatments. The highest N_2O emission within first 10 days of cultivation, irrespective of crop type and fertilizer dose, might be attributed to the high N fertilizer application in basal dose and that was expected to release high amount of NO_3-N in soil solution. This NO_3-N acts as one of the initial substrates for N_2O formation in soil. After initial increase, N_2O emission curve was dropped sharply and except immediately after top-dressing, N_2O emission from a particular vegetable crop field as affected by different treatments did not differ significantly. Results indicated that higher dose of N fertilizer application enhanced N_2O flux from both Chinese cabbage and red pepper field. Meng*et al.* (2005) also found that higher rate of chemical N fertilizer application increased the total N_2O flux in different soils. Application of chemical N fertilizer immediately releases inorganic N to the soil (Okonwu and Mensah, 2012) and that higher NO_3-N concentration in soil solution might be responsible for enhanced N_2O emission.

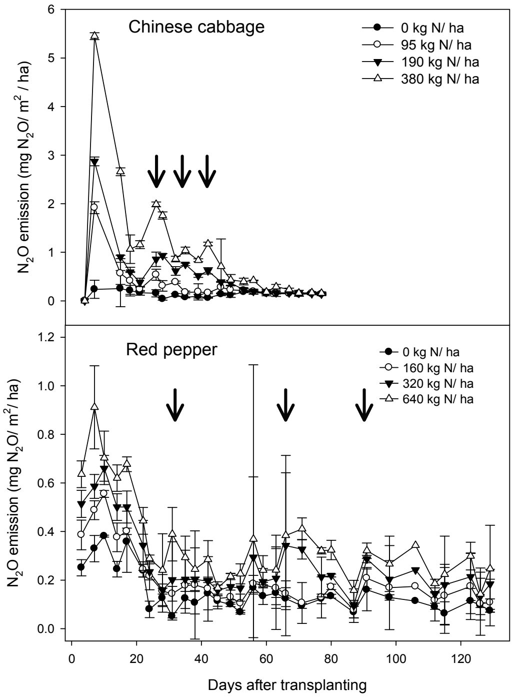

Fig. 1. Changes of N_2O emission rates in upland soils amended different rates of nitrogen fertilizer during two crop plant cultivations. (Note: ↓ indicates days of fertilizer application for side-dressing)

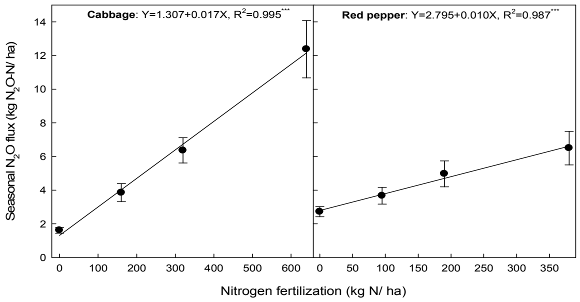

Fig. 2. Responses of seasonal N_2O emission fluxes to nitrogen application rates in upland soils during two vegetable cultivations.

N_2O emission inventory

Equation (ii) resembled with typical straight line equation (y = mx + c), and comparison of seasonal N_2O emissions with different N treatments gave the measure of emission factor (EF) for a particular agro-ecosystem. The values of EF were expressed as kg N_2O gas emitted due to application of unit kg N fertilizer. Data indicated that seasonal N_2O flux for unit amount of N fertilizer application from cabbage field (0.017 kg N_2O/ kg N fertilizer) was comparatively higher than that of red pepper field (0.010 kg N_2O/ kg N fertilizer), so it suggested that 1.7% of the applied N fertilizer was lost as N_2O during Chinese cabbage cultivation, while it was 1.0% in case of red pepper. As mentioned in Table 1, Chinese cabbage is comparatively short-duration vegetable crop and high dose of N fertilizer is applied in soil to obtain desired crop yield. Therefore, higher N_2O emission from Chinese cabbage field might be attributed to the higher N dose applied during Chinese cabbage cultivation and almost 70% higher N_2O emission per unit N application was recorded due to increasing fertilizer application rate above the recommended dose. Data indicated that Chinese cabbage cultivation in upland soil favoured N_2O emission as compared to red pepper. These results also supported the finding of Hideyuki and Tooru (2001), who proposed that total N_2O flux from cabbage cultivated plots was comparatively higher than that of other vegetable plots.

N_2O emission and soil properties

Electrical conductivity and both NH_4-N and NO_3-N concentrations of soil were steadily increased with increasing rate of N-fertilizer application (Table 2). Comparatively higher N-fertilizer application during cabbage cultivation may be attributed to the drastic increase in soil NO_3-N content of these plots, and that in turn increased the emission of N_2O gas through both nitrification and denitrification processes. These are microorganism-mediated processes and NH_4-N and NO_3-N are used as initial substrates by specific group soil microorganisms during these processes, respectively (Klemdtsson*et al.*, 1988). Higher correlation coefficient (Table 3) of N_2O flux with inorganic N-fractions (NH_4-N and NO_3-N) also confirmed that rate of N_2O emission was strongly dependent on the concentrations of these two forms of inorganic N. Values of these correlation coefficients were comparatively higher for red pepper cultivated plots than those of cabbage cultivation. In this experiment, red pepper was cultivated during warm summer (May 24 to August 30) while Chinese cabbage was cultivated in fall (autumn) season (September 15 to November 25). Calculation of mean soil temperature as the ratio of cumulative soil temperature and total cultivation duration (Table 1) indicated that mean soil temperature of red pepper field (27.3°C) was almost double of that for cabbage field soil (15.1°C). Therefore, the favourable soil temperature of pepper field might have hastened the rate of organic matter mineralization. Red pepper cultivation favoured organic C accumulation in soil as compared to Chinese cabbage. Application of N fertilizers increased organic C content in upland soil, however, the difference among different fertilizer applied soils were not statistically significant. Comparatively higher correlation of N_2O emission flux with soil organic matter in red pepper field may also be attributed to the comparatively faster organic matter decomposition under favourable soil temperature which in turn influenced rate of N_2O emission possibly by activating soil microorganisms.

Table 2. Chemical properties of upland soils amended with different rates of nitrogen fertilizer at the harvesting stage

Vegetables	Chinese cabbage					Red pepper				
N application (kg ha^{-1})	0	160	320	640	LSD$_{0.05}$	0	95	190	380	LSD$_{0.05}$
pH (1:5, H_2O)	6.6	7.3	7.5	7.6	0.5	6.4	6.3	6.2	6.1	0.3
Electrical conductivity (dS/ m)	0.25	0.72	1.53	2.55	0.07	0.35	0.63	1.35	2.18	1.0
Organic matter (g/ kg)	16	25	24	22	1.9	23	25	29	29	2.4
Total N (g/ kg)	0.81	1.16	1.59	2.21	0.11	0.87	1.29	1.40	1.55	0.13
Inorganic N (mg/ kg)										
NH_4^+	10.5	25.6	41.7	86.5	4.7	10.2	11.2	12.6	15.1	3.9
NO_3^-	8.4	65.8	109.2	151.2	0.9	7.4	9.5	13.0	16.2	0.5

Table 3. Correlation coefficients between N_2O emission flux and soil characteristics in upland soils amended with different rates of nitrogen fertilizer

Parameter	Vegetables	
	Chinese cabbage	Red pepper
Soil pH	0.844*	0.585
Electrical conductivity	0.996**	0.992**
Organic matter	0.424	0.885*
Total N	0.820*	0.841*
Inorganic NH_4-N	0.631	0.868*
Inorganic NO-N	0.768*	0.877*

* and ** indicate significance at 5 and 1% confidence.

N_2O emission and vegetable yield properties

Yields of both cabbage and red pepper were increased due to increasing dose of N-fertilizer (Fig. 3), though the rate of increase in crop yield was varied among treatments. Total yields of Chinese cabbage and red pepper were increased linearly with increasing amount of N-fertilizer up to recommended dose. But the yield curve was flattened due to increasing N-fertilizer application above recommended dose. Application of higher N fertilizer increased both crop yield and N_2O flux during cultivation. During this experiment, N_2O flux per unit yield parameter was used as an indicator to standardize the optimum N fertilizer dose during Chinese cabbage and red pepper cultivation in upland soils. Nayak*et al.*, (2006) introduced CH_4 emission per unit grain yield for explaining the treatment efficiency to increase rice productivity and also to suppress CH_4 emission. In this experiment, N_2O flux per unit yield was calculated as the ratio of seasonal N_2O flux to the total yield of cabbage or red pepper. Data indicated that the values of N_2O flux per unit yield did not vary due to increasing N-fertilizer dose up to the recommended dose i.e., increasing N fertilizer application up to the recommended dose for Chinese cabbage or red pepper did not affect the magnitude of N_2O flux per yield, though it steadily increased total crop yield. But N_2O flux per unit yield was sharply increased by increasing N-fertilizer dose beyond recommended dose. Therefore, N-fertilization following the recommended dose is possibly the most environment-friendly practice to obtain maximum vegetable production for both summer and fall (autumn) vegetable crops.

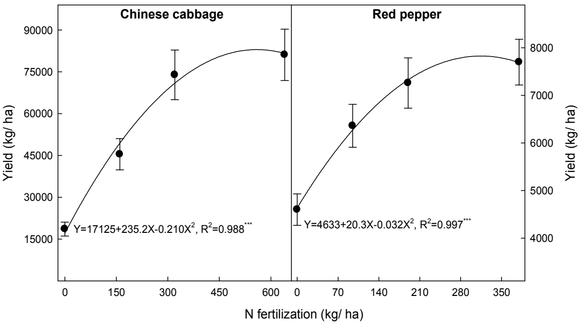

Fig. 3. Yield responses of two vegetables to different nitrogen application rates in upland soils.

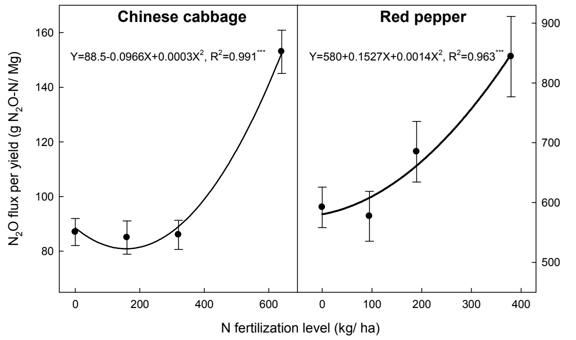

Fig. 4. Changes of N_2O flux per each vegetable yield at different nitrogen application rates in upland soils.

Conclusion

Application of excess N-fertilizers increased seasonal N_2O flux especially the N_2O flux per unit yield during both Chinese cabbage and red pepper cultivation. This suggested that the higher N fertilization than the recommended dose actually facilitates N_2O emission than boosting plant productivity. The N_2O inventory for upland farming in temperate region like Korea revealed that N_2O flux due to unit amount of N-fertilizer application for Chinese cabbage in fall (autumn) season was comparatively higher than that of summer vegetables like red pepper. Therefore, the judicious N fertilization following recommended dose is required to suppress N_2O emission with high vegetable productivity in upland soils.

Acknowledgement

This study was supported by the National Academy of Agricultural Science at Rural Development Administration (RDA), Agenda grant No. 20120401-030-511-001-06-00

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