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Full Length Article

Nitrogen Fertilization Management and Nitrous Oxide Emission in Lettuce Vegetable Fields in Central Vietnam

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Abstract

Vegetable production with high N inputs is a potential source of greenhouse gas emission and N_2O from soils. However, in Central Vietnam, high rates of N fertilization on sandy soils may not generate much N_2O by denitrification due to limited anoxia. This study was carried out to evaluate the impact of four N fertilizer rates including: 0, 30, 60 and 90 kg N ha^{-1} and three N fertilizer forms supplied as urea, ammonium sulfate and calcium nitrate on the yield of lettuce and the N_2O emission from loam and deep sandy soils in two crop seasons from January to April, 2015. The increase in the cumulative N_2O emission and the yield based N_2O intensity is proportional to the increase in N fertilizer application. Calcium nitrate fertilizer application at rate of 90 kg N ha^{-1} had the highest N_2O emission as compared with ammonium sulfate and urea fertilizers application, which raised more than 1.20 to 1.82 times (ammonium sulfate) and 1.60 to 1.91 times (urea) in loam and deep sandy soils, respectively. Compared to the N_{90} treatment, N_2O emission of N_{60} was reduced by 42% in loam soil and 30% in deep sandy soil without decreasing crop yield. The growing season emission factors (EFgs) were 0.40% to 0.61% of added N, emitted as N_2O and increased with N fertilizer application rate. N_2O fluxes reduced as the amount of applied N-fertilizer decreased significantly.

Keywords: Deep sandy soil; Emission factor; Lettuce yield; Loam soil; N rate; N type

Introduction

Nitrogen (N) is considered as one of the most significant nutrients in vegetables (Gerendás *et al*., 1997). N fertilizer application rates for lettuce, ranged from 40 to 120 kg N/ha and even more in some cases, while the national rate for this crop averaged from 30 to 60 kg N/ha (Hoa *et al*., 2011). According to Brady and Weil (2008), the nitrogen fertilizers are uptaken directly by plants or transformed into other different types via oxidation process when applied to agricultural systems. If the amount of nitrogen applied is high, it will be lost in ionic or gaseous form through leaching, volatilization, and denitrification. N_2O is formed in soils by chemodenitrification and during microbial processes through ammonia oxidation as well as denitrification with nitrate reduction (Robertson and Groffman, 2007). N_2O is an effective greenhouse gas (GHG) created in the soil and has significant effects both on climate and on stratospheric ozone (Wuebbles, 2009). A number of N fertilizer management techniques have been suggested for reducing nitrous oxide emission, including matching N supply with crop demand, optimizing splits application, using controlled release fertilizers and inhibitors (Parkin and Kaspar, 2006). However, there are still rare results to indicate the combination of various forms and rates of nitrogen fertilizer application for lettuce on low nitrous oxide emission on deep sandy compared to loam soils due to low anoxia. Therefore, this study was implemented to assess the impact of nitrogen fertilizer rates and forms on lettuce yield and N_2O emission from lettuce vegetable fields in loam and deep sandy soils of Thua Thien Hue province, Central Vietnam.

Materials and Methods

Experimental Site

The experimental sites were the fields of Huong An commune (16°28′2″N and 107°31′2″E), Huong Tra district and Quang Loi commune (16°36′56″N and 107°28′14″E), Quang Dien district, Thua Thien Hue province, Central Vietnam. The annual rainfall is about 2,300 mm and monthly temperature varies between 17°C and 38°C during the year, with a distinct dry season from April to August and rainy season from September to March. The typical soils were classified as Dystric Fluvisols

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(Gleyi-Dystric Fluvisols) (Alluvial soil; loam texture) in Huong An commune and Haplic Arenosols (Dystri Haplic Arenosols) (Deep sand texture) in Quang Loi commune (Bat and Khanh, 2015). The basic properties of topsoil (0 – 20 cm) before the experiment are given in Table 1.

Experimental Layout

The treatments consisted of three N fertilizer forms: Urea (46% N); $(NH_4)_2SO_4$ (20% N); Ca $(NO_3)_2$ (15% N) and four N fertilizer rates (0, 30, 60 and 90 kg N/ha). These experiments were arranged in a split plot design with N rates in subplots and N forms in main plots. Each treatment subplot was 2 m× 5 m and each treatment in main plot was 40 m^2 and carried out in three replicates. In sand, the seeds of local lettuce (*Lactuca sativa* L.) were sown on 10^{th} December, 2014 (first crop season) and 15^{th} February, 2015 (second crop season). Transplanting of lettuce seedlings into their respective plots in the field took place three weeks after sowing on 1^{st} January, 2015 (first crop season) and 12^{th} March, 2015 (second crop season). There was no use of irrigation for this experiment, as the need for water was completely based on rainfall. For the first crop season, lime at 400 kg ha^{-1} was applied 15 days before transplanting and incorporated into soil by plough. Pig manure (C 22%; N 0.83%; P 0.32% and K 0.55%) at 10 t ha^{-1} was spread on the row, and then covered by soil to a depth of over 5 cm at day of transplanting. The N fertilizers were applied with 25% as a basal fertilizer before transplanting, and 25% at 7 day intervals after transplanting. Superphosphate was also applied as basal fertilizer before transplanting at the rate of 60 kg P_2O_5 ha^{-1}. KCl was applied at 60 kg K_2O ha^{-1}(50% as basal and 50% at 14 days after transplanting). For the second crop season, lime and pig manure were not applied, the same amount of nitrogen fertilizer was kept. The amount of phosphorus and potassium fertilizers decreased by 30% compared to the first crop season.

N_2O Emission

Procedures of sampling and design of chamber were followed by guidelines from Parking and Venterea (2010). A cylindrical chamber base made of polyvinyl chloride pipe with an inner diameter of 0.31 m, installed in the center of each plot and put into the soil to a minimum depth of 5 cm. We used four headspace gas samples to identify N_2O flux and collected samples at a 10 min interval. Flux measurements were taken at 0, 10, 20, 30 min after chamber closure. Gas flux in measurements started at 7 to 28 days after transplanting. When gas samples were collected, air temperature and temperature in the chamber simultaneously were also monitored. Gas chromatography (GC-SRI 8610), which equipped with an electron capture detector (ECD) was used to analyse the N_2O (Parking and Venterea, 2010).

Lettuce Yield and Yield Based N_2O Emission Intensity

Lettuce yield was taken after harvest at two crop seasons. It was harvested at 30–39 days after planting. A total of 30 plants were sampled in the central four seed rows by selecting every eighth marketable plant in a row. Weight of whole-plant from a composite sample of 10 plants was determined. Plot marketable yield was measured from a 2 m^2 harvested area within the treatment plot at physiological maturity. Mean yield was calculated from yields in two cropping seasons in 2015 of each `soil.Yield based N_2O emission intensity was calculated as the ratio of cumulative N_2O to yield for each treatment plot expressed as g N_2O/ton marketable yield.

Cumulative Emission and N_2O Emission Factor

Growing-season cumulative N_2O emission from each sample position (collar) was calculated by the summation of the daily estimate of N_2O emission. The N_2O emission factor for the growing season period (EFgs), was expressed as a percentage of N applied as fertilizer that was emitted as N_2O-N following IPCC (2006):

$$EF_{gs} = \frac{(N_2O_{fert} - N_2O_{control})}{\text{Applied N}} x100,$$

Where N_2O_{fert} is the growing season cumulative N_2O emission (kg N ha^{-1}) of the fertilizer treatment,$N_2O_{control}$ is the growing season cumulative N_2O emission (kg N ha^{-1}) of control, and applied N is the amount of N applied as fertilizer (kg N ha^{-1}).

Statistical Analysis of Data

The SPSS 18.0 analytical software package was used for all statistical analyses. All data were analysed by calculating the mean and standard deviation (mean SD) for each treatment. Statistical analysis was performed by split plot of ANOVA model to analyze the effects of N fertilizer (rate and form) on yield and the N_2O flux, using the SPSS general linear model procedure. The means of three replicates using Tukey's test at $P<0.05$ were conducted to compare analysis of significant differences among treatments.

Results

N_2O Emission Fluxes

It was found highly inconstant momentary distribution with mainly low fluxes and few high flux rates after N-fertilization measures in both soils and crop seasons (Fig. 1a, b). The highest mean flux rates were measured with 219 μg N_2O-N m^{-2} h^{-1} and 117 μg N_2O-N m^{-2} h^{-1} during lettuce cultivation in the treatment of application 90 kg N ha^{-1} and calcium nitrate at crop season 2 (Fig. 1a–f and 1b–f).

Table 1: Basic properties of the top soil (0 – 20 cm)

Commune	Soil type	pH_{KCl}	Organic C (%)	Total N (%)	Total P (%)	Total K (%)	Clay (%)	Silt (%)	Sand (%)
Huong An	Alluvial soil	4.20	1.54	0.083	0.030	0.45	42	40	18
QuangLoi	Sandy soil	4.90	1.40	0.025	0.010	0.12	4	15	81

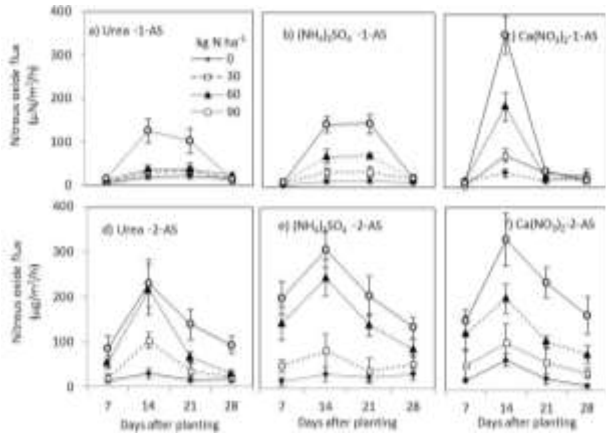

Fig. 1a: N fertilizer application and N_2O emission fluxes in loam soil (AS-alluvial soil)
1- crop season 1 from 6th January to 10th February 2015; 2- crop season 2 from 12h March to 20th April, 2015). Error bars indicate standard deviation

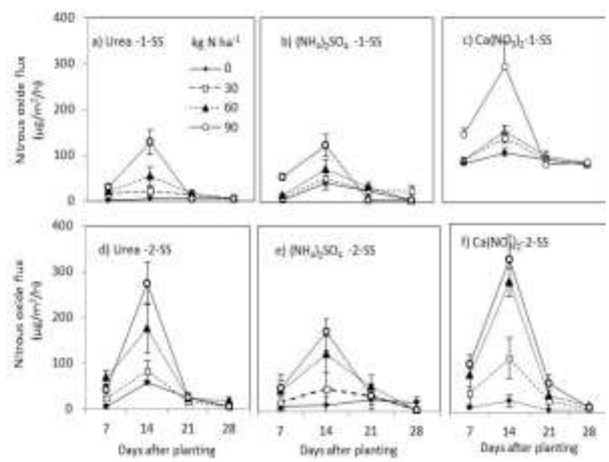

Fig. 1b: N fertilizer application and N_2O emission fluxes in deep sandy soil (SS- sandy soil)
1- crop season 1 from 6th January to 10th February 2015; 2- crop season 2 from 12h March to 20th April, 2015). Error bars indicate standard deviation

The lowest rate of N_2O flux emission was found using urea fertilizer application in both soils (17.6 to 100.7 µg N_2O-N m^{-2} h^{-1} in loam soil and 12.9 to 64.5 µg N_2O-N m^{-2} h^{-1} in deep sandy soil) followed by ammonium sulfate and calcium nitrate. N_2O emission flux rates also fluctuated due to the increasing growth and development of lettuce. N_2O peak emission flux rate was observed between 14 to 21 days after transplanting of lettuce in loam soil and 14 days in deep sandy soil. This is the main growth period of lettuce, which requires N fertilizer application. N_2O emission increased proportionally with the rate of N fertilizer application. Compared to the N_{90} treatment, N_2O emission was reduced by 37.1% to 46.9% in loam soil in season 1; 33.2% to 48.1% in loam soil in season 2; 38.6% to 65.8% for deep sandy soil in season 1and 10.1–21.0% for deep sandy soil in season 2 in the N_{60} treatment.

The relationship of nitrogen fertilizer application and average N_2O emissions was high correlation between (R^2>0.88) based on equations of polynomial regression. N_2O emissions increased positive with N fertilizer rates application and vice versa (Fig. 2).

Lettuce Yield and Yield Based N_2O Emission

The maximum lettuce yields were observed at 90 kg N ha^{-1} as urea fertilizer in loam soil and for ammonium sulfate fertilizer in deep sandy soil (Table 2). There was not found any significant differences in lettuce yield among types of N fertilizer application rates. Lettuce yields were found the lowest in control at both soils and seasons ranging from 7.15 to 7.56 t ha^{-1} (loam soil) and from 8.28 to 10.93 t ha^{-1} (deep sandy soil). This study revealed that optimum yields can be achieved with 60 kg·ha^{-1} of N for urea application in loam soil and ammonium sulfate in deep sandy soil. Yield based N_2O emission increased following the rates of N fertilizer application in the same type of N fertilizer and achieved the highest data at 90 kg N ha^{-1}, especially at calcium nitrate fertilizer application.

Growing Season Cumulative N_2O Emission and Fertilizer-induce Emission Factor

The cumulative N_2O emission of growing season varied significantly with N application rate and form, as well as their interaction (Table 3). In both studied soils, higher rate of N application of the three N fertilizer forms increased the cumulative N_2O emission over control. Calcium nitrate fertilizer application had the highest level of growing season cumulative N_2O emission and was significantly greater than all other N sources viz. 0.16 – 1.01 kg N_2O-N ha^{-1} in loam soil and 0.09 – 0.71 kg N_2O-N ha^{-1} in deep sandy soil. The average growing season cumulative emission for all treatments in loam soil was 1.5 times higher than in deep sandy soil. The increase in N_2O emission per unit applied N fertilizer was slightly higher in loam soil than in deep sandy soil, the relationship between fertilizer rate and season interaction is shown (Table 3). The calculated EF_{gs} ranged from 0.34 to 0.94% in loam soil and from 0.25 to 0.71% in deep sandy soil (Table 3).

Table 2: Effect of N fertilizer on yield of lettuce and yield based N_2O emission

N type	N rate (kg ha^{-1})	Average yield		Yield based N_2O emission	
		Loam soil (t. ha^{-1})	Deep sandy soil (t. ha^{-1})	Loam soil g N_2O/ton vegetable	Deep sandy soil g N_2O/ton vegetable
Urea	0	7.4^{cde}	9.6^{de}	14.8^{f}	10.3^{e}
	30	11.1^{b}	10.1^{cde}	19.1^{ef}	17.6^{de}
	60	13.6^{ab}	11.5^{bc}	27.6^{de}	27.4^{c}
	90	16.1^{a}	12.6^{ab}	39.8^{b}	36.2^{b}
Ammonium sulfate	0	7.1^{e}	8.7^{e}	14.6^{f}	12.8^{de}
	30	10.5^{bcd}	9.6^{de}	23.2^{def}	20.8^{cd}
	60	13.2^{ab}	12.5^{ab}	38.1^{bc}	22.6^{cd}
	90	15.3^{a}	13.6^{a}	60.2^{a}	27.8^{c}
Calcium nitrate	0	7.1^{de}	8.4^{e}	23.7^{def}	10.0^{e}
	30	10.7^{bc}	10.1^{cde}	29.1^{d}	25.5^{cd}
	60	13.4^{ab}	11.0^{bcd}	43.3^{b}	43.2^{b}
	90	15.5^{a}	11.7^{bc}	66.7^{a}	62.8^{a}

Data was calculated from mean data in two crop seasons in a soil. The data followed by the same letters within a column are not significantly different (p > 0.05) among different treatments

Table 3: Growing seasonal cumulative N_2O emission and fertilizer-induce emission factor (EF_{gs}) as influenced by fertilizer N rate and type in lettuce fields in two soils in 2015

N type	N rate (kg ha^{-1})	Cumulative N_2O emission		EF_{gs}	
		Loam soil (kg N_2O-N ha^{-1})	Deep sandy soil (kg N_2O-N ha^{-1})	Loam soil (kg N_2O-N ha^{-1})	Deep sandy soil (kg N_2O-N ha^{-1})
Urea	0	0.11^{g}	0.09^{f}	-	
	30	0.21^{efg}	0.17^{fgh}	0.34^{c}	0.26^{c}
	60	0.38^{cd}	0.29^{de}	0.45^{bc}	0.34^{c}
	90	0.64^{b}	0.42^{bc}	0.59^{bc}	0.38^{bc}
Ammonium sulfate	0	0.10^{g}	0.11^{gh}	-	-
	30	0.24^{def}	0.18^{fg}	0.45^{bc}	0.27^{c}
	60	0.51^{bc}	0.29^{de}	0.68^{ab}	0.25^{c}
	90	0.89^{a}	0.37^{cd}	0.87^{a}	0.28^{c}
Calcium nitrate	0	0.16^{fg}	0.09^{h}	-	-
	30	0.30^{de}	0.25^{ef}	0.47^{bc}	0.54^{ab}
	60	0.59^{b}	0.45^{b}	0.71^{ab}	0.61^{a}
	90	1.01^{a}	0.72^{a}	0.94^{a}	0.71^{a}

Data was calculated from mean data in two crop seasons in a soil. The data followed by the same letters within a column are not significantly different (p > 0.05) among different treatments

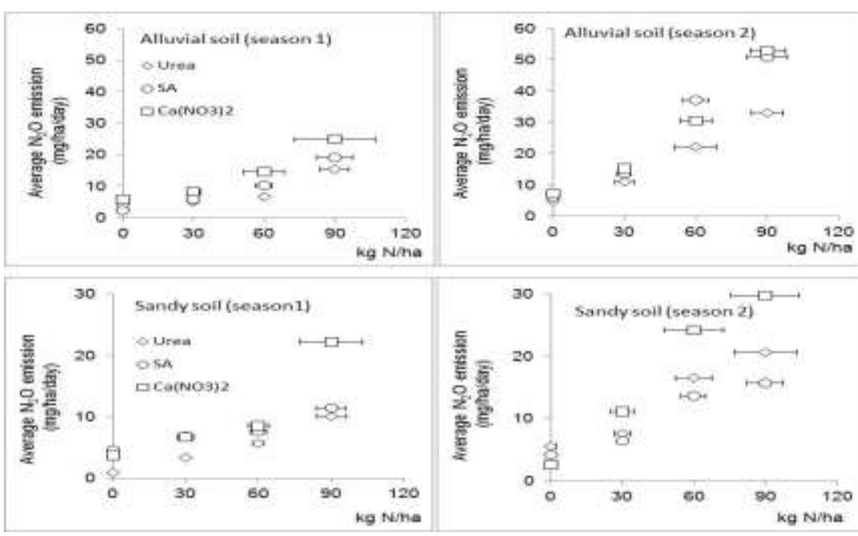

Fig. 2: Relation between N fertilizer application and average N_2O emission (SA – Ammonium sulfate); error bars indicate standard deviation, n = 3

The averaged EF_{gs} was higher in loam soil than in deep sandy soil being 0.61 and 0.40%, respectively. Application of N fertilizer at 90 kg ha^{-1} increased EFgs significantly over the lower rates of N fertilizers and control in both soils. N_2O emission from urea was sometimes substantially lower from nitrate based fertilizers.

Discussion

Nitrogen is considered as a significant factor in both crop growth and N_2O production (Erickson *et al.*, 2001). A period of high ammonium and nitrate concentrations provides substrate for N_2O producing microorganisms in soils. Denitrification generally occurs in environments with fluctuating oxygen concentrations. In general, higher clay content of the soil causes it to increase N_2O emission, because the chances of anaerobic condition increase (Velthof and Oenema, 1995). Li *et al.* (2015) indicated that N_2O emission mainly happened in the first five days after topdressing, and estimated for 75.8–95.2% of total N_2O emission made in the whole 10 days interval. Similar peaks in N_2O fluxes due to nitrogen fertilizer application were observed by Malla *et al*. (2005). Wang *et al.* (2011) reported that nitrogen fertilizer application increased significant seasonal N_2O emission from vegetable fields ($P<0.0001$). Microbial nitrification and denitrification rate increases with more N availability, thereby escalating N_2O emission (Liu *et al*., 2011). The important reasons for the variations in N_2O emission between nitrogen fertilizer treatments would be the availability of NH_4 and NO_3 in the soil as sources for processes of nitrification and denitrification. Bouwman *et al.* (2002) contrasts with results of present study that ammonium nitrogen fertilizers results in significantly higher emission of N_2O than nitrate nitrogen fertilizers. Dobbie and Smith (2003) compared the effect of different N fertilizer types on N_2O emission to conclude that ammonium nitrate gave higher emission than urea. Eckard *et al.* (2006) concluded that increasing annual rate of N fertilizer resulted in higher annual N_2O emission exponentially, with the rate of increase being faster for nitrate than urea fertilizer. Ammonium based N fertilizer generally produces low N_2O emission relative to nitrate based fertilizers when applied. Gao *et al.* (2013) indicated a positive relation between N application rates and N_2O emission. It can be deduced from the various studies that an increase in the amount of N added to the soil increases the emission of N_2O. These results were similar with field studies from Drury *et al.* (2008) who concluded that N_2O emission is related well with application of fertilizer N rate.

Nagda and Chauhan (1991) observed that marketable size of lettuce was very small in field plots that did not receive N fertilizer. The results of this study reflect the fact that the soil chosen for this test was low in residual N. Generally, sandy soils have low organic matter and low plant-available N due to leaching by irrigation and intensively cropping (Fageria, 2009). The application of N fertilizer significantly increased yield for lettuce (Table 2). The interaction between N rates, types and yields was also significant ($P < 0.05$). Yield responses to the N fertilizer treatments were similar in both growing seasons. In season 2, there was a slight decreased in lettuce yield with all N fertilizer application rates and types. Yield in treatments that received N fertilizer was significantly ($P < 0.05$) greater than yields in treatment without N fertilizer at the same type of N fertilizer application. This was probably the result of high temperature 25.5ºC in season 2 as compared to 20.7ºC in season 1 causing comfortable leaf growth and hence a higher need for water (Rosenzweig and Liverman, 1992). Nitrogen is considered as a co-limiting factor in crop growth and N_2O production. Crop N requirement is related with crop yield, then higher N inputs increased higher yields. Erickson *et al.* (2001) pointed out that the available N in the soil is over the requirements of opposing biota, fluxes of N_2O may be extensive and display threshold responses according to the level of N input. Thus, the reduction of N inputs by minimizing the amounts of N fertilizer application plays an important role in N_2O mitigation strategies in vegetable production systems. Kaiser and Ruse (2000) and Van Groenigen *et al*. (2004) reported similar relationships between N-inputs or N use efficiencies and the N_2O emissions have been found for arable farming. A decrease in N fertilization is also highly required for farmers and helps them to maximize their profits if it does not hamper the yields.

Li *et al.* (2015) pointed out that cumulative N_2O emission was 0.48–5.01 kg N ha^{-1} in the cucumber growing season, estimating for 0.28–0.38% of nitrogen application. Nitrogen fertilizer treatment N_{600} reduced the amount of N_2O emission significantly by 53.4% compared to N_{1200}. De Klein *et al.* (2001) concluded that the EF for synthetic fertilizer was very well within the default IPCC range. They found the EF of 0.9% at the highest N application rate and N_2O emission factors for N fertilizer application of <0.1–1.9% (median 0.5%) and <0.1–12% (median 3.2%) as N fertilizers were applied as urea and calcium nitrate, respectively. Van Groenigen *et al.* (2004) also reported that there was much lower N_2O emission under maize land on sandy soil in comparison of clay soil. Average EFs for the sandy soil were lowest in calcium ammonium nitrate fertilizer with 0.08%, followed by cattle slurry of 0.51% and combinations of both with 0.26%. This corresponds with our findings in loam and deep sandy soils due to little anoxia and short duration of lettuce.

Conclusion

N_2O emission depended on N fertilizer rates and forms application, soil as well as crop season. The highest N_2O emission was from calcium nitrate fertilizer, followed by ammonium sulfate and urea fertilizers application. Reduced the nitrogen application rate to 60 kg N/ha decreased N_2O emission. Based on this study, N_2O emission in deep sandy soil was lower than in loam soil due to anoxia for the present lettuce production in loam and deep sandy soils in Central Vietnam. Our results clearly show that potential for N_2O emission from vegetable fields can be reduced by optimizing the N-fertilizer amount. A reduction in the amount of N-addition by 30 kg ha^{-1} from the amount used, had no negative effect on the vegetable yield and reduced

N_2O emission. An environmentally comprehensive management strategy must be included in the limitation of high N-surplus in order to minimize N_2O emission from vegetable production.

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