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Factors Influencing N_2O Emissions of Major Vegetable Cropping Systems in Peri-Urban Hanoi, Vietnam

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ABSTRACT: Crop management practices in intensive vegetable production can influence nitrous oxide emissions from soils. This study investigated emission factors from different vegetable management practices. Interviews were conducted with 60 vegetable farmers to identify practices including soil management, nitrogen fertiliser use and irrigation in Vannoi and Dangxa communes in the Hanoi peri-urban area. Practices responsible for high N_2O emissions were overuse of nitrogen fertilisers and furrow irrigation. An improvement in farmers' adoption of best practices in fertiliser application and irrigation could reduce emissions without affecting crop productivity.

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1. INTRODUCTION

Methane and nitrous oxide have global warming potential indexes relative to carbon dioxide of 25 and 298, respectively (IPCC, 2014). Agricultural activities are responsible for 84% of global N_2O emissions (Smith, 2008). Globally, vegetable production is estimated to contribute 9.5×10^7 kg N_2O-N yr^{-1} (Rashti, Wang, Moody, Chen, & Ghadiri, 2015). Average N_2O emissions in subtropical climates were 1.6–1.9 kg N ha^{-1} yr^{-1} and 0.8–0.9 kg N ha^{-1} yr^{-1} in temperate climates (Bouwman, Boumans, & Batjes, 2002; Stehfest & Bouwman, 2006). Vegetable production in the United States contributed the highest N_2O emissions at the rates of 6.5 - 8.5 kg N_2O-N yr^{-1} (Mummey, Smith, & Bluhm, 1998). Dryland crops including vegetables account for 30% of total greenhouse gas emissions (mostly N_2O) from the agricultural sector in Vietnam (Ministry of Natural Resources and Environment, 2014).

Crop management practices affect N_2O emissions. Intensive vegetable cropping practices including high rates of nitrogen fertiliser, frequent irrigation and tillage practices, combined with short-term crops with multiple harvests, all contribute to N_2O emissions (Rashti et al., 2015). These factors are not yet well understood for vegetable cropping systems in some developing countries including Vietnam (Chapuis-Lardy, Wrage, Metay, Chotte, & Bernoux, 2007), making estimation and mitigation of N_2O emissions difficult.

The Hanoi peri-urban region is an important area for vegetable production in Vietnam, with around 40 different vegetables grown on 12,000 hectares of agricultural land, accounting for 31% of agricultural production in the Hanoi area (Tam, 2016). Vegetable production in this region is likely to increase (Everaarts, Neeteson, Huong, & Struik, 2015) because vegetable production has higher returns per hectare to growers compared to rice or other crops (T. T. T. Ha, 2008). The increasing consumer demand for vegetables from the major city of Hanoi provides opportunities for vegetable producers in the Red River delta (Huong, Everaarts, Neeteson, & Struik, 2013).

Farms in this region are small, with an average size of 2,360 m^2 (Van Hoi, Mol, & Oosterveer, 2009). High demand for vegetables in Hanoi has resulted in intensive vegetable production of four to eight vegetable crop seasons a year with relatively short fallow periods (Everaarts et al., 2015; Huong et al., 2013). The intensive vegetable production systems are supported by a high level of inputs, especially nitrogen fertilisers, potentially resulting in high N_2O emissions (Mosier & Kroeze, 2000; Stehfest & Bouwman, 2006).

Studies of agricultural greenhouse gas emissions and their driving factors are limited in Vietnam. There are some studies on greenhouse gas emission studies in rice crops (Oo, Nguyen, Win, Cadisch, & Bellingrath-Kimura, 2013; Pandey et al., 2014; Thu, Loan Bui Thi, Van, & Hong, 2016; Trinh et al., 2017) which focused on greenhouse gas emissions, especially methane (CH_4) in paddy fields with flooded conditions. There does not appear to be any published scientific evidence on greenhouse gas emissions in vegetable crops. To address this research gap, a survey on management practices influencing N_2O emissions was examined to develop recommendations to reduce N_2O emissions.

2. MATERIALS AND METHODS

The study identified some of the factors causing variation in emissions. The survey of vegetable farmers was used to identify the range of farmers' management practices and then determine the potential for emissions reduction and identify where more detailed studies are needed.

2.1 Sample area selection

The research was conducted in two peri-urban areas: Vannoi commune in Dong Anh District and Dangxa commune in Gia Lam District in Hanoi, Vietnam. These locations are typical vegetable production regions, supplying vegetables to a population of around 7.8 million in Hanoi city. The Vannoi commune has about 120 ha of vegetable production land, of which 60 ha is for intensive production (People's committee of Vannoi commune, 2015). The Dangxa commune has 45 ha of vegetable production land, which was previously used for rice production (People's committee of Dangxa commune, 2015).

The annual rainfall of Hanoi is approximately 1700–1900 mm, mainly from May to September. The average annual temperature is 23–24 °C, the average maximum temperature in summer/autumn is 30 °C and the average minimum in winter/spring is 12.5 °C (Bureau of Meteorology in Vietnam during 2010–2015).

Two villages were selected from each commune. In each of the four villages, 15 farmers were randomly selected for the survey. These farms were selected because they grew common vegetable species (choy sum, mustard and cabbage) and represented the typical alluvial soil type in this region.

2.2 Farmer survey

2.2.1 Sample selection

Two villages with the largest vegetable production areas in each commune (Dangxa and Vannoi) were selected and a list of all vegetable producers who owned at least one piece of land for growing vegetables was compiled after consultation with the local extension agent. Fifteen vegetable growers were then randomly selected in each village, giving 30 respondents in each commune. A total of 60 respondents participated in the survey[1].

Interviews of about 30–45 minutes duration were conducted by the researcher at farmers' homes or farms. The interviews were conducted in Vietnamese and later translated into English. In some cases, clarification of responses was required, and this was achieved by re-interviewing or by telephone. Field observations and photos were used to supplement information on farming activities including soil preparation, irrigation and fertiliser usage. The farmer survey used questionnaire-guided interviews on characteristics of crop management practices related to N_2O emissions and was conducted from August to October 2016 and revisited in 2017.

2.2.2 Survey questionnaire

The questionnaire-guided interview focused on crop management practices likely to affect N_2O emissions including:

1. Use of nitrogen (N) fertiliser including amount, sources (including manure) and timing of nitrogen application;
2. Irrigation management including frequency, volume, water sources and types such as furrow, drip and overhead irrigation;
3. Soil preparation including tillage methods, and the amount and treatment of crop residues.

Rainfall and its distribution over the study period were collected from the weather station closest to the study communes.

2.2.3 Survey data calculation

Data collected on irrigation and chemical nitrogen fertiliser, cattle manure and crop residues from the survey was used to calculate the amount of water and nitrogen which are important factors controlling N_2O emissions.

1. The amount of water supplied was calculated based on water pumps (750w) with the capacity of water released (3.5 m^3 $hour^{-1}$), number of hours of each irrigation event and number of irrigation events in each crop season (survey data). Total amount of water was then a combination of the amount of water from irrigation and amount of rainfall in each season
2. The amount of nitrogen for each vegetable crop was calculated based on nitrogen rates in the three major nitrogen fertiliser sources which farmers applied. Nitrogen from the fertiliser base containing 5% N, 10% P and 3% K was calculated. Urea (56% N) was used to supplement the base fertiliser.
3. Nitrogen from chicken manure was calculated using results on the amount of nitrogen from chicken manure of 5.7–11.6 N g kg^{-1} dry weight from an independent study on vegetable production in Vietnam (Khai, Ha, & Öborn, 2007). In this study, the average 8.7 g kg^{-1} dry weight from Khai et al. (2007) was used to calculate the nitrogen contribution from manure.
4. The nitrogen contributed from fresh vegetable residues was calculated based on results of the amount of nitrogen which was

[1]*This study was approved by the Human Research Ethics Committee of the University of Sydney [approval No: 2016/628]*

2.08 g kg^{-1} fresh weight of mustard and 2.46 g kg^{-1} fresh weight of choy sum (Khai et al., 2007). In this study, a common nitrogen value of 2.3 g kg^{-1} fresh weight of vegetable residues was used.

N (fresh vegetable residues) = Amount of fresh vegetable residues ×0.0023

2.4 Data analysis

Data was analysed using SPSS to derive descriptive statistics including frequencies, percentages and mean of fertiliser, irrigation and tillage associated with N_2O emissions. ANOVA and the Student-Newman-Keuls test were used to determine the differences at statistically significant levels (P<0.05) in N_2O emissions, nitrogen amount from the different farms and vegetable yields.

3. RESULTS

3.1 Crop management practices from farmer survey

3.1.2 Nitrogen fertiliser application

Nitrogen fertiliser application for vegetables in the autumn season is shown in Table 1. Urea, NPK (5:10:3) and chicken manure were the primary nitrogen sources for both study communes, and most of the nitrogen came from urea. Nitrogen rates from Dangxa were twice those used in Vannoi (Table 1). More urea and less manure were applied in Vannoi compared to Dangxa.

Table 1. Nitrogen application for vegetable crops in autumn for Dangxa and Vannoi

Commune	N from NPK (Kg ha^{-1})	%	N from Urea (Kg ha^{-1})	%	N from manure (Kg ha^{-1})	%	Total N (Kg ha^{-1})	%
Dangxa (n=30)	29.6±5.3 a	12.9	136.0±15.8 a	59.4	63.4±7.6 a	27.7	229.0±22.2 a	100
Vannoi (n=30)	16.0±4.1 b	13.6	82.4±11.7 b	70.2	22.5±4.9 b	19.2	117.4±14.4 b	100
P	0.05		0.008		0.001		0.001	

Note: Data are mean ± standard error of the mean. Means which are significantly different (P<0.05) are indicated by different letters.

Actual nitrogen application rates differed significantly from the government recommended rates of the Hanoi Department of Agriculture and Rural Development (Table 2). Farmers' application rates of nitrogen were 22% to 36% higher than the nitrogen amount recommended. Vegetables with a growing period longer than three months such as cabbage, luffa, cauliflower and pumpkin buds received a larger amount of nitrogen compared to vegetables with a shorter growing period of a month such as choy sum and mustard.

Cabbage, choy sum and mustard, three popular vegetables representing 77% of total plots in study farms, received a considerable excess of nitrogen. Cabbage received the highest at 306 kg ha^{-1}, more than double the maximum recommended government rate, while mustard received 9% more than the maximum recommended rate. Although choy sum received the lowest, it was still twice the maximum nitrogen amount recommended (Table 2). Some other vegetables such as water spinach and round eggplant received less nitrogen than the recommended amounts. However, they were grown on a small scale.

Table 2. Farmer application and government recommendation on nitrogen rates for individual vegetables in autumn in Dangxa and Vannoi

Vegetable	Number of plots	Total N	N recommendation*	
			Min	Max
Cabbage	29	306.2 d	124.2	155.2
Cauliflower	3	203.3 abcd	89.1	113.4
Choy sum	33	100.8 a	33.3	52.4
Luffa	11	168.9 abc	NA	NA
Malabar nightshade	8	142.7 a	122.5	145.8
Mustard	46	124.4 a	103.4	113.2
Pumpkin buds	4	333.8 bd	76.5	93.2
Round eggplant	3	164.4 ab	180.8	216.2
Water spinach	3	87.1 a	208.3	245.4
Average		181.3	117.2	141.9
P		<0.001		

Note: Data are mean ± standard error of the mean. Means which are significantly different (P<0.05) are indicated by different letters.

NA means not available. Although more vegetables were grown in this season, only vegetables with three or more plots were retained for statistical analysis. * nitrogen recommendations are extracted from technical guidelines issued by Hanoi Department of Agriculture and Rural Development for individual vegetables in 2016.

Most farmers applied urea to crops two to three times, as top dressings. NPK compound fertiliser and chicken manure were usually applied as basal dressings before sowing or transplanting.

3.1.2 Nitrogen in vegetable residues

The amount of nitrogen in fresh vegetable residues remaining in the field after harvest was relatively low, depending on the vegetable species. The nitrogen amount for most vegetables was less than 10 kg ha^{-1} with the exception of cauliflower due to the large proportion which is inedible. Main crops including cabbage, mustard and choy sum provided approximately 3 to 7 kg N ha^{-1} if their residues were incorporated into soils (Table 3).

Table 3. Amount of fresh vegetable residue and nitrogen in autumn vegetable residues for Dangxa and Vannoi

Vegetable	Number of plots	Fresh residue (t ha^{-1})	N from fresh residue (kg ha^{-1})
Cabbage	29	3.22 ± 0.43	7.41 de
Cauliflower	3	7.73 ± 4.36	17.78 g
Choy sum	33	1.42 ± 0.34	3.26 ab
Luffa	11	4.54 ± 0.43	10.45 df
Malabar nightshade	8	3.07 ± 1.02	7.05 acd
Mustard	46	2.06 ± 0.36	4.74 abc
Pumpkin buds	4	3.36 ± 0.97	7.72 acdef
Round eggplant	3	4.42 ± 1.32	9.92 def
Water spinach	3	1.14 ± 0.07	2.62 a
Average		3.73	8.46
P			<0.001

Note: Data are mean ± standard error of the mean. Means which are significantly different (P<0.05) are indicated by different letters. Although more vegetables were grown in this season, only vegetables with three or more plots were retained for statistical analysis.

3.1.3 Irrigation

Private water wells and district public pumping stations were the main irrigation sources for vegetable production in both communes. Private water wells were drilled near farmers' fields and private motorised pumps were used to deliver water. Water supply via the public pumping station was irregular and not well coordinated with vegetable crop needs due to the main aim to serve rice crops.

The amount of water supplied to crops varied significantly (Table 4). For example, vegetables with long growing periods (3–6 months), such as cabbage, cauliflower and malabar nightshade, consumed 2-6.7 million litres ha^{-1} compared to about 1.2 million litres ha^{-1} for shorter term crops such as choy sum and mustard (Table 4). Vegetables in both communes generally were irrigated twice a week using furrow irrigation.

Table 4. Amount of water use estimated for individual vegetables in autumn in Dangxa and Vannoi

Vegetable	Number of plots	Estimated amount of water (mL ha^{-1})
Cabbage	29	2.0 ac
Cauliflower	3	6.7 d
Choy sum	33	1.2 ab
Luffa	11	1.4 abc
Malabar nightshade	8	2.5 c
Mustard	46	1.2 ab
Pumpkin buds	4	0.7 a
Round eggplant	3	2.0 abc
Water spinach	3	2.5 abc
Average		2.2
P		<0.001

Note: Data are mean ± standard error of the mean. Means which are significantly different (P<0.05) are indicated by different letters.

Although more vegetables were grown in this season, only vegetables with three or more plots were retained for statistical analysis.

3.1.4 Soil tillage

Different implements were used for soil tillage in the two study communes. In Dangxa, small two-wheeled tractors were used to lightly cultivate the top-soil layer (0 -10 cm) of permanent bed rows prior to sowing or transplanting. Compacted soils were cultivated with larger tractors and disc ploughs, and beds were then re-formed by hand hoes and bed surfaces flattened using rakes. In Vannoi, farmers used hoes to till their soils instead of tractors.

4. DISCUSSION AND IMPLICATIONS

4.1 Effects of nitrogen fertilisers on N_2O emissions

The survey of farmers showed the nitrogen fertiliser amount applied to autumn vegetable farms varied greatly from 38 kg to 326 kg N ha^{-1}. This great variation in nitrogen fertilisers is consistent with an independent study in the Red River delta (N. Ha, Feike, Back, Xiao, & Bahrs, 2015) including this study area which reported that the average nitrogen fertiliser application ranged from 85 to 882 kg N ha^{-1} $year^{-1}$ (Khai et al., 2007). A wide range of nitrogen fertiliser applications from 266 kg N ha^{-1} to 782 kg N ha^{-1} for vegetables was also found in China (Zheng, Han, Huang, Wang, & Wang, 2004).

Actual nitrogen fertiliser rates applied to vegetables were 22% to 36% higher than nitrogen rates recommended by the Hanoi Department of Agriculture and Rural Development, particularly for some common vegetables such as choy sum, mustard and cabbage. Farmers may perceive the generic nitrogen fertilizer recommendations to be as too conservative, and apply more, leading to an overuse of nitrogen fertilizer. Moreover, farmers can use many other nutrient source inputs such as organic fertilizers or legume crops, further contributing to the overuse of nitrogen fertilizer. Uncertainty regarding weather conditions and soil characteristics are also factors, resulting in the over application of fertilizer (Sheriff, 2005). Farmers' expectations of high yields, frequent irrigation and low levels of of education are major factors leading to overuse of nitrogen fertilizers. Manure application, soil fertility and distance to fertilizer markets can be negatively correlated with the use of fertilizers (Zhou, Yang, Mosler, & Abbaspour, 2010). Overuse of nitrogen fertilisers for these vegetables is probably because these vegetables had high commercial market demand. Thus, farmers invest in a high amount of nitrogen fertilisers, irrigate crops frequently and cultivate large areas with multiple crops to ensure yield and supply. In contrast, some vegetables including water spinach, amaranth and sweet leaf bush are grown in small areas for household use for the farmers' daily vegetable meals, and these vegetables received less inputs.

The considerable overuse of nitrogen fertilisers compared to local government recommendations results in higher input costs and increases N_2O emissions. Nitrous oxide emissions increase approximately linearly with increasing nitrogen fertiliser rates (Halvorson, Del Grosso, & Reule, 2008) and increase exponentially when excessive nitrogen fertilisers are applied (Snyder, Bruulsema, Jensen, & Fixen, 2009). Previous studies also indicated that larger amounts of nitrogen and water application significantly increased N_2O emissions (Snyder et al., 2009; Xiong, Xie, Xing, Zhu, & Butenhoff, 2006). This finding suggests improving adoption of nitrogen rates recommended by local government could be an appropriate option to reduce N_2O emissions. This was also suggested by previous studies (Johnson, Franzluebbers, Weyers, & Reicosky, 2007; Snyder et al., 2009). Improved adoption could be achieved by enhancing the effectiveness of extension activities through training and establishing field demonstration models (N. Ha et al., 2015).

Chicken manure also partly contributes to total nitrogen amounts, resulting in increased N_2O emissions. Chicken manure is commonly used in Dangxa, contributing to 27% of total nitrogen in this commune. It has also been encouraged by government agricultural extension services through organic production technical guidelines in 2016 with recommended rates of manure application from 4,000 kg to 11,000 kg ha^{-1}. However, the amount of chicken manure has received less attention in counting total nitrogen fertiliser application. Therefore, farmers do not generally reduce the equivalent amount of chemical nitrogen fertiliser application after using organic fertilisers which results in an excess of nitrogen, potentially increasing N_2O emissions.

The amount of nitrogen from vegetable residues being returned to soils in both communes was insignificant at 2.6 to 7.8 kg N ha^{-1}. The amount was much lower than other studies. For example, the amount of nitrogen from cauliflower residues was 111 kg ha^{-1} and onion residues was 21 kg ha^{-1} (Riley, 2002). The low nitrogen rates for vegetable residues at the two study communes were because the vegetables, mostly leafy vegetable species, are harvested manually, leaving few inedible parts such as roots and unusable leaves. Although the crop residues increased N_2O emissions due to increased nitrogen and organic carbon inputs from the crop biomass (Chen, Li, Hu, & Shi, 2013; Koga, 2013), soil health improvement by adding the organic matter, soil carbon and nitrogen from the vegetable residues may outweigh the N_2O emissions, particularly given the poor total soil carbon and nitrogen (unpublished data) in these vegetable production areas.

4.2 Effects of irrigation on N_2O emissions

Furrow irrigation is a common practice for vegetable areas in Dangxa and Vannoi communes, resulting in increased N_2O emissions. Previous studies indicated that furrow irrigation results in high water-filled pore space, enhancing the activities of nitrifying bacteria

(Jha, Singh, & Kashyap, 1996), or limits the oxygen concentration which can cause anaerobic conditions and denitrification (Amha & Bohne, 2011). Together with nitrogen fertiliser application, furrow irrigation increased N_2O emissions.

One strategy to reduce N_2O emissions is to convert from furrow to drip irrigation. The use of subsurface drip irrigation by the Australian processing tomato industry has reduced the risk of nitrous oxide emissions (Montagu et al., 2017). Similarly, the use of subsurface drip irrigation combined with nitrogen application as a "fertigation" can reduce N_2O emissions by over 70% compared to furrow irrigation (Kennedy, Suddick, & Six, 2013). Furrow irrigation resulted in 18% loss of N_2O emissions while the figure was 4% with subsurface drip irrigation (Kallenbach, Horwath, Kabir, & Rolston, 2007). However, in this study, many vegetable farmers in the Hanoi peri-urban region are hesitant to invest in drip irrigation because they have several small fields in different locations. Therefore, they retain furrow irrigation due to its low cost and simple use. Drip and sprinkler irrigations have been increasingly applied by leading farmers and research institutions which may encourage adoption by farmers in the future.

4.3. Effects of tillage on N_2O emissions

Significantly higher N_2O fluxes are reported in conventional tillage compared to the no-tillage during soil cultivation associated with planting, because anaerobic conditions from conventional tillage facilitate denitrification, resulting in N_2O production (K. Smith D. Watts T. Way H. Torbert S, 2012; Sainju, Stevens, Caesar-TonThat, & Liebig, 2012; Venterea, Burger, & Spokas, 2005). A meta-analysis study from Van Kessel et al., (2013) indicated the effects of different types of tillage (reduced, conventional and no-tillage) vary according to the timeframe of studies. Among all 239 comparisons, no-till or reduced tillage did not change the quantum of N_2O emission compared to conventional soil cultivation in the short-term treatments, but in long term treatments, they reduced N_2O emissions significantly. However, a study by Sheehy et al., (2013) reported an increased N_2O emissions under no tillage on clay soils compared to conventional soil tillage. This was due to dense soil structure causing increased soil moisture and poor aeration in no-tillage compared to conventional tillage, leading to N_2O emission produced through the nitrification process.

The use of small tractors or hoes by vegetable farmers to prepare soils in Hanoi, Vietnam could be considered as reduced tillage which is likely to reduce N_2O emissions. For instance, the N_2O emissions after tillage combined with basal fertiliser application and irrigation from four vegetable farms were 14 times higher than before tillage. The interaction of nitrogen fertiliser, irrigation and tillage to increase N_2O emission has also been indicated by other studies (Snyder et al., 2009; Venterea et al., 2005). Therefore, it is suggested to not combine tillage, irrigation and fertilizer application with soil cultivation to avoid increasing N_2O emissions.

5. CONCLUSIONS

This study indicated that overuse of nitrogen fertilisers and furrow irrigation are likely to increase N_2O emissions. The study results can help improve nitrogen fertiliser management practices through complying strictly with nitrogen recommendations for individual vegetables to reduce greenhouse gas emissions associated with commercial vegetable production in peri-urban Hanoi, Vietnam.

Future research should consider why farmers have not adopted the government's nitrogen fertiliser recommendations because if vegetable growers avoid overuse of nitrogen fertilisers, they not only save input costs but also reduce N_2O emissions. The finding in this study also suggest that extension services should focus on efficiency of technical guideline transfer to improve farmers' adoption of known best practice.

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