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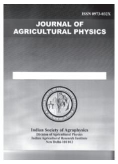

Research Article

Influence of Tillage and Soil Physical Properties on N_2O Emission in Agri-horti Ecosystem

TARUN ADAK*, G. PANDEY AND S. RAJAN

ICAR- Central Institute for Subtropical Horticulture, Rehmankhera, Lucknow-226101, Uttar Pradesh

ABSTRACT

Estimation of nitrous oxide from across agri-horticultural system is a prerequisite for having an idea about the climate change contribution at local levels. Understanding the ecological process occurred during the food or fruit production to supply chain forms the basis of adaptation strategies. Soil physical properties along with chemical properties and tillage types have tremendous influence on the nitrous oxide (N_2O) emission cycle. Biological activities significantly contribute in the emission process through nitrification/de-nitrification alteration. Mitigation strategies should be evolved in such a way or scale so that the quantity of N_2O emission should be reduced making ecosystem safe and habitable. The present work focused on study in smaller or larger units on N_2O emission cycle. Zone specific emission factor and effective soil determinants should be developed.

Key words: Horticultural ecosystem, Nitrous oxide emission, Climate change, Soil physical parameters, Agroecosystem

Introduction

Global climate change along with related factors is significantly changing the earth ecosystem. The geological contribution and the biogeochemistry were given maximum attention to quantify the amount of each unit contributing at local condition to the overall growth of green house gases. Emission of nitrous oxide, nitric oxide, methane, carbon dioxide, carbon monoxide, etc. as well as depletion of ozone layer needs to be quantified from food to supply chain so as to alter the mitigation strategies. Repository of research data across agri-horticultural ecosystem suggested that each of the orchards has tremendous contribution towards building up of emission process; although there might be some small contributions which may pile up over the decades or so (Dickinson *et al.*, 2019; Masters, 2019). The status of mineralogical, hydrological and environmental cycle determines the emissivity and further process to follow antagonistic or synergistic pathways over a period of longer duration. Linn and Dornan (1984) nicely described the role of water filled pores on the emission of nitrous oxide production under tilled and non-tilled conditions. Under moist and dry condition with temperature and nitrate content, variable nitric oxide emission (NO) was recorded suggesting the determinant role of soil structure on emission in tropical savannah soil (Cardenas *et al.*, 1993). Inubushi *et al.* (1999) explained the interaction of salt type and concentration with soil moisture on the N_2O emission and nitrogen dynamics in Yellow soil and Andosol. It was observed that drip irrigation system lowers down the N_2O emission from melon produce than furrow system of irrigation with and without the use of nitrogenous fertilizer. A range of 0.45 to

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*Corresponding author,
Email: Tarun.Adak@icar.gov.in,
cishtarunadak@gmail.com

0.92 kg N_2O-N ha^{-1} was recorded across dry and wet areas suggested the role of irrigation scheduling in arid and semi-arid regions (Sánchez-Martýn *et al*., 2008). A considerable amount of annual N loss (0.8 to 10.0 and 11.0 to 34.4 kg N_2O-N ha^{-1} across replicates in fertilized and grazing condition during 2002 and 2003) in the form of N_2O emission was also estimated from the grassland in Ireland (Hyde *et al*., 2006). Ravishankara *et al.* (2009) opined that being N_2O emission unregulated by the Montreal protocol, it will have tremendous impact on the building up in the atmosphere with detrimental role on O_3 layer depletion. Ofcourse seasonal and region specific variability in its emission may be encountered as observed in almond orchards in California; a narrow range of 0.53 to 0.65 kg N_2O-N ha^{-1} $year^{-1}$ with lower emission factor of 0.19 to 0.25 was recorded (Decock *et al*., 2017). Similarly, Pang *et al.* (2009) observed 48.2, 36.8 and 31.9 µg N_2O m^{-2} h^{-1} annual average emissions from 0.5, 1.5 and 2.5 m apple tree row with greater emission in summer months. Zhang *et al.* (2019) reported that tropical regions having grasslands and forest made significant contribution towards global N_2O budgets with average forests (3.62 Tg N yr^{-1}) and grasslands (1.40 Tg N yr^{-1}) emission. Generally, June to November contributes more in the emission inventory from forests while growing season had significant addition in grasslands. The combined effects of soil temperature and moisture showed a variability pattern of N_2O emission; a lower (0.22) from ungrazed semi-arid steppe (Inner Mongolia, China) < 0.67 (tropical rain forest, Queensland, Australia) <0.96 kg N ha^{-1} yr^{-1} (temperate spruce forest, Germany) was quantified (Luo *et al*., 2013). Hassler *et al.* (2015) recorded reduced CO_2 (107.2 to 115.7 mg C m^{-2} h^{-1}) and methane emission (-3.0 to -14.9 µg C m^{-2} h^{-1}) in the oil palm and rubber plantations than forest areas suggested reduced soil organic matter build up by reduced litter fall and reduced N build up in soil. Statistically influences of biochar application on the dynamics of soil parameters and emission rates were also recorded. Use of nitrification inhibitor is an example for restricting the process and emission cycles. Based on three years' field experimentation with rainfed barely grown in a clayey loam texture soil under semiarid Mediterranean climate, Abalos *et al.* (2017) observed that rainfall distribution had effects and reduce N_2O emission by using nitrification inhibitor-DMPP. Similarly, Pfab *et al.* (2012) recorded similar response of nitrification inhibitor in reducing emission and lowers down the emission factor from a vegetable field in loamy soil in Germany. In addition to current analysis, biochar reduced nitrous oxide emission in loamy cropped soil as seen in undisturbed core and disturbed soil samples. Thus, contribution of different factors towards emission potential is to be identified and quantified.

Effects of soil physical properties on N_2O emission

Physical properties of soil greatly influence the physical processes and rate of N_2O emission. Bulk density, porosity, water filled pore space, temperature and moisture content etc. had statistically significant influence on the emission inventory. The reduced oxygen diffusivity and increasing respiration under differential temperature increase and moisture content alters gas emissions. Soil texture-a robust determinant factor plays another major role in the emission process as observed by Weitz *et al.* (2001) in clay and loam soils having annual and perennial crops. Singurindy *et al.* (2006) recorded textural effects from urine treated soils on differential N_2O emission. Further, interaction effects of salinity and soil texture indicated that with increasing salinity, emission enhanced (46.81 to 780.69 µg N kg^{-1}) in sandy clay loam soil as compared to silty clay soil (11.81 to 60.74 µg N kg^{-1}) as observed by Yu *et al.* (2019). Dobbie and Smith (2001) recorded higher emission from grassland as compared to arable soils under variable temperature ranges; however, 30 and 12-fold increase in emission from arable soils with greater water filled pore spaces than grasslands was noted. Undisturbed core soil samples from temperate and boreal forest sites when kept under incubation with soil moisture and temperature ranges of 0 to 300 kPa and 5 to 20°C, respectively, showed variable rates of nitric oxide and nitrous oxide emissions (Schindlbacher *et al.,* 2004). Such variations were due to the effect of soil ecological process underlying a forest habitat. The interaction between soil physical factors and biological processes determine the exchange of green house gases between soil and atmosphere. In this connection, water filled pores, temperature and compaction driven microbial actions play important role in nitrification-denitrification processes (Smith *et al*., 2003; Khalil and Baggs, 2005; Armour *et al.,* 2013). Bateman and Baggs (2005) experimentally proved that different capacity of water filled pore spaces (WFPS) had significantly influence on the nitrification (35 to 60 per cent WFPS). In fact, soil related parameters like types, bulk density and others predominantly affect on the gas diffusion in soils (Conen *et al*., 2000; Fujikawa and Miyazaki, 2005). Bessou *et al*. (2010) described statistically positive role of compaction on nitrous oxide emission. Soil moisture content do differ emission rates and quantity while electrical conductivity also affects on microbial process which alters the N_2O emission. It was noticed that there was reduction in emission from 2.0 to 0.86 mg N_2O-N m^{-2} from 0.5 to 2.0 dSm^{-1} EC (del Prado *et al*., 2006; Adviento-Borbe *et al*., 2006). The water filled pore space significantly controls emission; rainfall event alters the process as described by Du *et al.* (2006) wherein annual N_2O flux varied between 0.25 to 1.62 kg N ha^{-1} from greening to littering stages in grasslands. Emission and gas diffusivity were positively responsive to bulk density and moisture contents (Klefoth *et al.,* 2014). Xu *et al.* (2016) recorded differential diurnal pattern in N_2O emission when watering on surface and subsurface at 12, 15 and 18 cm depths; 423.31 to 639.13 µg N_2O m^{-2} h^{-1} during May month after first watering whereas during July after second watering, 178.28 to 390.21 ìg N_2O m^{-2} h^{-1} was observed. At lower compaction level (bulk density of 1.35 Mg m^{-3}) and water filled pore space (57.4 to 98.3%) emits higher cumulative nitrous oxide (278 to 577 mg N m^{-2} d^{-1}) as compared to greater bulk density (1.45 Mg m^{-3}) with 130 to 561 mg N m^{-2} d^{-1} (Rabot *et al.* 2016). Abbasi *et al.* (2020) inferred moisture content, temperature and rainfall interaction during growing season from 2012 to 2015 and cumulative emissions of 517.72 to 1178.75 g N_2O-N ha^{-1} yr^{-1} was recorded with yield of 4.01 to 4.65 (Soybean), 4.60 to 4.88 (Corn) MT ha^{-1}. Wang *et al.* (2018) expressed that soil reaction act as dominant modifier in emission process across regional scales in presence of moisture and other physical fraction of soils; although soil reaction had utmost impact on denitrification process as recorded by S¡imek and Cooper (2002) and Čuhel *et al.* (2010). Kitzler *et al.* (2006) noted that high pH in calcareous mountain forest soil emit lower trace gases. Moreover, nitrification rates were greater in high clay soil than soils with lower clay percentage with soil reaction influencing mainly on ammonia oxidizing bacteria (Pereira e Silva *et al*., 2012). The substrate and its chemical composition, types and quality of residues either in agricultural lands, forest or agroforestry system showed variable pattern of N_2O emission. Zhang *et al.* (2014) evaluated the substrates composition for N_2O emission process and showed different contribution to the overall process as followed in the order of $(NH_4)_2SO_4$<amino acid <maize straw. Millar and Baggs (2004) evaluated agroforestry residues of *Sesbania, Crotalaria, Macroptilium* and *Calliandra* to indicate the quality composition impacts on emission flux in a Kenyan oxisol. Even, in absence of sufficient rainfall and low labile organic carbon, black soils emitted lower N_2O (Chen *et al*., 2014). The effect of land management comes into play to alter emission process and thereby quantity. Dann *et al.* (2013) noticed that the fluxes were higher at soil surface as compared to water tables. Bandyopadhyay and Lal (2014) concluded that large macro-aggregates contributed (37.9%) towards bulk N_2O emissions was greater as compared to micro-aggregates and mineral fraction. Moreover, cumulative N_2O emissions from different aggregate size fractions accounted for 56% of the emissions from the bulk soil. The speed at which N_2O emission taking place in soil depends on the rate of water filled pore space volume and connectivity as well. The wetting and drying cycle's had impacts on the emission with higher in the first cycle than in next cycles (Rabot *et al.,* 2015). Even, accumulation of nitrous oxide during thawing

period under snow cover contributes to the air and split dose of 80 kg ha^{-1} not only increased Yield (23%) but reduced emission (16%) also as found by Russenes *et al.* (2019). Yin *et al.* (2020) expressed that soil indicators like dissolved organic carbon, moisture, temperature etc positively correlated and impacts on the emission rate. Thus, role of soil physical determinants on the N_2O flux was quantified across rainfall, water regimes, pore space dynamics, role of temperature etc. in order to understand the direct or indirect influence. Area under drip fertigated orchards and other soil and water conservation measures implemented in fruit farming needs to be identified for this purpose (Adak *et al*., 2019). Further study should lead to wide spectrum hydrothermal and hydrological regimes in various soil types having different soil textural classes to develop inventory of N_2O flux and thereby policy planning for mitigation strategy.

Influence of tillage, cover crops and residue management on N_2O emission

Land management system consisting of different tillage components, cover crops, litter fall, residue incorporation and crop rotation etc. statistically impacts N_2O emission across agri-horticultural ecological niche. Table 1 summarizes some of the soil management related affects on the flux. The placement of fertilizer depths in combination of tillage and irrigation management was also known to alter the quantity of green house gases evolution. MacKenzie *et al*. (1998) recorded 50 to 450 ng of N m^{-2} s^{-1} N_2O emission from heavy clay, sandy loam, clay and silty clay loam soils over a period of three years under the influence of tillage, corn-soybean-alfalfa, corn soybean crop rotations etc. while Jantalia *et al.* (2008) observed the differential rate of nitrous emission from a Rhodic Ferralsol Brazilian soil. The effectiveness of several cover crops were also tested in order to reduce N_2O emission and also to enhance the efficiency of the added fertilizer. Justes *et al.* (1999) concluded that cover crops radish decrease the nitrate leaching in soil. Quality of irrigation water also determines the emission along with cover cropping in tomato as well; winter legume however as cover crops increased growing season N_2O emission than without cover crop under conventional furrow irrigation system while subsurface drip system lowers down the emission in coarse loamy or silt loam soils (Kallenbach *et al*., 2010)**.** Incorporation of crop residue modifies the emission pathways and rate of evolutions. Baggs *et al*. (2000) found that crop residue incorporation with high nitrogen content in lettuce residue emitted higher flux while cowpea-maize residue effecting the N_2O emission in tropical luvisol (Frimpong *et al*., 2011). In order to predict precisely nitrous oxide emission from soil, regression model was found to be more accurate as observed by Stacey *et al.* (2006). Metay *et al.* (2007) recorded emission was exponentially related to water filled pore space at top surface (10 cm depth) soil and estimated annual N_2O emissions ranged from 31 to 35 g N_2O-N ha^{-1} $year^{-1}$ for conventional and no-tillage system. Abdalla *et al.* (2014) obtained reduced tillage with cover crops (5.3 kg ha^{-1}) had higher annual nitrous oxide flux than no-tillage (3.8 kg ha^{-1}) with variable soil temperature (14.5 to 14.6°C) and water filled pore space (43 to 44%). Abalos *et al.* (2013) documented the possible effect of maize stover incorporation with organic/chemical fertilization in barley crop cultivated under Mediterranean climate. The said incorporation enhanced N_2O emission while replacement of urea by pig slurry reduced considerable emission irrespective of crop residue incorporation. In northern China plains, Gao *et al.* (2016) observed that maize and wheat residue with 250 kg N ha^{-1} increased emission flux than only addition of 250 kg N ha^{-1} in black soil (Vertisol) while in alluvial soils, wheat residue increased and maize residue decreased nitrous emissions. Tillage effects significantly on the emission fluxes across the food or fruit producing system. Baggs *et al.* (2003) found that zero and conventional tillage differs in their interaction with cover crops and fertilization on the emission in silt loam soil of England. Maximum emission was observed in conventionally tilled bean (*Vicia faba*) and zero tilled rye; a similar response was noted in zero tillage after residue + fertilizer application. Rochette (2008) opined that no-till only enhanced the emission as a function of soil

Table 1. Role of soil managements on the N_2O flux across various agri-horti ecologies

Reference	Country	Soil type and texture	Ecosystem service	N_2O emission dynamics	Management system involved
Jones *et al.* (2017)	Arkansas, USA	Silt loams (mesic Typic Fragiudult and thermic Typic Hapludult)	Organic apple orchard	Denitrifiers dynamics showed potential for enhanced denitrification.	Ground cover (compost, wood chips, paper mulch, or mow-and-blow) and nutrient management (poultry litter, organic commercial or no fertilizer)
Cheng *et al.* (2017)	Jiangsu Province, China	Gleyi-Stagnic Anthrosols	Peach orchard	Fertilized peach orchard is potential emitter (Two years average N_2O emission raised from 3.2 to 9.3, 10.3, and 20.1 kg N ha^{-1}. N_2O emission factor (1.32 to 1.86%)	Organic and chemical N fertilization
Müller Júnior *et al.* (2019)	Santa Catarina, southern Brazil	Local soil	Onion production in no-tillage system	Higher emission in poultry manure addition in presence of oilseed radish	Addition of cover crops like oilseed radish, black oat and weed residues with and without poultry manure under no-tillage practice
Friedl *et al.* (2018)	Subtropical Australia, Casino (New South Wales), Gympie and Kerry (Queensland)	A pellicVertisol, a ferric Acrisol and a mollic Fluvisol (clay, loam and sandy clay loam)	Intensively managed dairy pastures soil	Increased soil moisture during wetting cycles after irrigation or rainfall triggers N_2O emissions.	Wetting and drying cycles in pastures
Guardia *et al.* (2016)	Madrid, Spain	Silty clay loam (Typic Calcixerept)	Maize	Low cumulative N_2O emissions (0.57 to 0.75 kg N_2O-N ha^{-1} yr^{-1})	Cover crops (*Vicia sativa*) and barley, irrigation and fertility management
Basche *et al.* (2014)	USA, India, UK, China, Kenya, Denmark, Japan, Italy	Variable soil types	Cereals, Grapes, pasture, tomatoes, afalfa etc.	Based on 106 observations, it was concluded that 40 percent study showed cover crops reduce emission whereas rest indicate increase. Legume crop enhanced emission.	Legume and non-legume cover crops
Bradley *et al.* (2011)	Québec, Canada	Sandy loam and clay	Riparian buffer strip and maize	Higher emissions in riparian buffer strips than in adjacent maize fields.	Earthworm and litter (switchgrass, alfalfa, corn stover and red oak, apple, Rhododendron)

Contd...

Table 1 contd.

Reference	Country	Soil type and texture	Ecosystem service	N_2O emission dynamics	Management system involved
Cameron *et al.* (2011)	Canterbury, New Zealand	Templeton silt loam	Pastures (mixture of perennial rye grass and white clover	Dicyandiamide reduced N_2O emission from grazed pasture.	Urine, dung, urea fertilizers, Dicyandiamide in different combinations
Frimpong and Baggs (2010)	Tamale, Ghana	Reddish brown sandy loam	Cowpea, *Mucuna pruriens* and *Leucaena leucocephala*	Emission from all residues was positively correlated with residue C:N ratio and negatively correlated with residue chemical composition. Ratio of 25:75 Leucaena:Fertilizer and cowpea: fertilizer emitted greater N_2O.	Incorporation of crop residue and fertilizer ratio combination
Drury *et al.* (2006)	Ontario, Eastern Canada	Clay loam soils	Wheat-corn-soybean rotation with tillage and N placement for three seasons	Emission in zone-tillage was 20 and 38% lower than no-tillage and moldboard plow tillage at deeper N placed. Shallow N placement had lower emission.	Tillage (moldboard plow:15 cm depth, fall zone-tillage:21 cm width, 15 cm depth and no-tillage). Shallow (2 cm) and deep (10 cm) N place ment depth.

aeration. The rate of fluxes under no-till was recorded to be lower (0.06), higher (0.12) and higher (2.00 kg N ha^{-1}) as compared to tilled soils with good, medium and poor aeration, respectively. Similarly, Garland *et al.* (2011) concluded that higher N_2O emission from no-tillage (0.19 kg N_2O-N ha^{-1} growing $season^{-1}$) vineyard as compared to conventional tillage (0.13 kg N_2O-N ha^{-1} growing $season^{-1}$) in Willows silty clay soils of California, USA; even the different emission rates were also recorded across rows of differential tillage practices. The conventional or zero tillage has different potential to global warming potential. Dendooven *et al.* (2012) recorded that these systems do differ along with cover crop residue and /or fertilizer for better carbon sequestration and thereby vary in green house gas emission. Garcia-Marco *et al.* (2016) noticed that conventional tillage enhanced emission by about 68% as compared to no-tillage whereas liming reduced 61% emission in tillage imposed soils than no-tillage one. Contrasting to the findings Li *et al.* (2016) noted that tillage does not enhanced emission in a semiarid environment of south-eastern Australia. Yu *et al.* (2018) obtained an interesting result of reducing nitrous oxide emission from soil. Plastic mulching reduced (19-28%) and in presence of nitrapyrin, it further reduced (23-39%) emission. Further, earthworm and Collembola dominantly enhanced emissions (Zhu *et al.*, 2018). Plaza-Bonilla *et al.* (2018) are in opinion that no-tillage reduces yield scaled emission in rainfed Mediterranean ecology. Moreover, Wu *et al.* (2020) found that addition of N enhanced N_2O emission from 4.05 mg N m^{-2} in no-addition to 4.37 to 6.62 mg N m^{-2} (0.96 to 1.92 g N m^{-2} and 5 to 10 mg N kg^{-1}) during freeze-thaw cycles. Dynamics of N_2O flux as a function of management-induced factors was quantified across the globe involving tillage-related factors. Such system needs to ensure reduction in emission so that atmosphere remains clean and healthy without adversely affecting productivity.

Potential of green house gas emission from the agri-horticultural system needs to be quantified; this is in fact required from view point of evolving mitigation strategies. Literature suggested that spatial and temporal variations of

N_2O emission in the food/fruit supply chain depends on a variety of determinants starting from tillage, alternate drying and wetting cycles, conservation strategies, types, placement and quantity of fertilizers, microbial role, soil aeration, porosity, salinity, bulk density, pH, cover crops, residue retention, denitrifiers, nitrification inhibitors etc. The role of each system like forest, pasture, grassland, agro-forestry, annual, perennial etc. differs in their potential to contribute to the total N_2O fluxes. Water quality and conservation practices do have some positive role in mitigating the fluxes. Rainfal, soil temperature in the ecological process significantly contributes to the ongoing emission of N_2O. Linquist *et al.* (2012) meta-analytically proved that yield-scaled global warming potential of rice was 4 times higher than maize and wheat. Zhu *et al.* (2015) observed variable rate of emission in banana orchard under urea application rate and urease inhibitor. Rowlings *et al.* (2013) estimated N_2O emission (1.7 to 7.6 kg N_2O-N ha^{-1} yr^{-1}) from 30 years old litchi orchard in the humid subtropical region of Australia following orchard management. Addition of biochar to soil improves the water holding capacity and porosity and reduced bulk density. Thus, its addition leads to lowers down the fluxes of N_2O from soils (Case *et al.*, 2012). The nitrification-denitrification process along with the inhibitors modifies the imbibitions process of evolving the gases. Ambus (1998) quantified N_2O emission from riparian grassland, coastal grassland, spruce forest, beech forest and an agricultural field and concluded that lower sites having higher soil organic matter and wetter release higher fluxes. Use of dicyan-diamide, slow release fertilizers, neem coated fertilizer etc. are some of the ways to reduce the emission. Dennis *et al.* (2012) and Ernfors *et al.* (2014) observed that nitrification inhibitor reduced N from cattle urine/slurry in grazed grassland. Litter decomposition and wetting soils in acidic forest also contribute to the fluxes sometimes may be of minute quantity. Even, under field conditions soil temperature affects the longevity of nitrification inhibitors as shown by Kelliher *et al.* (2014); with soil temperature of 8 and 16°C, 39 and 25 days, it can persist in soil to its half value. Management options consisting of hippuric and benzoic acids are not mitigating the *in-situ* emission as shown by Krol *et al.* (2015). Thus, management options should be developed in such a way that emits lower emission from clay loam and clay soil. Water filled pore spaces are the key drivers in this process of evolving greater N_2O emission (Volpi *et al.*, 2017).

Conclusion

All these study suggested that indeed there is a need to develop inventory from each segment of the ecosystem. Further, management for mitigation should be evolved for location/site specific regions involving agricultural produce or fruit farming. Future study should include emission factor along with the flux should be taken into account while developing the data base and region-specific factor should be developed.

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