Current World Environment Vol. **11**(2), 423-428 (2016)

Nitrification Inhibitors: A Perspective tool to Mitigate Greenhouse Gas Emission from Rice Soils

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http://dx.doi.org/10.12944/CWE.11.2.10

(Received: June 13, 2016; Accepted: August 11, 2016)

ABSTRACT

Rice fields are significant contributors of greenhouse gases mainly methane and nitrous oxide to the atmosphere. Increasing concentrations of these greenhouse gases play significant role in changing atmospheric chemistry such as mean air temperature, rainfall pattern, drought, and flood frequency. Mitigation of greenhouse gases for achieving sustainable agriculture without affecting economical production is one the biggest challenge of twenty first century at national and global scale. On the basis of published scientific studies, we hereby assess the use of nitrification inhibitors for greenhouse gas mitigation from rice soil. Biologically oxidation of ammonium to nitrate is termed as nitrification and materials which suppress this process are known as nitrification inhibitors. Soil amendment by addition of certain nitrification inhibitors such as neem oil coated urea, nimin-coated urea; dicyandiamide, encapsulated calcium carbide, and hydroquinone reduce cumulative methane and nitrous oxide emission from rice. Firstly, these inhibitors reduce nitrous oxide emissions both directly by nitrification (by reducing NH_4^+ to NO_3^-) as well as indirectly by de-nitrification (by reducing NO_3^- availability in soil). Secondly, methane emission from rice soil can be reduced by enhancing methane oxidation and suppressing methane production and further by reducing the aerenchymal transportation through rice plant. Application of some of the nitrification inhibitors such as calcium carbide and encapsulated calcium carbide reduce methane production by releasing acetylene gas which helps in reducing the population of methanogenic microbes in the soil. Application of nitrification inhibitors also helps to maintain soil redox potential at higher level subsequently reducing cumulative methane emission from soil. Plant derived organic nitrification inhibitors (neem oil, neem cake, karanja seed extract) are eco-friendly and possess substantial greenhouse gas mitigation potential from rice. In the current scenario of global warming and environmental pollution, application of organic plant derived nitrification inhibitors is much needed for sustainable agriculture.

Keywords: Rice, Methane, Nitrous oxide, Nitrification inhibitors.

INTRODUCTION

Global climate change is one of the biggest challenges of the twenty first century. Enhance greenhouses effect lead to rise in mean global air temperature and it is projected that mean temperature may increases from 1.5 to 4.5 °C by the end of 21st century (IPPC 2013). Rise in atmospheric greenhouses gases (GHGs) such carbon di-oxide, methane (CH_4), chlorofluorocarbon and nitrous oxide (N_2O) concentration in atmosphere due to anthropogenic activities leads to global warming (IPCC 2007). According to IPCC (2014) carbon di-oxide (Fossil fuel and industrial processes), Carbon di-oxide (Forestry and other land use), CH_4, N_2O and fluorinated gases contributes 65 %, 11 % , 16%, 6% and 2 % respectively at global level in 2010 (Figure 1). Methane and nitrous oxide are two major GHGs emitted from rice (*Oryza sativa* L.) agro-ecosystem. At global level rice cultivation alone contribute 10 % of total CH_4 emission (GMI 2011) while the global warming potential of N_2O is 298 times higher (Rees et al. 2013) than carbon di-oxide, so mitigation of both CH_4 and N_2O is needed to combat global warming. There are mainly four different types of rice ecosystem namely upland, rainfed, irrigated and deer rice ecosystem (Adhya et al. 2014). Deep rice and irrigated rice ecosystem are main sources of CH_4 emissions to atmosphere will upland and dry period in between continuous flooded are main sources of N_2O emissions to atmosphere from rice soil. In deep and continuous irrigated rice anaerobic conditions lead to sharp decline in soil redox potential (Ali et al. 2015; Hussain et al. 2015; Dubey 2005) which results in CH_4 production. In flooded rice methanogens bacteria consume soil organic carbon and emit CH_4 (Nazaries et al. 2013; Penning and Conrad 2007). Methane produce by methanogens in rice soil, generally emits to atmosphere by three (diffusion, ebullition and aerenchymal transportation) possible mechanisms (Green 2013; Tokida et al. 2013; Das and Baruah 2008; IPCC 1996; Neue 1993). In rice soil N_2O is produce by both biological (nitrification and denitrifcation) and chemical decomposition process (Lan et al. 2014; Baggs 2011; Ussiri and R. Lal 2007; Freney 1997; Bremner 1997). Nitrogen base fertilizer are main sources of N_2O production in rice soil and about 1.25 % of the total applied nitrogen is converted into atmospheric N_2O (Bouwman 1994) under aerobic condition in soil but under flooded rice less than 0.1 % of applied N fertilizer is emitted as N_2O (Freney et al 1997). Methane and N_2O production is rice soil is effect

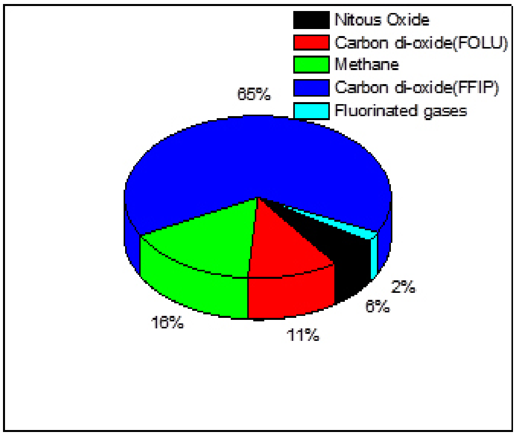

Fig. 1: Percentage contribution of various anthropogenic greenhouse gases emissions at global level in 2010 (IPCC 2014)

by several factors such as water managements, soil pH, redox potential, temperature, soil matter of the soil, soil microorganisms diversity, transplanting methods, rice cultivar, Crop duration and type of time of fertilizer application (Hussain et al. 2015; Hadi et al. 2010; Conrad 2007; Dubey 2005; Conrad 2002, Le Mer and Roger 2001). The nitrification inhibitor play potent role in mitigating GHGs emissions from different rice argo-ecosystem. In this review study we develop understating of NI in rice soil to mitigate GHGs emissions to combat global warming issues.

Methane and nitrous oxide mitigation potential of nitrification inhibiters in rice

Biological oxidation of ammonium to nitrate through nitrite by nitrifying bacteria species *Nitrosomanas* and *Nitrobacter* respectively is known as Nitrification and material which retard or inhibit nitrification process termed as Nitrification inhibitors (NI) (Hussian et al. 2015; Saharwat 2004). In current scenario of global warming application of NI for reducing greenhouse gases emissions such as N_2O and CH_4 from rice soil have good environmental sound as this compound also reduce nitrate water pollution load also. NI reduces N2O emission directly by retarding nitrification in soil and by reducing availability of nitrate for de-nitrification indirectly. Several studies revels that application of NI such as dicyandiamide (Hussain et al. 2015; Datta and Adhya 2014; Linquist et al. 2012; Li et al. 2009; Pathak et al. 2003), urease (Hussain et al. 2015; Majumdar et al. 2003), hydroquinol (Li et al. 2009) and thiosulphate (Malla et al. 2005) can mitigate CH_4 emission from rice soil. Similarly, several previous studies reports that nitropyrimidine (Majumdar et al. 2003), dicyandiamide (Datta and Adhya 2014; Linquist et al. 2012; Li et al. 2009; Pathak et al. 2002), benzoic acid (Majumdar et al. 2003) nimim (Datta and Adhya 2014) and thiosulphate (Malla et al. 2005; Kumar et al. 2000) have significant N_2O reduction potential in rice soil (Table 1).

Li et al. (2009) have reported that combined basal application of HQ/DCD reduces CH_4 emissions by 35.38 %. In combination the application of HQ and DCD at tillering and panicle initiation stage reduces CH_4 emission by 19.04 and 12.24 % respectively as compare to control in rice soil (Li et al. 2009). Malla et al. (2005) reported that organic plant- derived

Table 1: Influences of different nitrification inhibiters on GHGs emission in rice soil

Reference and Country	Treatment	CH_4 (kg ha^{-1})	M %	N_2O (kg ha^{-1})	M %
Datta and Adhya (2014), India	Control (Prilled urea)	246.22	Control (C)	1.60	Control (C)
	Urea (U) + Dicyandiamide (DCD)	372.36	-51.23	1.20	25.00 %
	U + Nimim	250.17	-1.60	0.49	69.38 %
	U + Karanjin	294.59	-19.65	0.99	38.13 %
Li et al. (2009), China	Control (Urea)	43.39	C	3.90	C
	Hydroquinone /DCD basal	28.04	35.38	2.98	23.59
	HQ/DCD at tillering	35.13	19.04	1.73	55.64
	HQ and DCD at panicle initiation	38.08	12.24	3.23	17.18
Malla et al. (2005), India	Urea(Control)	27.0	C	0.76	C
	Urea + hydroquinone	30.2	-11.85	0.73	3.95
	Urea + neem cake	23.9	-11.48	0.68	10.53
	Urea + coated Ca-carbide	23.4	13.33	0.54	28.95
	Neem oil coated urea	24.9	7.78	0.60	21.05
	Urea + dicyandiamide	23.8	11.85	0.63	17.11
	Urea + thiosulphate	28.4	-5.19	0.50	34.21
Pathak et al. (2003), India	Urea	21.3	C	--	NA
	Urea + DCD	14.9	30.05	--	NA
	Urea + Farmyard manure	36.5	-71.36	--	NA
	No N	16.3	23.47	--	NA
Pathak et al. (2002), India	Urea	--	NA	8.32	C
	Urea + DCD	--	NA	6.54	21.39
	Urea + Farmyard manure	--	NA	5.11	38.58
	No N	--	NA	3.15	62.14
Xu et al. (2002), China	Control	190.26*	C	17.25**	C
	HQ	132.97*	30.11	13.2**	23.48
	DCD	89.22 *	53.11	9.14**	47.01
	HQ+DCD	79.50*	58.22	6.51**	62.26
Kumar et al. (2000)	Urea	--	NA	0.16	C
	$(NH_4)2SO_4$	--	NA	0.24	-50
	Urea + dicyandiamide	--	NA	0.14	12.50
	$(NH_4)2SO_4$ + dicyandiamide	--	NA	0.17	-6.25
	Urea + thiosulphate	--	NA	0.15	6.25
Majumdar et al. (2000), India	Urea	--	NA	0.59	C
	Urea + dicyandiamide	--	NA	0.49	16.95
	Nimin coated urea	--	NA	0.57	3.39
	Neem coated urea	--	NA	0.53	10.17

Bharati et al. (2000), India	Control	1204 µg kg^{-1} soil	C	--	NA
	Sodium azide	380 µg kg^{-1} soil	68.44	--	NA
	Aminopurine	941 µg kg^{-1} soil	21.84	--	NA
	Pyridine	908 µg kg^{-1} soil	24.58	--	NA
	Dicyandiamide	634 µg kg^{-1} soil	47.34	--	NA
	Thiourea	1065 µg kg^{-1} soil	11.54	--	NA
	Ammonium thiosulfate	1060 µg kg^{-1} soil	11.96	--	NA

(-)-More emission; M-mitigation; NA-not applicable; * mg CH4 pot−1; **mg N2O-N pot−1

neem oil coated urea reduce total CH_4 by 7.78 % from rice as over inorganic fertilizer (urea) application along (Table 1). Inorganic NI such calcium carbide coated urea and DCD reduces total emissions by 13.33 and 11.85 % than control (urea) respectively from paddy cultivation (Malla et al. 2005). In field experiment conducted at research farm of Indian Agricultural Research Institute, Pathak et al. (2003) observed that DCD along with urea reduce total cumulative CH_4 emission from 21.3 kg ha^{-1} to 14.9 kg ha^{-1} which show that DCD application along with urea mitigate 30.5 % of total emission as compare to control (urea). In laboratory study conducted by Xu et al. (2002) observed that HQ (132.97 mg CH_4 pot^{-1}) and DCD (132.97 mg CH_4 pot^{-1}) amendment alone and in combination (89.22 mg CH_4 pot^{-1}) were effective for reducing CH_4 emissions as compare to control (190.26 mg CH_4 pot^{-1}). Bharti et al. (2000) invested impact of six different NI on CH_4 production and observed that all the compound reduce mean CH_4 production. Mean CH_4 production from control (1204 ìg kg^{-1} soil) is reduce to 380, 941, 908, 634, 1065 and 1060 ìg kg^{-1} soil by sodium azide, aminopurine, pyridine, thiourea and ammonium thiosulfate respectively(Table 1). Datta and Adhya (2014) observed that organic NI such as nimim and karanjin are most effective for reducing N_2O emission in rice as campare to inorganic NI DCD and prilled urea. Nimim reduce total N_2O emission by 69.38 % were as karanjin to reduce N_2O emission by 38.13 % as compare to prilled urea (Table 1). In other field experiment Malla et al. (2005) also observed.

That organic NI neem cake and neem oil coated urea reduce N_2O emsiion by 10.53 % and 21.05 % than control (urea). In similar study Malla et al. (2005) reported that HQ, DCD, thiosulpahte along with urea and calcium carbide coated urea mitigate N_2O emission by 3.95, 17.11, 34.21 and 28.05 % as compare to control from rice soil (Table 1). Li et al. (2009) observed that HQ and DCD basal application in rice reduce total cumulative N_2O emission to 3.90 kg ha^{-1} as compare to control 3.90 kg ha^{-1}. HQ/DCD application at tillering and panicle intiation stages of rice reduces N_2O emission by 55.64 and 17.18 % respectively in Chinese soil (Table 1). Pathak et al. (2002) reported that soil amendment by DCD along with urea mitigate N_2O emission by 21.39 % than soil amendment by urea alone in rice soil. Xu et al. (2002) also observed that HQ, DCD and HQ plus DCD reduces N_2O emissions to 13.2, 9.14 and 6.51 mg N_2O-N pot^{-1} as compare over control (17.25 mg N_2O-N pot^{-1}) respectively.

CONCLUSION

The increasing trend of human population in Indian and at global level creates treamdmous pressure on agricultural system for feeding. This demand leads to evolution of modern agriculture and rice is important stable food for majority of population in world. Rice production is major source for greenhouse gases emission which leads to global warming. In this study we synthesized the published data to provide suitable rice management for greenhouses mitigation by fertilizer management (Nitrification inhibitors). We found that nitrification inhibitors interventions in rice can be one effective tool to anticipate global warming. For instances, inorganic nitrification inhibitors such DCD, HQ and thiosulphate application have methane and nitrous oxide mitigation potential from rice cultivation. Recently the mitigation potential of few organic nitrification inhibitors such as karanjin, nimim and neem oil coated urea was also explored. Fertilizer management practices like nitrification inhibitors application sound environmental friendly and help in achieving sustainable agricultural goal.

ACKNOWLEDGEMENTS

Author is thankful to Head of the Division (Dr. S.D Singh) Center for Environment Science and Climate Resilient Agriculture, Indian Agricultural Research Institute, New Delhi-10012, India, for all support and encouragement.

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