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Effect of soil applied natural and synthetic nitrification inhibitors on nitrogen transformations and nitrification inhibition in NW Himalayan region of Himachal Pradesh

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ABSTRACT

Usefulness of nitrification inhibitors (NIs) has been identified in reducing the soil nitrogen losses of applied N fertilizers. We conducted an incubation experiment to evaluate the effects of soil applied NIs on nitrogen transformations (NH_4^+& NO_3^-) and NI in sandy clay loam soil. Powdered extracts of pomegranate rind, melia fruit, neem cake were prepared and added in soil at concentration of 20 and 40 g kg^{-1} soil, respectively, while calcium carbide was added at 30 g kg^{-1} soil. Sources of N, P and K were urea, single super phosphate (SSP), murate of potash (MOP) at the rate of 1.98, 3.50 and 0.88 g^{-1}pot, respectively. Sole application of urea was taken as the control treatment. Treated soils were incubated at 25°C for 42 days. Results revealed that at the end of incubation, highest NH_4^+-N retention (126.30 mg N kg^{-1}) and total soil nitrogen (TSN) (152.72 mg kg^{-1}) was recorded under CaC_2 @ 30 g kg^{-1} soil treatment. Maximum NO_3^--N accumulation (42.26 mg N kg^{-1}) was associated with melia fruit @ 20 g kg^{-1} soil treatment. Regarding the nitrification inhibition, treatment of neem cake 40 g kg^{-1} soil recorded maximum nitrification inhibition (44.31 %). Amongst the different nitrification inhibitors tested, lowest levels of nitrified N (20.41 and 22.05%) were recorded under the application of CaC_2 @30 g kg^{-1} soil and neem cake @40 g kg^{-1}, while the maximum (54.5%) was observed in treatment comprising of urea alone (control). Eco-friendly and cost-effective plant based nitification inhibitors were identified superior as compared to synthetic on nitrification inhibition.

1. INTRODUCTION

Agricultural production needs to be increased by 70% for keeping pace with world's population which has been projected to be around 9.6 billion by 2050 (Francesco and Mariangela, 2016). Improvement in agricultural production can be achieved either through high yielding cultivars and hybrids or by increasing cropping intensity. Modern agricultural ecosystems majorly depend upon higher inputs of N fertilizer for sustaining productivity as atmospheric fixed N is rarely adequate for high production systems (Dinnes *et al.,* 2002; Subbarao *et al.,* 2006; Abbasi and Khizar, 2012). In India, urea isused as the main source of nitrogenous fertilizers applied to soil. But sub-optimal urea dosage leads to poor crop quality while dosage more than crop demands result into potential nitrate leaching from organic as well as inorganic N sources. Urea applied to soil firstly hydrolyzes quite rapidly into ammonium ions (NH_4^+) and afterwards converted to nitrite (NO_2^-) and nitrate (NO_3^-) through nitrification process (Kiran and Patra, 2003). Nitrate form of N is subjected to many losses and ultimately lost through percolation, denitrification gaseous emissions of N_2O, and NO from the soil nutrient pool (Zaman *et al.,* 2009). Therefore, lower nutrient use efficiency (NUE) of applied fertilizer N can be attributed to many reasons like surface run off, leaching losses, volatilization, denitrification and fixation of micronutrients in the soil due to high pH (Singh *et al.,* 2018). Excessive losses of N due to NO_3^- leaching or loss through denitrification result into very poor recovery of applied nitrogen (Yadav and Mohan, 1982). Several approaches have been practiced by many researchers till now to improve nitrogen fertilizer use efficiency such as use of slow release fertilizers (Malhi *et al.,* 2003), amending urea with salts and acids, adoption of super granular form of urea (Shah and Wolfe, 2003), several chemicals (N-serve and dicyandiamide) which retards the urea hydrolysis and nitrification (Kiran and Patra, 2003).

Suppression of the nitrification process through inhibitors therefore can be effective strategy to lower the N losses by NO_3^- leaching and by gaseous N emissions (Subbarao *et al.,* 2006). Researchers have reported that several NIs *i.e.* nitrapyrin (2-chloro-6-tricholoro methyl pyridine), sodium azide, sodium chlorate, dicyandiamide, ATC (4-amino-1-2-4-triazole), N-serve) inhibited the NH_4^+ oxidation to NO_3^- (McCarty, 1999; Abbasi *et al.,* 2003; Fangueiro *et al.,* 2009; Khalil *et al.,* 2009; Zaman *et al.,* 2009; Souri, 2010; Pereira *et al.,* 2010; Kiran and Patra, 2003) but their use has limitations as they bear high cost, risk on soil micro flora, lack of availability and could be agent of water and soil pollution (Patra and Sukhma, 2009; Vyas *et al.,* 1993; Ahmad *et al.,* 2014).

Besides these synthetic NIs, several researchers reported that inexpensive sourceslike CaC_2 and plants like *karanj* (*Pongamia glabra*), *neem* (*Azaddirachta indica*), and *tea* (*Camellia sinensis*) possess the NI properties (Freney *et al.,* 2000, Kiran and Patra, 2003; Majumdar, 2002; Abbasi *et al.,* 2011). These natural NIs are cheaper and easily available as compared to synthetic and chemical based NIs (Upadhyay *et al.,* 2011). However, the effect of these natural inhibitors for inhibiting nitrification, N transformations and increasing NUE in agriculture ecosystem is still not clear. In India, very less research work has been done on these aspects. Keeping this in view, this study was carried out to evaluate the efficiency of plant based NIs pomegranate, melia, commercial neem cake and synthetic NI calcium carbide (CaC_2) on N transformations and nitrification inhibitions in soil.

3. MATERIAL AND METHODS

Soil and Plant Materials

The study was conducted under laboratory conditions during 2018-19. Soil used in the experiment was sandy clay loam, collected from cauliflower fields, located at farm area of Soil Science UHF, Solan (HP), India. The soils are classified as *Typic Eutrochrepts*. Soil samples were collected from surface layer (0-15 cm), air dried and sieved (2 mm). Some physical and chemical properties of the soil were determined and presented in Table 1.

Table: 1
Some physical and chemical properties of the soil used

Physico-chemical properties	Value
Sand (%)	47.3
Silt (%)	29.6
Clay (%)	23.1
Textural class	Sandy clay loam
Bulk density (g cm^{-3})	1.5
Particle density (g cm^{-3})	2.5
Soil pH	6.7
EC (dS m^{-1})	0.2
Organic carbon (g kg^{-1})	10.9
Available N (kg ha^{-1})	317.2
Available P (kg ha^{-1})	49.1
Available K (kg ha^{-1})	196.7
Available Fe (mg kg^{-1})	14.4
Available Mn (mg kg^{-1})	7.1
Available Zn (mg kg^{-1})	2.7
Available Cu (mg kg^{-1})	3.2

Plant materials used in study were collected from different areas near university campus. Rind part of pomegranate and fruits of melia were used for the study. For the extraction of plant derivatives, selected plant materials were cleaned, air dried and ground to pass 2 mm sieve, then kept in plastic bags at room temperature (25°C) and humidity (35%) until use.

N Transformations and Nitrification Inhibition

Sieved soil samples were washed with 0.01 N KCl to leach out the inorganic forms of nitrogen present in the soil. Then leached soil was air dried and plastic pots of 6.5″ length and 14″ diameter were selected and filled with 3 kg soil. Soil was further treated with solutions containing urea (1.98 g pot^{-1}), SSP (3.50 g pot^{-1}) and muriate of potash (0.88 g pot^{-1}), respectively as per treatment. To compare the effect of plant derivatives on nitrification on soil with synthetic chemical inhibitor *i.e.* calcium carbide (CaC_2), set of pots were treated with 90 g of CaC_2 with similar fertilizer rates. Soil of control treatments was treated with solution contains only urea, SSP and MOP at the same rate as that of other treatments. The moisture content of all treatments was maintained at field capacity measured with pressure plate apparatus during the study period. Eight treatments were triplicated and incubated at 25°C for 42 days and presented in Table 2. Soil samples were drawn at weekly interval *i.e.* 0, 7, 14, 21, 28, 35 and 42 days after treatment with derivatives for the estimation of inhibition of nitrification, Nh_4^+ and NO_3^- forms of nitrogen, released from the soil treated with different doses of plant derivatives in comparison to the chemical based inhibitor (CaC_2) and control treatment. Soils were extracted with 2 M KCl, then the amount of NH_4^+ and NO_3^- was determined by procedure given by Bremner and Edwards (1965), percentage inhibition of nitrification was calculated as per procedure given by Bremner and McCarty (1988).

Statistical Analysis

For working out the analysis of variance, the data have been analyzed as per Panse and Sukhatme (1967) for completely randomized design (CRD).

3. RESULTS AND DISCUSSION

Ammonical Nitrogen (NH_4^+-N)

Different treatments exhibited almost similar values of

Table: 2
Different treatments applied in this study

S.No.	Treatments	Amount added per pot
T_1	Powdered pomegranate rind @ 20 g kg^{-1} of soil	Powdered pomegranate rind @ 60 g + Urea @1.98 g + SSP @3.50 g + MOP @0.88 g
T_2	Powdered pomegranate rind @ 40 g kg^{-1} of soil	Powdered pomegranate rind @ 120 g + Urea @ 1.98 g + SSP @ 3.50 g + MOP @0.88 g
T_3	Powdered melia fruits @ 20 g kg^{-1} of soil	Powdered melia fruits @ 60 g + Urea @1.98 g + SSP @ 3.50 g + MOP @ 0.88 g
T_4	Powdered melia fruits @ 40 g kg^{-1} of soil	Powdered melia fruits @ 120 g + Urea @ 1.98 g + SSP @ 3.50 g + MOP @ 0.88 g
T_5	Commercial neem cake @ 20 g kg^{-1} of soil	Neem cake @ 60 g + Urea @ 1.98 g + SSP @ 3.50 g + MOP @ 0.88 g
T_6	Commercial neem cake @ 40 g kg^{-1} of soil	Neem cake @ 120 g + Urea @ 1.98 g + SSP @ 3.50 g + MOP @ 0.88 g
T_7	Calcium carbide (CaC_2) @ 30 g kg^{-1} of soil	CaC_2 @ 90 g + Urea @ 1.98 g + SSP @ 3.50 g + MOP @ 0.88 g
T_8	Control (Urea alone)	Urea @ 1.98 g + SSP @ 3.50 g + MOP @ 0.88 g

Table: 3
Effect of nitrification inhibitors on the NH_4^+-N content (mg kg^{-1} soil)

Treatment	Incubation days							Mean	CD (0.05)
	0	7	14	21	28	35	42		
T_1: PR @ 20 g kg^{-1} soil	107.0	64.4	61.5	46.2	41.4	38.7	29.7	58.2	2.9
T_2: PR @ 40 g kg^{-1} soil	104.3	69.3	66.5	50.2	46.8	43.5	33.9	61.9	2.5
T_3: MF @ 20 g kg^{-1} soil	98.4	65.7	60.2	57.2	64.6	47.6	46.6	64.1	2.8
T_4: MF @ 40 g kg^{-1} soil	101.8	78.9	76.5	70.3	74.7	62.4	42.8	73.7	3.4
T_5: NC @ 20 g kg^{-1} soil	99.7	76.3	68.3	80.9	92.1	95.7	84.6	84.7	4.8
T_6: NC @ 40 g kg^{-1} soil	102.3	104.1	96.3	109.3	115.6	117.6	112.5	107.5	5.1
T_7: CaC_2 @ 30 g kg^{-1} soil	105.4	117.4	112.6	123.7	134.1	139.0	126.3	121.8	6.5
T_8: Control (Urea alone)	104.1	64.4	51.3	32.1	30.8	28.9	22.5	50.9	3.2
Mean	102.8	79.4	74.2	79.4	75.0	71.7	62.4		
CD T (0.05)	5.1	4.3	4.4	4.3	3.5	3.9	3.3		
CD T × I (0.05)	3.8								

**Where, PR = Pomegranate rind, MF = Melia fruit, NC = Neem cake*

NH_4^+-N content at day 0 of incubation, but the maximum NH_4^+-N content (107.0 mg N kg^{-1}) was recorded under T_1 treatment but was found at par with T_2, T_4, T_6, T_7 and T_8 at day 0, whereas, the lowest NH_4^+-N content (98.4 mg N kg^{-1}) was recorded under T_3 which was also found statistically at par with T_5 and T_4 (Table 3). The NH_4^+-N concentration in T_1continued to decrease with time and very little concentration (29.7 mg N kg^{-1}) was recorded in the soil by the end of incubation *i.e.* day 42. Maximum NH_4^+-N content of 139.0 mg N kg^{-1} was found in T_7 treatment during day 35. Treatment T_8 (urea alone) exhibited a sharp decline in the NH_4^+-N content from 104.1 mg N kg^{-1} (at day 0) to 22.5 mg N kg^{-1} (at day 42), decrease being 78.4%. Highest NH_4^+-N concentration (126.3 mg N kg^{-1}) at the end of incubation was recorded under T_7 followed by T_6 (112.5 mg N kg^{-1}) and the percent increase was to the tune of 12.25%. Temporal increase and decrease in the NH_4^+-N concentration have been observed between 14 and 42 days in the treatments T_3, T_4, T_5, T_6 and T_7. However, no such variation has been recorded under the T_1, T_2 and T_8 treatments. Treatments T_6 and T_7 maintained higher concentrations of NH_4^+-N in the soil during the incubation over other treatments in. However, the interaction between incubation and treatment (I×T) revealed that different treatments had significant effect on the soil NH_4^+-N content. Based on the mean value of NH_4^+-N under different treatments, it was found that NH_4^+-N was in the order of $T_7 > T_6 > T_5 > T_4 > T_3 > T_2 > T_1 > T_8$, thus indicating the effectiveness of chemical and plant based derivatives in effectively inhibiting nitrification as compared to the urea alone treatment (control). The less recovery of NH_4^+-N concentration as compared to applied N could be due to volatilization as NH_3 or NH_4^+ fixation by the clay minerals.

Nitrate Nitrogen

The data presented in showed that maximum NO_3^--N content (66.8 mg N kg^{-1}) at day 0 was recorded under T_8 treatment (urea alone), while the lowest (41.6 mg N $kg^{-1)}$ was recorded in T_2 (PR @ 40 g kg^{-1} soil) (Table 4). The nitrate content in all the treatments were found to decrease with incubation period and the lowest NO_3^--N (24.2 mg N kg^{-1}) was recorded in T_2 after 42 days. Among different treatments, accumulation of maximum NO_3^--N content in soil

Table: 4
Effect of nitrification inhibitors on the NO_3^--N content (mg kg^{-1} soil)

Treatment	Incubation days							Mean	CD I (0.05)
	0	7	14	21	28	35	42		
T_1: PR @ 20 g kg^{-1} soil	43.1	42.3	39.6	33.6	35.7	33.6	26.7	36.4	1.7
T_2: PR @ 40 g kg^{-1} soil	41.6	40.3	36.6	32.7	30.9	28.1	24.2	33.5	1.6
T_3: MF @ 20 g kg^{-1} soil	43.2	46.0	44.4	43.2	40.3	39.6	35.2	42.3	2.0
T_4: MF @ 40 g kg^{-1} soil	44.1	43.6	41.3	40.1	38.4	37.8	33.3	40.8	1.6
T_5: NC @ 20 g kg^{-1} soil	42.1	39.6	36.1	34.6	32.4	31.9	30.6	34.7	1.7
T_6: NC @ 40 g kg^{-1} soil	42.7	32.8	30.2	28.6	28.1	26.3	24.3	29.1	1.1
T_7: CaC_2 @ 30 g kg^{-1} soil	41.7	33.7	31.5	29.6	27.6	27.1	25.6	29.9	1.3
T_8: Control (Urea alone)	66.8	64.1	63.2	58.4	49.3	45.8	38.1	55.1	2.5
Mean	45.7	42.8	40.4	37.6	35.3	33.8	29.7		
CD T (0.05)	2.2	2.2	1.2	2.0	1.5	1.4	1.2		
CD T × I (0.05)	1.6								

**Where, PR = Pomegranate rind, MF = Melia fruit, NC = Neem cake*

Table: 5
Effect of nitrification inhibitors on the total soil N (mg kg^{-1} soil)

Treatment	Incubation days							Mean	CD I (0.05)
	0	7	14	21	28	35	42		
T_1: PR @ 20 g kg^{-1} soil	150.1	106.7	101.1	98.0	77.1	72.3	56.4	94.5	3.9
T_2: PR @ 40 g kg^{-1} soil	145.9	109.5	103.1	101.9	77.7	71.6	58.1	95.4	3.2
T_3: MF @ 20 g kg^{-1} soil	141.5	111.7	104.6	108.8	104.9	87.2	81.8	105.8	2.4
T_4: MF @ 40 g kg^{-1} soil	145.8	122.6	117.8	118.9	113.1	100.3	76.1	113.5	3.5
T_5: NC @ 20 g kg^{-1} soil	141.7	115.9	104.4	110.9	124.5	127.7	115.2	120.0	5.1
T_6: NC @ 40 g kg^{-1} soil	144.9	136.9	126.5	132.8	143.7	143.9	136.8	137.9	4.9
T_7: CaC_2 @ 30 g kg^{-1} soil	147.0	151.1	144.1	147.1	161.7	166.1	151.9	152.7	6.7
T_8: Control (Urea alone)	170.9	123.4	114.5	117.6	80.1	74.8	60.5	105.9	3.3
Mean	148.5	122.2	114.5	117.0	110.3	105.5	92.1		
CD T (0.05)	5.2	4.5	3.8	3.9	4.3	4.4	3.4		
CD I × T (0.05)	3.9								

**Where, PR = Pomegranate rind, MF = Melia fruit, NC = Neem cake*

was recorded under T_8 treatment throughout the incubation period as compared to rest of the treatments. NO_3^--N varied among the plant derivatives treatments. Maximum concentration of NO_3^--N (42.3 mg N kg^{-1}) was recorded in T_3 treatment followed by 40.8 mg N kg^{-1} in T_4 treatment, while the minimum NO_3^--N content was observed in T_6 (29.1 mg N kg^{-1}) which was found to be statistically at par with T_7 treatment. Treatment of T_3 increased the soil nitrate level by 45.1% over T_6 treatment. Maximum concentration of NO_3^--N in soil (45.7 mg N kg^{-1}) was observed at day 0 of incubation, while the minimum (29.7 mg N kg^{-1}) was recorded at 42 days of incubation and the decrease was 34.6. The extent and rate of NO_3^--N accumulation in NIs treated soils was much lower compared to N treated soil (without NI's). Interaction between incubation and treatment (I×T) revealed that all the treatments had significant effect on the soil NO_3^--N content. Highest nitrate accumulation in T_8 (55.1 mg kg^{-1}) could be due to no inhibitor application.

Total soil nitrogen (TSN)

At day 0, maximum TSN (170.9 mg kg^{-1} soil) was recorded in T_8 treatment and minimum (141.5 mg kg^{-1} soil) was observed in T_3 treatment which was found to be at par with T_2, T_4, T_5 and T_6 treatments at 0 day of incubation (Table 5). The contents of total N under T_8 were 20.79% higher over T_3 treatment. Maximum TSN was observed under T_7 treatment (152.7 mg kg^{-1} soil) and lowest (95.4 mg kg^{-1} soil) was in T_2 treatment.

Nitrification inhibition (%)

The nitrification inhibition varied amongst different treatments and after 42 days of incubation, maximum inhibition (36.6%) was observed in T_2 (pomegranate rind powder @ 40 g kg^{-1} soil) followed by 36.2% in T_6 (Neem cake @ 40 g kg^{-1} soil) (Table 6). Minimum inhibition of 7.48% was, however, obtained in T_3 (melia fruit powder @ 20 g kg^{-1} soil).

Nitrified Nitrogen

Nitrified nitrogen was calculated on nitrate basis *i.e.* (Nitrate concentration / Total nitrogen)*100. The results of the incubation experiment revealed that the extent of nitrified N was much higher in the T_8 (without plant derivative) treatment (54.5%) as compared to plant derivatives applied treatments (Table 7). Minimum value of nitrified nitrogen was documented in T_7 (20.4%) treatment. The treatment of pomegranate rind @ 20 g kg^{-1} (T_1) and melia fruit @ 20 g kg^{-1} soil (T_3) also recorded high nitrified N. Overall T_8 treatment had higher nitrified N, whereas in CaC_2 had minimum inhibitory effects on nitrified N as compared to other throughout the incubation period. Maximum variations in nitrified N were observed between 14 and 20 days in terms of increasing and decreasing nitrified N rates.

Higher concentrations of NH_4^+-N and lower concentrations of NO_3^--N in the treatments of plant derivatives could be due to the reason that plant derivatives retarded the nitrification in soil and showed higher inhibition percentage. The results are in agreement with the Mehdi *et al.* (2014) and Ruanpan and Mala (2016). Drastic reduction in NO_3^--N could be due to fixation, volatilization and immobilization of nitrogen (Toselli *et al.,* 2010). The results are in agreement with the findings of Kholdebarin and Oertli (1992).Abbasi and Adams (2000) reported that application of NIs increased the N recovery and inhibited both the accumulation of NO_3^--N and emission of N_2O. Incorporation of DCD and DMPP significantly delayed the transformation of NH_4^+-N and formation of NO_3^--N (Guo *et al.,* 2019; Joseph and Prasad, 1993; Barbara *et al.,* 2006; Cui *et al.,* 2011; Opoku *et al.,* 2014). Use of natural products as NIs could have a great potential for increasing fertilizer NUE. Similar findings were supported by Kiran and Patra (2003). Di *et al.* (2007) reported that NIs have a strong potential to mitigate N_2O emissions. The inhibitory effect of CaC_2 could

Table: 6
Effect of nitrification inhibitors on nitrification inhibition (%)

Treatment	Incubation days							Mean
	0	7	14	21	28	35	42	
T_1: PR @ 20 g kg^{-1} soil	35.5	34.1	37.4	42.4	27.6	26.6	30.0	33.4
T_2: PR @ 40 g kg^{-1} soil	37.7	37.2	42.0	44.0	37.4	38.7	36.6	39.1
T_3: MF @ 20 g kg^{-1} soil	35.4	28.2	29.8	26.1	18.4	13.5	7.5	22.7
T_4: MF @ 40 g kg^{-1} soil	34.1	31.9	34.7	31.4	22.1	17.4	12.7	26.3
T_5: NC @ 20 g kg^{-1} soil	37.1	38.2	42.9	40.7	34.4	30.2	19.6	34.7
T_6: NC @ 40 g kg^{-1} soil	36.1	48.9	52.3	50.9	43.1	42.6	36.2	44.3
T_7: CaC_2 @ 30 g kg^{-1} soil	37.7	47.5	50.1	49.3	43.9	40.9	32.7	43.2
T_8: Control (Urea alone)	-	-	-	-	-	-	-	
Mean	31.7	33.2	36.1	35.6	28.4	26.2	29.7	

**Where, PR = Pomegranate rind, MF = Melia fruit, NC = Neem cake*

Table: 7
Effect of nitrification inhibitors on the nitrified N (%)

Treatment	Incubation days							Mean
	0	7	14	21	28	35	42	
T_1: PR @ 20 g kg^{-1} soil	28.7	39.6	39.1	34.3	46.3	46.5	47.3	40.3
T_2: PR @ 40 g kg^{-1} soil	28.5	36.8	35.5	32.1	39.7	39.2	41.6	36.2
T_3: MF @ 20 g kg^{-1} soil	30.5	41.2	42.4	39.7	38.4	45.5	43.1	40.1
T_4: MF @ 40 g kg^{-1} soil	30.2	35.6	35.0	33.7	33.9	37.7	43.7	35.7
T_5: NC @ 20 g kg^{-1} soil	29.7	34.2	34.6	31.2	25.9	25.1	26.6	29.6
T_6: NC @ 40 g kg^{-1} soil	29.5	23.9	23.8	21.6	19.5	18.3	17.8	22.1
T_7: CaC_2 @ 30 g kg^{-1} soil	28.3	22.3	21.9	20.2	17.1	16.3	16.9	20.4
T_8: Control (Urea alone)	39.1	51.9	55.2	49.6	61.5	61.3	62.9	54.5
Mean	30.6	35.7	35.9	32.8	35.3	36.2	37.5	

**Where, PR = Pomegranate rind, MF = Melia fruit, NC = Neem cake* be attributed to its capacity to release acetylene which is regarded as a potent NI (Smith *et al.,* 1993). Keerthisinghe *et al.* (1993) reported that application of calcium carbide lowered the rate of nitrification and reduced the emission of N_2O. The mode of action of different NIs vary with soil properties (Barth *et al.,* 2001). Application of melia although gave higher values but did not give significant results as compared to other treatments. Similar observations were recorded by Toselli *et al.* (2010) and reported that application of fresh ground melia leaves were ineffective as they rather stimulated the release of mineral N in soil instead of lowering the nitrification rate. Application of NIs decreased the extent of NH_4^+ disappearance in soil (Kaleem *et al.,* 2011; Abbasi and Khizar, 2012; San *et al.,* 2011; Joseph and Prasad, 1993). Adoption of combined use of plant derivatives, NPK fertilizers and organic sources improved the N recovery in all the treatments over the control. The enhanced N recovery could be attributed to the efficacy of these inhibitors to decrease the extent of NH_4^+ disappearance.

4. CONCLUSIONS

Results of the incubation studies concluded that the application of neem cake powder @ 20 g kg^{-1} soil results in the maximum inhibition of nitrification. The application of pomegranate rind powder and melia fruit powder also exhibit NI tendencies and can be effectively used after proper processing and experimenting at different concentrations. It is further concluded that the different nitrification inhibitors directly affected the nitrogen transformations in the soil which is reflected in higher soil organic carbon, macro (N, P and K) and micronutrients (Zn, Cu, Fe, Mn). Highest NH_4^+-N concentration (126.30 mg N kg^{-1}) under this treatment corresponds with a lower (29.95 mg kg^{-1}), NO_3-N which reflects the superiority of nitrification inhibitors to reduce the N losses.

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