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Nitrogen dynamics in soil, nutrient uptake and nitrogen use efficiency of maize under different nitrification inhibitors and varying nitrogen doses

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Abstract
Rapid nitrification is one of the key factors of inefficient nitrogen use in maize and use of neem oil-coated urea holds immense promise to use fertilizer nitrogen efficiently. Therefore, a field experiment was conducted at the Research Farm of Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi to get insights on effect of the different doses of nitrification inhibitors and varying levels of nitrogen on the NH_4^+ and NO_3^--nitrogen content in soil, nutrients uptake and nitrogen use efficiency of maize. The treatment consisted of three nitrification inhibitors (Dicynadiamide, neem oil and meliacin) each with two different concentrations (350 and 700 ppm of neem oil and meliacin and 5% and 10% of Dicynadiamide) and two levels of nitrogen (135 and 180 kg N/ha). Result showed that different parameters *viz.* grain yield, stover yield and harvest index were significantly influenced by levels of nitrogen and nitrification inhibitors. The meliacin coated urea (MCU) at 350 ppm @ N_{180} recorded maximum grain yield and stover yield which was comparable with MCU_{700}@N_{180}. Uptake of nitrogen, phosphorus and potassium by grain, straw and total uptake was significantly higher with MCU_{350}@N_{180}. Highest agronomic efficiency and physiological efficiency were recorded with the application of MCU_{350}@N_{180} and highest nitrogen harvest index (NHI) was obtained with MCU_{700}@N_{135}. Maximum concentration of NH_4^+-N in soil was recorded with application of MCU_{700}@N_{180} and it was significantly higher over all other levels of nitrogen and nitrification inhibitors. The higher amount of soil NH_4^+-N for longer period with MCU_{350}@N_{180} indicated that this treatment had the most durable effect on nitrification inhibition. It was concluded that the coating of urea with meliacin @ 350 ppm is effective in enhancing the nutrient uptake, nutrient use efficiency and yield of *kharif* maize.

Keywords: Dicynadiamide, meliacin, neem oil, nitrogen harvest index, nitrogen use efficiency

Introduction
Maize (*Zea mays* L.) assumes worldwide significance due to its versatile nature having wider adaptability under varied agro-climatic conditions. Maize is one of the most important crops of India after rice and wheat that has been cultivated over 9.6 m ha area with average productivity of 3.0 tonnes/ha compared to the world average of 5.8 tonnes/ha.

Maize is an exhaustive feeder of nutrients and balanced and adequate application of fertilizer nutrients is needed not only for improving the current yield level but also for sustaining the profitability of the farm. Among the different nutrients, the role of nitrogen has been very important in increasing maize production as it plays an important role in plant metabolism such as protein synthesis thus, strongly influencing both protein content and yield. Fertilizer nitrogen has contributed an estimated 40% to the increase in per capita food production over the past 50 years (Mosier *et al.*, 2004) [8]. But the excessive use of nitrogen fertilizers has raised various global concerns mainly due to the low efficiency of nitrogen fertilizers, resulting in negative impact on atmosphere, ground water pollution and hazardous effects on other components of ecosystem. On an average recovery of fertilizer nitrogen in India ranges from 20-50% (Prasad, 1998). The unaccounted 67% fertilizer nitrogen escapes through different routes and may contribute to contamination of water bodies and the atmosphere (Shoji *et al.*, 2001) [10]. There are a variety of new management practices and technologies that can promote nitrogen use efficiency and alleviate environmental pollution. One of the mitigation technologies that has proved to be highly effective in reducing fertilizer nitrogen losses and increasing nitrogen use efficiency and yield in a few cropping systems is the application of nitrification inhibitors (Majumdar *et al.*, 2002; Zaman *et al.*, 2009; Cui *et al.*, 2011;

Moir *et al*., 2012) [6, 12, 3, 7]. The positively charged ammonium nitrogen cations are retained by negatively charged soil colloids and are less subject to leaching and denitrification losses. One of the most promising approaches of maintaining nitrogen in the soil as ammonium is to add a nitrification inhibitor with the fertilizers.

Globally, many nitrification inhibitors have been useful in increasing the nitrogen use efficiency and crop yields. However, most of the nitrification inhibitors such as nitrapyrin, A.M. (2-amino-4-chloro-6- methylpyridine), dicyandiamide and ammonium thiosulphate remain still unpopular with most Asian farmers due to their higher costs and limited availability. Hence, a need is being increasingly felt to identify and use some new indigenous nitrification inhibitors for increased nitrogen use efficiency in maize. In this direction, use of neem-cake or neem oil-coated urea holds immense promise. Afterwards, several studies at the Indian Agricultural Research Institute, New Delhi, have indicated an increase in nitrogen use efficiency and yields of rice by using neem cake or neem oil emulsion-coated urea (Kumar *et al*., 2012) [4]. However, limited information is available on the use of nitrification inhibitors in maize and there is a need to identify and evaluate some new indigenous nitrification inhibitor for increase nitrogen use efficiency in maize. Therefore, present study was conducted to assess the changes in nitrogen content in soil and different nitrogen use efficiencies of maize under different nitrification inhibitors and varying levels of nitrogen.

Materials and Methods

A field experiment was conducted at the research farm of Division of Agronomy, Indian Agricultural Research Institute, New Delhi, situated at 28.4° N latitude and 77.18° E longitude with an altitude of 228 meters above the mean sea level. New Delhi has semi-arid and sub-tropical climate characterized by hot dry summer and cold winter. The daily maximum and minimum temperature ranged from 26 to 44.5°C and 7.7 to 29.8°C respectively and the total rainfall of 494 mm was received during the crop period. The soil of experimental field was sandy loam in texture, low in organic carbon and available N and medium in available P and K with pH 7.7. The experimental farm used in the present study was under a maize-wheat cropping system for the last three years having even topography and a good drainage facility. The field experiment consisted of fourteen treatments with three nitrification inhibitors (Dicyandiamide, neem oil and meliacin) each with two different concentrations (Prilled urea coated with DCD @5% and @10% weight by weight and 350 and 700 ppm for neem oil and meliacin, respectively) and two levels of nitrogen (135 and 180 kg/ha) was laid out in randomized block design having three replications. 'PMH-3' is a late maturing hybrid released in 2008 at Punjab Agricultural University (PAU), Ludhiana, was planted on ridges made at 75 cm and intra row spacing of 20 cm. The per hectare recommended dose of P_2O_5 (60 kg) and K_2O (50 kg) were applied to the crop in the form of single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O) respectively, as basal. One third of nitrogen as per treatments was applied as basal and remaining amount of nitrogen was applied in two equal splits at knee height and pre-tasseling stages as per the treatments. The uptake of nutrient in grain and stover was computed by multiplying nutrient content to yield and dividing by 100. Different nitrogen use efficiencies were computed by formula suggested by Kumar *et al*, (2011) [5].

Results and Discussion

Nutrient uptake by grain and stover of maize

Significant variations in N, P and K uptakes were found due to different nitrification inhibitors and level of nitrogen (Table 1). Application of meliacin coated urea at 350 ppm concentration and 180 kg N/ha application rate resulted in the highest values of N, P and K uptakes by grain, stover and total plant. These values were significantly superior to all the remaining treatments except N uptake in grain, stover and total plant; and P uptake in grain and total plant at neem oil coated urea application with 700 ppm concentration at 180 kg N/ha, where both of these treatments remained statistically similar. The nutrient uptake is the function of their concentration and dry matter production therefore, higher values of dry matter at higher concentration of nutrient with $MCU_{350}@N_{180}$ treatment reulted in higher uptake with this treatment. Bender *et al*. (2013) [2] also reported similar results in their research experiment.

Table 1: Grain yield and macronutrient uptake (kg/ha) in grain and straw of maize as influenced by different nitrification inhibitors at varying concentration and N levels.

	N uptake		P uptake		K uptake		Grain yield (t/ha)
	Grain	Stover	Grain	Stover	Grain	Stover	
Control	39.01	12.56	7.99	4.12	10.27	47.64	3.80
Urea $@N_{180}$	71.60	18.19	14.40	7.18	18.79	59.59	6.26
$NOCU_{350}@N_{135}$	63.26	16.02	12.50	6.27	16.66	56.45	5.68
$NOCU_{350}@N_{180}$	79.19	20.00	15.15	6.98	19.83	60.45	6.68
$NOCU_{700}@N_{135}$	70.88	15.24	13.72	6.25	18.03	54.66	6.15
$NOCU_{700}@N_{180}$	85.91	20.25	16.74	7.41	20.92	61.73	6.98
$MCU_{350}@N_{135}$	73.02	17.03	13.73	6.56	18.11	59.56	6.24
$MCU_{350}@N_{180}$	89.82	22.48	17.39	8.72	22.46	66.58	7.25
$MCU_{700}@N_{135}$	70.17	14.69	13.42	5.59	17.69	50.70	6.10
$MCU_{700}@N_{180}$	88.23	23.33	16.41	7.95	22.12	66.28	7.14
$DCD_{5\%}@N_{135}$	71.56	15.65	12.96	5.62	18.51	57.33	6.17
$DCD_{5\%}@N_{180}$	80.38	19.36	15.85	8.00	20.47	61.07	6.61
$DCD_{10\%}@N_{135}$	62.10	15.69	11.29	6.63	15.11	54.12	5.46
$DCD_{10\%}@N_{180}$	76.42	19.06	14.60	7.97	19.67	60.34	6.35
SEm +	3.5	0.8	0.4	0.5	0.4	0.7	0.2
LSD (P=0.05)	10.1	2.4	1.1	1.3	1.2	2.1	0.57

Effect of different nitrification inhibitors and nitrogen levels on yield

The different doses of nitrification inhibitors and levels of nitrogen demonstrated significant effect on grain yield, stover yield and harvest index (Table 1). Highest grain yield (7.25 t/ha) and stover yield (7.93 t/ha) were obtained with $MCU_{350}@N_{180}$ followed by $MCU_{700}@N_{180}$. These increases in grain yield was 15.81% over 180 kg N/ha through urea without any nitrification inhibitor. The remarkable improvement in growth and yield attributes with $MCU_{700}@N_{180}$ may have caused a significant increase in grain yield, which was significantly higher than urea without any nitrification inhibitor. There was an improvement in grain yield with the application of $MCU_{350}@N_{180}$ over $MCU_{700}@N_{180}$ probably due to fact that increased coating thickness of meliaciin might have reduced NO_3^- -nitrogen availability. Higher dry matter accumulation with the application of $MCU_{350}@N_{180}$ was the reason for higher yield. Similar results were also reported by Kumar *et al*, 2011 [5].

Table 2: The NH_4^+ and NO_3^- -nitrogen content in soil (mg/kg) at different growth stages of maize (0-30 cm) and nutient use eificency as influenced by different nitrification inhibitors at varying coinentration and N levels.

Treatment	Knee height		Tasseling		Grain filling		Harvesting		Agronomic efficiency (kg grain increased/kg of N applied)	Apparent nitrogen recovery (%)	Physiological efficiency (kg grain increased per kg increase of N uptake)	Nitrogen harvest index (%)
	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-	NH_4^+	NO_3^-				
Control	13.43	9.30	12.20	9.52	7.28	12.58	6.52	10.30	-	-	-	75.7
Urea @N_{180}	17.22	16.26	15.99	16.38	11.14	19.42	8.38	14.43	14.1	24.5	85.4	79.7
$NOCU_{350}@N_{135}$	23.28	11.43	22.05	11.25	12.79	15.26	9.20	13.43	15.0	22.0	87.9	79.7
$NOCU_{350}@N_{180}$	23.60	12.43	22.37	12.47	11.20	17.09	7.36	14.29	14.8	26.5	89.1	79.7
$NOCU_{700}@N_{135}$	25.15	10.20	23.92	10.21	13.30	14.24	8.34	12.60	17.3	21.2	84.9	82.2
$NOCU_{700}@N_{180}$	25.64	10.76	24.41	11.17	14.09	16.29	8.69	13.40	16.6	32.3	78.0	80.9
$MCU_{350}@N_{135}$	23.25	13.42	22.02	13.79	13.67	15.66	10.52	13.52	17.8	22.7	91.8	81.1
$MCU_{350}@N_{180}$	25.34	12.35	24.40	12.56	12.70	18.14	9.68	11.13	19.5	30.7	93.6	79.9
$MCU_{700}@N_{135}$	25.37	11.54	24.14	11.71	13.14	15.00	9.48	12.52	16.9	19.5	76.1	82.7
$MCU_{700}@N_{180}$	26.39	10.76	25.16	10.08	14.30	17.16	10.71	13.21	18.0	32.7	87.2	79.1
$DCD_{5\%}@N_{135}$	22.70	9.32	21.47	13.11	12.29	15.54	8.61	13.39	18.3	22.1	85.2	82.1
$DCD_{5\%}@N_{180}$	22.81	11.41	21.58	11.53	10.93	16.41	7.43	14.32	17.2	28.5	75.9	80.6
$DCD_{10\%}@N_{135}$	25.08	8.73	23.85	12.44	12.51	15.20	8.63	12.37	14.7	16.5	88.3	79.8
$DCD_{10\%}@N_{180}$	25.63	10.51	23.34	11.27	13.51	14.61	10.68	12.71	15.1	23.8	80.2	79.8
SEm +	0.156	0.156	0.156	0.259	0.325	1.303	0.221	0.194	0.8	0.7	1.7	1.1
LSD (P=0.05)	0.453	0.453	0.453	0.752	0.945	3.787	0.642	0.565	2.4	1.9	4.8	3.2

N Nitrogen use efficiency

The Nitrogen use efficiencies *viz*. agronomic efficiency, apparent nitrogen recovery and physiological efficiency of applied nitrogen and nitrogen harvest index showed significant differential behavior due to varying nitrification inhibitors, their concentration and different nitrogen levels (Table 3). $MCU_{350}@N_{180}$ application presented the highest values of agronomic efficiency, apparent nitrogen recovery and physiological efficiency while, nitrogen harvest index remained highest with the application of $MCU_{700}@N_{135}$. Higher yield and nutrient uptake with these treatments caused the higher values of agronomic efficiency, apparent nitrogen recovery, physiological efficiency and nitrogen harvest index with the use of meliacin coated urea at respective concentration and nitrogen level. Yoshida *et al*, (1981) [11] also reported similar type of findings in their experiment.

Here, Agronomic efficiency, kg yield increase/kg N applied; Apparent nitrogen recovery, kg uptake increase/kg N applied; Physiological efficiency, kg yield increase/kg increase in N uptake; Nitrogen harvest index, kg uptake in grain/kg uptake in grain + stover.

Nitrogen dynamics (NH_4^+ and NO_3^- -Nitrogen content) in soil

NH_4^+ and NO_3^- -nitrogen content in the upper layer of soil (0-30 cm) were influenced significantly at all the growth stages of maize (Table 4). Soil analysis carried out after fertilization showed an increase of ammonium and a reduction of nitrate content in the treatments with nitrification inhibitors. With advancement of crop, effects of nitrification inhibitors were diminished and nitrate content were increased. Maximum numerical value of NH_4^+-N in soil was found with application of $MCU_{700}@N_{180}$ at knee height stage (26.39 mg/kg), tasseling stage (25.16 mg/kg) and at harvesting (10.71 mg/kg) and minimum with control followed by Urea@N_{180} which shows durability of meliacin in nitrification inhibition. In contrast to this, maximum NO_3^- -N in soil was found in plots which received 180 kg N through urea and minimum under $DCD_{10}@N_{135}$ at all the growth stages of maize. Here, higher concentration (700 ppm) of MCU reported higher amount of NH_4^+-N in soil than 350 ppm MCU due to increased nitrification inhibition. The findings of Begum *et al*, (2007) [1] were in close conformity of the results.

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