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CONTROL OF UREA HYDROLYSIS AND NITRIFICATION IN SOIL BY CHEMICALS – PROSPECTS AND PROBLEMS

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KEY WORDS

Fertilizer N efficiency Inhibition of nitrification Plant growth Urease inhibitors

SUMMARY

A review is made of the recent work to assess the prospects of regulating urea hydrolysis and nitrification processes in soils by employing chemicals that can retard urea hydrolysis and nitrification. The possible benefits from control of nitrogen transformations in terms of conserving and enhancing fertilizer nitrogen efficiency for crop production and the problems associated with their use with regard to N metabolism of plants have also been discussed with examples. Prospects of using cheap and effective indigenous materials and chemicals for control of urea hydrolysis and nitrification under specific soil situations appear eminent in improving the fertilizer nitrogen efficiency. Urease inhibitors may be helpful in reducing problems associated with ammonia volatilization if this is not offset by leaching of urea. On the other hand retardation of nitrification appears useful in reducing losses that accompany nitrification due to leaching and denitrification, and with the plants that metabolize equally well with relatively higher amounts of NH_4–N may be more effective in improving the utilization of fertilizer N under these situations.

INTRODUCTION

Modern agricultural technology based on continuous research has contributed handsomely to the success of the present agricultural strategy. One of the important tools of the technology are fertilizers, particularly nitrogenous fertilizers. The role of fertilizer nitrogen has been vital in increasing food production. But due to the present energy crisis, fertilizers have become very expensive and warrant their judicious use to get maximum output from each input of the nutrients. Efficiency of fertilizer nitrogen particularly under tropical agriculture rarely exceeds 50 per cent and is usually only 30–40 percent[2,31,75,91,97].

Improved fertilizer nitrogen efficiency will not only help in more food pro-

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duction but will also minimize eutrophication of surface and ground waters, which are of prime concern not only for the developing countries but also for the developed nations. There has been increased awareness about the contribution of fertilizer nitrogen for polluting the surface and ground waters with nitrate as a result of application of high rates of nitrogen for achieving increased production with improved genetic materials. The greatest challenge to the present generation thus is to provide food for the evergrowing world population and at the same time to conserve our environment from pollution.

Among the mechanisms that contribute most to the nitrogen lossers' are: denitrification, leaching and ammonia volatilization[26,74,75,91,97]. Except for ammonia volatilization losses, all other losses are associated with the nitrification of ammonium or ammonium forming fertilizers. The term nitrification here is used to signify the biological oxidation of ammonium to nitrate via nitrite mediated by *Nitrosomonas* and *Nitrobacter* species of nitrifying bacteria respectively.

Urea is the most important nitrogen fertilizer and its use is steadily increasing in the world agriculture and this trend is likely to continue[11,21,30,42]. Also urea is a unique chemical nitrogen fertilizer in that its transformation to ammonium and use efficiency is controlled by the urease activity.

$$NH_2CONH_2 + 2H_2O \xrightarrow{\text{urease}} (NH_4)_2CO_3$$

In most arable soils urea is rapidly converted to ammonium carbonate by soil urease, which results into several problems encountered in the use of urea as a fertilizer including rise in the pH of soil, ammonia and nitrite toxicity to germinating seeds and growing seedlings and gaseous loss as ammonia[11,20,23,24,25,30,35,106]. There is an obvious need for finding solutions to these problems caused by the rapid hydrolysis of urea by soil urease for promoting the efficient use of this fertilizer. One approach for finding solution to these problems lies in controlling urea hydrolysis in soils by using chemicals called 'urease inhibitors' that can retard urea hydrolysis. It is envisaged that retardation of urea hydrolysis in soils will result in reduction of loss of ammonia through volatilization, and alleviation of nitrite and ammonia toxicity to young seedling plants. Nitrification inhibitors also help check accumulation of nitrite in soils[15].

The objective of this paper is to review the prospects of controlling urea hydrolysis and nitrification in soils with the help of chemical agents and the possible benefits accuing in terms of ultimate better utilization of urea and ammonium fertilizers for crop production.

CONTROL OF UREA HYDROLYSIS IN SOIL

It must be pointed out first that the testing of several compounds as urease inhibitors has been facilitated with the development of a simple and rapid method for this purpose by Douglas and Bremner[28], which was earlier hindered due to lack of suitable technique. The earlier methods used for evaluation of compounds as urease inhibitors were solely based on measuring ammonia evolved from soils treated with urea and the compounds proposed as urease inhibitors. Apparently the methods were cumbersome and time consuming for testing of a large number of compounds[28], which is prerequisite for finding ideal urease inhibitors that are: cheap and effective at reasonable concentrations and of course non-phytotoxic to plants and seeds. The technique developed by Douglas and Bremner[28] for evaluating compounds for inhibiting soil urease involves measurement of the effect of the test compounds on the amount of urea hydrolysed by incubation of soils with urea (1000 ppm urea N) and toluene at 37°C for 5 h. The amounts of unhydrolysed urea remaining in the soil is determined colorimetrically by extraction with 2 *M* KCl having a urease inhibitor, phenylmercuric acetate[27]. Though toluence is commonly used to inhibit microbial growth in assay of soil urease its use causes more problems than it solves and the use of this reagent may not be necessary especially for short incubation times[11].

A number of studies for evaluation of compounds as urease inhibitors have been conducted employing jack bean urease enzyme. In one of the earlier studies, Quastel[79] reported that dihydric phenols and quinones inhibited urease. It was concluded that the dihydric phenols were effective in inhibiting urease after their autooxidation to quinone form. These compounds inhibited urease by reacting with the sulfhydryl groups, essential for the enzyme activity. However, sometimes there is little consistency in the results on inhibition of synthetic urease and soil urease because potent inhibitors of synthetic urease are often rendered inactive due to physico-chemical and biological reactions in the soil system. Waid[112] concluded that acetohydroxamic acid and other hydroxamates are potent specific inhibitors of urease *in vitro* are relatively ineffective in soils when compared to other less specific inhibitors of urease and there is need for research to explain this difference. Possible explanations are unfavourable pH; adsorption by soil materials; inactivation of inhibitors by several mechanisms including formation of ferric chelates, microbial decomposition of hydroxamates; failure of hydroxamates to permeate cells and inhibit intracellular urease and proliferation and formation of urease by soil microorganisms. Studies have also indicated that the native urease in soils is remarkably stable because of protection against microbial degradation and inactivation by the soil constituents[117]. Equipped with such knowledge it may be possible to contribute to a general strategy to control transformations brought about by organisms in soil to the advantage of man and without detriment to the environment.

The review of literature (Table 1) brings out that there are compounds that can inhibit soil urease and thereby retard urea hydrolysis in soils. These include a vast array of classes of compounds, the more important being: mono and polyhydric phenols, quinones and benzoquinones[9,12,70,71]; hydroxamic acid derivatives including acetohydroxamates[77,78,112]; insecticides especially organophosphorus and carbamate insecticides[60,89,90]; heterocyclic mercaptans[40]; substituted ureas and phenyl ureas and metallic compounds[9,47,98,104]. A few examples from different classes of compounds proposed for inhibiting soil urease activity will be described briefly.

In a series of studies, Bremner and colleagues at Iowa State University evaluated more than 130 compounds for retardation of urea hydrolysis and concluded that p-benzoquinone (PBO) and hydroquinone (HQ) are the most promising of the compounds tested for reduction of problems encountered with use of urea as a fertilizer[9,13,71]. The effects of p-benzoquinone (PBQ) and hydroquinone (HQ) on urea hydrolysis in 25 soils studied increased with the

Table 1. Compounds proposed as urease inhibitors

Class of compounds/materials		References
1	Mono and polyhydric phenols, quinones, anthroquinones and benzoquinones	9, 12, 68, 71, 79
2	Antimetabolite compounds	70
3	Hydroxamates	9, 34, 54, 77, 78, 112
4	Substituted ureas and phenylureas	51, 98
5	Pesticides	18, 19, 60, 89, 90
6	Heterocyclic mercaptans	40
7	Metallic compounds	9, 48, 104, 107
8	Miscellaneous compounds and materials (chelating compounds, biuret, solvents, nonedible oil seed cakes and their constituents, organic residues and manures *etc.*)	5, 9, 10, 32, 60, 86

amount of PBQ or HQ added. The percentage inhibition of urea hydrolysis after 24 h of incubation with 50 ppm of the compounds ranged from 0 to 100 %[71]. The activity of compounds to retard urea hydrolysis decreased with time, and with increase in temperature and tended to increase with the decrease in soil organic matter content. Addition of substituted p-benzoquinones (at the rate of 2.3 parts/100 parts of urea) decreased the gaseous loss of urea N as ammonia from a urea-treated sandy soil incubated for 14 days at 20°C from 62.8 % to 0.1 % (ref. 12, Table 2).

Lethbridge and Burns[60] reported that the three organophosphorus insecticides examined: accothion, malathion and thimet inhibited urea hydrolysis by jack bean urease urease and soil urease. Inhibition of urea hydrolysis after 60 days of application of 1000 ppm of the insecticides to a sandy clay loam was 40 % in case of accothion and exceeded 50 % in the case of malathion and thimet. The effects on inhibition of urea hydrolysis though significant were less pronounced at lower concentrations of the insecticides (50 and 200 ppm). The hydrolysis of urea by jack bean urease was almost prevented by 1000 ppm concentration of these insecticides. Sahrawat[89,90] evaluated the effects of two organophosphorus insecticides, malathion and parathion, and carbofuran, a carbamate insecticide on urea hydrolysis in soil and reported that while carbofuran had no significant effect on urea hydrolysis, both malathion and parathion retarded urea hydrolysis when added at 10 and 50 ppm of soil. 50 ppm concentration of malathion and parathion retarded urea hydrolysis upto 3 weeks though urea hydrolysis without the insecticide treatments was complete by one week (Table 3).

The results of studies by Lethbridge and Burns[60] and Sahrawat[90] suggest that the proper timing of the organophosphorus insecticides with urea could be important in retardation of urea hydrolysis by soil urease, in addition to achiev-

Table 2. Effects of substituted p-benzoquinones on ammonia volatilization loss from a sandy loam fertilized with urea during 14 days of incubation*

Compound	Recovery of urea-N as ammonia (%)
None	62.8
2,3-Dimethyl-p-benzoquinone	0.1
2,5-Dimethyl-p-benzoquinone	0.1
2,6-Dimethyl-p-benzoquinone	0.1

* 10 g soil sample incubated at 20°C and 50 % WHC moisture after treatment with 1000 ppm of urea N and 50 ppm of benzoquinone mentioned.

Source: Bundy and Bremner[12].

ing control of insect pests by this class of insecticides. The retardation of urea hydrolysis could be important in alleviation of problems of ammonia volatilization and ammonia toxicity in soils with high pH and poor buffering capacity.

Gould *et al.*[40] examined the effects of several heterocyclic organic sulfur compounds on soil urease activity and reported that these compounds retarded urea hydrolysis and the percentage inhibition ranged from 0 to 46 % after 24 h of incubation when applied at 100 ppm concentration of soil. The mercaptans, however, were significantly less effective urease inhibitors than benzoquinone (Table 4). Balasubramanian *et al.*[5] studied the effect of organic manuring with farm yard manure, maize stalk, and *Pongamia glabra* seed cake (at 1 % organic carbon level) on soil urease and reported that appreciable increase in the urease activity was observed due to application of both maize stalk and *Pongamia* cake, the latter treatment being more effective in maintaining the soil urease activity at a higher level during a 60 days study in a sandy loam soil.

Table 3. Effects of malathion and parathion on urea hydrolysis in a sandy loam (pH 7.7 organic C 0.58 %)*

Treatment	% inhibition of urea hydrolysis after weeks				
	0.5	1	2	3	4
Malathion	44	29	20	11	0
Parathion	61	35	30	21	0

* The soil sample treated with 100 ppm of urea N and 50 ppm of insecticide incubated under aerobic condition (60 % WHC moisture).

Source: Sahrawat[90].

Table 4. Effects of heterocyclic sulfur compounds and benzoquinone on soil urease activity in a silt loam treated with 400 ppm of urea-N and 100 ppm of inhibitor*

Compound tested	% inhibition
1,2,4-thiadiazole-2,5-dithol	46
5-amino-1,4-thiadiazole-2-thiol	27
2-mercapto-1-methylimidazole	13
222'-di(5-amino-1,3,4-thiadiazole) disulfide	11
5,5'-di(3-phenyl-1,3,4-thiadiazole-2-thione) disulfide	6
5-mercapto-3-phenyl-1,3,4-thiadiazole-2-thione potassium salt	0
1,4-benzoquinone	88

* Soil samples incubated at 32 % soil moisture (field capacity) and 25°C for 24 h.

Source: Gould, Cook and Bulat[40].

Fernando and Roberts[32] reported that the polyphenols present in the black tea cake are effective in retarding urea hydrolysis both *in vitro* and by soil urease thereby reducing losses due to ammonia volatilization. These byproducts if available cheaply will be an economic proposition for the use in retardation of urea hydrolysis in soils especially by reducing ammonia volatilization loss.

May and Douglas[65] examined the effects of some effective urease inhibitors namely, catechol, p-benzoquinone, 2,5-dimethyl-p-benzoquinone and phenylmercuric acetate on the growth and yield of wheat in a pot-culture study with a sandy soil (pH 4.6; organic C, 2.41 %) fertilized with urea. All the compounds tested were found to inhibit the germination of wheat seeds, but only 2,5-dimethyl-p-benzoquinone inhibited germination at the minimum concentration required for retardation of soil urease activity. Catechol, p-benzoquinone, and 2,5-dimethyl-p-benzoquinone prevented damage to the germinating seeds with 53.6 ppm of urea N, but had no effect on yield or N uptake by the wheat crop. The results of this study and earlier work[64] suggest that the phytotoxicity of the compounds proposed as urease inhibitors should be considered before recommending their use for crop production. Mishra and Flaig[68] evaluated the ability of anthroquinone, quinones and phenolic compounds to inhibit mineralization of urea N in soils by measuring their effects on urease activity and nitrification. While anthraquinones did not affect the mineralization of urea N, 1,4-naphthoquinone, 2-methyl-1,4-naphthoquinone, 2-3-dichlorohydroquinone, 4,6-ditert butyl-0-benzoquinone, 4-tert butylpyrocatechol and 4,6-ditert butylpyrocatechol inhibited both urease activity and nitrification. Interestingly it was observed that the hydrolysis of 100 ppm of urea N was not prevented though the compounds partially retarded soil urease activity. Perhaps the fraction of soil urease remaining uninhibited was enough to hydrolyze 100 ppm of urea N.

CONTROL OF NITRIFICATION IN SOILS

It has been recognized that if nitrification could be retarded, the losses accompanying nitrification *viz* leaching and denitrification will be minimized under stituations, where these losses are high. Perhaps the greatest interest in the use of nitrification inhibitors has been boosted with the discovery and use of Dow Chemical Company's Nitrapyrin (N-serve)[2-chloro-6-(trichloromethyl) pyridine] as an effective blocker of nitrification in soil[37,38]. Encouraged with the success obtained in inhibiting nitrification by Nitrapyrin, numerous compounds have been proposed for regulating nitrification in soils. The list includes a vast array of compounds including organic and inorganic com-

Table 5. Compounds proposed as nitrification inhibitors

Class of compounds/materials	References
A. *Non-edible oil seed cakes and their isolates, plant products*	
1 *Pongamia glabra* seed and its isolates	93, 96, 100
2 *Azadirachta indica* seed and isolates	4, 50, 95, 101
3 Vegetable tannins, waste tea	6, 53
B. *Chemical compounds other than pesticides*	
1 Nitrapyrin (2-chloro-6-(trichloromethyl) pyridine)	13, 37, 38, 43, 48, 75, 88, 93, 102, 108
2 A.M. (2-amino-4-chloro-6-methyl pyrimidine)	13, 22, 75, 110, 115
3 Dicyandiamide	43, 59, 63, 72, 75, 82, 83, 84
4 'ST' sulfathiazole, sulphadrugs	(13), 69, 76
5 Sulfur compounds	8, 33, 67
6 Thiourea and substituted urease	7, 13, 58, 80, 88, 115
7 Chelating compounds	55, 57, 58, 88
8 Anilines	3, 7, 13, 105
9 Furano and furano flavonoid compounds	93, 94
10 Anthraquinones, Quinones, Catechol, phenols	14, 68
C. *Pesticides*	1, 17, 29, 36, 39, 49, 52, 66, 73, 75, 85, 89, 90, 111, 118
D. *Inorganic compounds* (Azides, chlorides, chlorates, metals *etc.*)	13, 41, 48, 56, 59, 62, 99, 116

pounds, pesticides, chelating agents and plant products (see Table 5). In general compounds possessing some sort of biological activity have been evaluated for their ability to retard nitrification process in soils[87]. The structure-activity relationship studies have been employed to identify the functional groups imparting nitrification inhibitory activity[87,93]. Sahrawat[87] has proposed a scheme for the development of cheap, specific and effective inhibitors of nitrification for systematic approach in this area of research.

A large body of literature that has accumulated on nitrification inhibitors has been reviewed from time to time[31,43,46,75,87] and some important references on the subject are summarised in Table 5. The objective of the present report is not to review and describe the voluminous data on the use of nitrification inhibitors but is to critically review the prospects of controlling nitrification in soils with a few examples of different situations where the use of these chemicals result in minimising nitrogen losses and increasing the N efficiency for crop production. Also the ineffectiveness of these chemicals under certain situations has been discussed with possible explanations.

Investigations carried out by Swezey and Turner[103] showed that formulation of urea, ammonium sulfate, aqueous and anhydrous ammonia with Nitrapyrin inhibited nitrification and increased the efficiency of fertilizers for irrigated cotton, maize and sugarbeet on soils ranging from sandy loam to clay. Rajale and Prasad[81] reported that nitrapyrin, A.M. fertilizer and IBDU gave significantly higher yield, N uptake and percent recovery of urea N by rice crop as compared to urea applied as a single application or split application (1/2 at transplanting and 1/2 at panicle situation). The grain yield of rice was increased from 5766 kg/ha (urea single application) to 6357 kg/ha by Nitrapyrin and to 6438 kg/ha by A.M. fertilizer. The recovery of applied N was only 28.6% with urea and was increased to 47.5% and 52.2% by Nitrapyrin and A.M. fertilizer respectively (Table 6).

On the other hand, Lewis and Stefanson[61] observed that Nitrapyrin did not affect the yield and N uptake of wheat in some Australian soils. This was perhaps due to the fact that wheat utilized nitrate nitrogen better than ammonium nitrogen as $NaNO_3$ gave higher yields over ammonium sulfate as source of nitrogen (Table 7). Nitrapyrin inhibited nitrification of ammonium and this affected the growth of wheat, which preferred nitrate over ammonium. The yield and N uptake of wheat observed the following order though all the treatments were not significantly different: Ammonium sulfate > Ammonium

Table 6. Effects of nitrification inhibitors on yield, N uptake and recovery of applied nitrogen by IR 8 rice.

Treatment	Grain yield (kg/ha)	Straw yield (kg/ha)	N uptake (kg/ha)	Apparent recovery of applied N (%)
Urea (single application)	5766	7570	113.5	28.6
Urea (2-split application)	6015	8018	117.5	34.0
Urea + Nitrapyrin	6357	8551	131.0	47.5
AM-fertilizer	6438	8656	134.2	52.2
IBDU	6412	8168	133.6	51.1
LSD (0.05)	161	423	1.0	4.1

Source: Rajale and Prasad[81].

Table 7. Effects of inhibiting nitrification by nitrapyrin on yield and N uptake of wheat

Treatment	Grain yield (kg/ha)	Straw yield (kg/ha)	N uptake (kg/ha)
Ammonium sulfate	1331	7530	45.6
Ammonium sulfate + Nitrapyrin	1327	7595	46.8
Sodium nitrate	1624	7935	54.6
LSD (0.05)	366	810	12.8

Source: Lewis and Stefanson[61].

Table 8. Effects of inhibiting nitrification of fall-applied anhydrous ammonia by nitrapyrin on grain yield and quality of corn*

Treatment	Grain yield (q/ha)		Grain protein (%)	
	Expt. 1	Expt. 2	Expt. 1	Expt. 2
NH_3	20.2b	97.1a	8.0b	8.4a
NH_3 + Nitrapyrin	62.0c	98.4a	7.6b	9.0b

* Values not followed by the same letter in a column differ significantly at the 5% level of probability.

Source: Warren *et al.*[113].

sulfate + Nitrapyrin > sodium nitrate. In a study on examining the effect of inhibiting nitrification of fall applied anhydrous ammonia by Nitrapyrin, Warren *et al.*[113] reported that in one experiment, Nitrapyrin significantly increased the grain yield and protein of corn but the effect was not significant in another experiment (Table 8). Similarly Hendrickson *et al.*[45] did not observe any advantage on yield and N uptake of corn by retarding nitrification of fall and spring applied anhydrous ammonia with Nitrapyrin.

In a greenhouse pot study with rice, Sahrawat and Mukerjee[92,93] reported that treatment of ammonium sulfate or urea with Karanjin, a furanoflavonoid from *Pongamia glabra* seeds, and Nitrapyrin significantly increased the yield, N uptake and grain protein of rice. The results summarized (Table 9) from these studies indicate that the grain yield of rice was increased by 31–54%, total N uptake by 36–68% and grain protein by 2–14% by inhibiting nitrification with Karanjin[87].

These examples point out the lack of consistency in the performance of nitrification inhibitors in improving yield and fertilizer efficiency. But it should be emphasized that the use of nitrification inhibitors may not be profitable for crops which do not metabolize well when fed with higher amounts of ammonium nitrogen[45,61]. Also under situations where nitrification does not result

Table 9. Effects of karanjin on yield and composition of rice grown in greenhouse pot experiment

Crop particular	% increase by inhibiting nitrification
Grain yield	31–54
Grain + straw yield	21–25
N uptake	36–68
Grain protein	2–14

Source: Sahrawat[87].

in loss of nitrogen the efficiency of nitrogen will not improve by retardation of nitrification. It has also been recognized that greater nitrification in soils occur at warmer temperatures and at higher soil pH. Both of these factors, which would increase the activity of the nitrifying organisms may also increase degradation of nitrification inhibitors like Nitrapyrin and their effectiveness may be decreased under such situations[108,109].

Hendrickson, Walsh and Keeney[45] observed interesting results which indicated that while nitrification can be significantly slowed by application of nitrification inhibitor; a yield response may not result, probably because of nitrification not leading to N losses. Retardation of nitrification varies widely even within the same field and this illustrates the problems involved in predicting whether nitrification inhibitor application will be effective or not in reducing N losses and improving yields[45]. The large volume of literature that has accumulated clearly indicates that there are compounds available, which can retard nitrification in soil under controlled conditions in laboratory but the use of nitrification inhibitors has not been accepted universally for crop production under field conditions[46,75]. The main reason for the inconsistency in the performance of nitrification inhibitors is probably due to the diversity of soil, crop and environmental conditions under which these chemicals have been employed. The following points emerge conspicuously from the literature on the use of nitrification inhibitors: –

1. Under situations where losses of nitrogen due to leaching and denitrification accompanying nitrification of fertilizer nitrogen occur, use of nitrification inhibitors may be advantageous.

2. Nitrification inhibitors are more effective in light textured soils so their use may be more effective under these soil conditions. But the effectiveness of these compounds decreases fast in heavy textured soils (*e.g.* see ref. 13).

3. The application of nitrification inhibitors should be confined to the soil microsites where nitrification occurs rather then treating the entire soil volume so that the concentration of these compounds could be high enough for a

reasonable period. As an example, treatment of the oxidised zone of a flooded paddy soil with a nitrification inhibitor may help in retardation of nitrification and minimization of subsequent losses due to leaching or denitrification. Controlling nitrification at the sites in soils where it occurs also ensures the most effective and economic use of nitrification inhibitors. Evidently the amounts required to control nitrification at microsites will be exceedingly smaller than that required for the entire soil mass.

4. Nitrification inhibitors in admixture with urea may enhance losses through ammonia volatilization under certain soil situations for example when surface applied[15,44] or from bare soils[22]. However, these facts need to be investigated in presence of growing crop plants and established crop canopies.

5. Another important point that should be looked for while using the nitrification inhibitors is to see that these materials or compounds are intimately mixed with the fertilizers (so that each molecule of the fertilizer has a molecule of the inhibitor) before application to soil. It thus seems reasonable to conclude that the coating of fertilizers with the solutions of the nitrification inhibitors may be far more effective and efficient than their mixing. In this regard the mobility of fertilizer and inhibitors with the soil solution should also be considered. For example, dissimilar mobility of the fertilizer and nitrification inhibitor from a coated material or mixture of the fertilizer and inhibitor in a system may result in ineffectiveness of these materials.

6. Application of nitrification inhibitors like Nitrapyrin is helpful in elimination or reducing nitrite accumulation in soils fertilized with higher rates of urea (ref. 15, Table 10).

7. Use of nitrification inhibitors may not be useful for crops that do not metabolize well when fed with relatively higher amounts of ammonium following inhibition of nitrification (ref. 61, Table 7).

Table 10. Effect of nitrapyrin (10 ppm) on nitrite formation in storden sandy clay loam treated with urea (400 ppm N)*

Treatment	Maximum amount of NO_2–N (ppm) formed during 21 days
Without Nitrapyrin	174
With Nitrapyrin	0

* Soil sample incubated at 30°C and 60% WHC moisture.

Source: Bundy and Bremner[15].

CONCLUSIONS

The review of literature brings out the importance of controlling urea hydrolysis and nitrification in soils by the use of chemical agents. There are enough evidences in literature that point out the potentiality of some chemicals as urease and nitrification inhibitors. It has been usually recognised that use of nitrification inhibitors will be helpful in minimising nitrogen losses under situation where losses due to denitrification and leaching are high, but may not be advantageous where nitrification does not lead to loss of N. Nitrification inhibitors may also be useful in the alleviation of the problem of accumulation of nitrite in soils.

Urease inhibitors will undoubtedly be useful under situations where leaching loss of urea does not offset the advantage by retardation of urea hydrolysis. Delay in urea hydrolysis will be a step forward in reducing ammonia volatilization loss and ammonia and nitrite toxicity. However, there is lack of data on the use of urease inhibitors under greenhouse or field conditions in relation to crop growth though laboratory data provide encouragement for such studies. Also there is dearth of data on the use of nitrification inhibitors in relation to pollution of ground and surface waters with nitrate though their role in crop production has been recognised.

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