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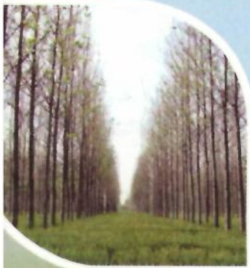


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Indigenous materials for increasing efficiency of fertilizer nitrogen

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INTRODUCTION

Fertilizer nitrogen continues to play a vital role in consolidating the gains of Green Revolution in India, thus forms a key component to address food security of the country. The second most important factor responsible for increased food/ cereal production has been the fertilizer nitrogen (Prasad and Shivay, 2015). The journey to food security in India is weaved around high-yielding crop varieties and improved agronomic practices while addressing the issues of biotic and abiotic stresses. Our agronomists played a critical role of stabilizing and enhancing the performance of improved as well as traditional crop varieties. Among various agronomic practices, fertilizer use, especially of N has been the centre of attention and research in the country. While it has been argued that India needs more and more N fertilizers to support its food production and an estimate of 22-25 million tonnes of N fertilizer production has been projected (Prasad, 2007), scientists are increasingly looking at improving the N-use efficiency by crops as a necessary tool not only to economize N fertilizer use but also arrest environmental degradation.

The N content in Indian soils continue to be low, ranging from 0.02% to 0.1% (Prasad, 2007); a possible explanation is that enough organics are not introduced into the agro-ecosystems and the applied N fertilizers are soluble and thus easily lost from the system. While the debate on the availability and feasibility of increased additions of organics razes on, it has become a bare necessity to maintain and enhance food production through the use of chemical fertilizers, especially of N.

FATE OF APPLIED NITROGEN IN INDIAN AGRICULTURE

There are principally 3 routes through which applied fertilizer N flows in agro-ecosystems:

(i) Crop removal, (ii) N losses from soil-plant system and (iii) N storage in soil

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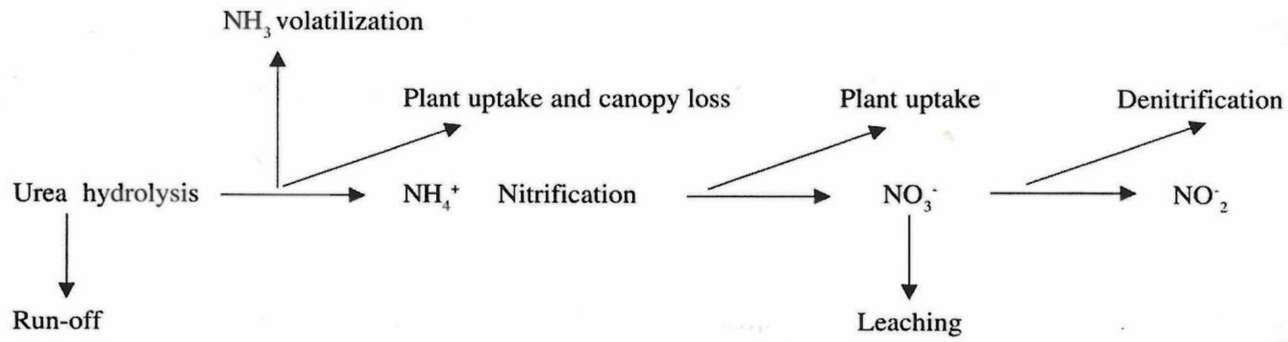
Crop removal

Most field crops recover 25-50% of applied N (Prasad, 2013). Cereals remove 20 to 75 kg N/tonne grain and nearly 27-51% N harvested by the crops is contained in stover (Prasad, 2007); the values vary according soil-climatic factors and agronomic management. While these values throw light on the N use by crops, surprisingly, unit N required to produce unit grain has increased over the years. Studies conducted at IARI have shown that 16.2 and 20.1 kg grain/kg N of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L. emend Fiori & Paol) are produced respectively (Prasad, 2007) and these figures have further declined to 11.4 and 6.2, respectively, based on the analysis of data from the trials on farmers' field by the ICAR-The Indian Agricultural Statistics Research Institute (IASRI) (cf. Prasad, 2007). Therefore, it is safe to conclude from this research that in India, the field crops, especially rice and wheat will continue to need more N additions to maintain and further increase production levels. However, this trend is not sustainable economically and environmentally in future.

Nitrogen losses from soil-plant system

Nitrogen is lost from soil-plant system through several mechanisms such as run-off, leaching, denitrification, NH_3 volatilization, loss from crop canopy. In India, urea is the major source of N accounting to >80%. However, urea itself, being soluble is lost easily from soil besides creating favourable soil pH conditions for NH_3 volatilization. The possible pathways of urea movement in soil-plant system is briefly described here.

Whenever urea is surface applied to the crop fields and heavy rains fall soon after application, a part of the applied urea is lost through run-off. These losses are estimated to be about 10 kg N/ha (Katyal, 1989). However, these values may vary depending on rain-fall intensity, soil conditions, slope, crop cover and others. The regions having most run-off loss of urea are sloping lands in the mountainous tracts in Himalayas and Konkan belt of Maharashtra, where rice is the crop grown during the rainy season. Unfortunately, data on run-off losses of urea from crop fields based on field studies are lacking and we are missing vital data which may be a major pathway in monsoon dependent Indian agriculture where urea is mainly



broadcast applied.

Ammonia volatilization losses of N could be important in many situations where urea is the main source of N. Urea on hydrolysis, is converted to ammonium carbonate which readily raises pH of the local soil sites and is prone to conversion to NH_3 gas which volatilizes readily. In India, our country, most farmers broadcast urea, making it vulnerable to immediate losses through NH_3 volatilization. Several estimates put these losses to values ranging from 8 to 30% (Prakasa Rao and Bhat, 1984; Sudhakara and Prasad, 1986; Prasad, 2007). The main issue has been the method of estimation of NH_3 volatilization; semi-open chamber methods (Prakasa Rao and Bhat, 1984) do give a fair idea of such losses, though not quantitatively. Deep placement of urea in soil can largely reduce such losses (Prakasa Rao and Puttanna, 1987; Katyal *et al.*, 1987). Thus deep placement of nitrogen should receive as much attention as the placement of phosphorus (Devasenapathy and Palaniappan,1995; Prasad, 2013).

Nitrification of N fertilizers produce NO_3^- which is soluble and prone to leaching losses. Leaching of nitrates have several agricultural and environmental implications (Prakasa Rao and Puttanna, 2000, 2006). Once again, methodologies adopted to assess nitrate leaching have not improved over the years and still researchers depend on qualitative estimates to evolve better agronomic interventions. Under irrigated conditions in light-textured soil-nitrate leaching could be substantial (Bijay-Singh and Sekhon, 1976). Pot culture studies with rice have shown that under intensive low-land conditions, even NH_4^+ is leached out in light-textured soils; leaching of N was 17% and 15% from ammonium sulphate and urea, respectively, and could be reduced with such agronomic interventions as use of nitrification inhibitors, neem-cake (Prakasa Rao and Prasad, 1980). Studies have shown high magnitude of nitrate leaching losses in rice–wheat cropping systems in north-west India (Bijay-Singh *et al.*, 2007). Pathak *et. al.* (2004) suggested that 15-16% of applied N could be lost through leaching.

Where submerged soil conditions prevail such as in low land rice, nitrates are converted to N oxides by denitrifying bacteria as:

$$NO^-_3 \text{ denitrifying organisms} \longrightarrow N_2, N_2O$$

The N oxides readily are released to the atmosphere and this process is called denitrification. Prasad and Lakhdive (1969) showed in a laboratory experiment that N is lost through denitrification under submerged conditions. Several researchers have reported useful estimates of denitrification losses ranging from 10 to 50% of applied N in India (Krishnappa and Shinde, 1980; Katyal *et al.*,1985; Mosier *et al.*, 1990, Aulakh *et al.*, 2001; Pathak *et al.*, 2004). Quantification of denitrification losses from crop fields remains a challenge and an average loss of about 25 kg N/ha with the application of 120 kg N/ha is reported (Ladha *et al.*, 2005). Nitrogen losses are the highest under alternate wetting and drying cycles (Prasad and Rajale, 1972; Prasad, 2011).

Nitrogen can also escape from plant canopy. Wetselaar and Farquhar (1980) suggested that N in the form of NH_3 could be lost from plant canopy during plant senescence. Not much information is available on this subject in India. However, N balance studies using ^{15}N have provided some knowledge on the movement of N in soil-plant systems in India (Katyal *et al.*, 1985; Goswami *et al.*, 1988).

Nitrogen storage in soil

Most of the N stored in soils is in organic forms; inorganic forms of N are highly reactive and are subject to easy movement and lost from the agro-ecosystems. High temperatures and heavy rainfall during the monsoon season render easy decomposition of soil organic matter in India. While it is a constant struggle to maintain and increase soil organic matter in Indian soils, the question of storing N in soils has been elusive. Generally, N content in soils is as low as 0.02% N (Krishnamoorthy and Govindarajan, 1977) to 0.3% N (Manickam, 1965) in India. The main issue is not as much as estimating N status of Indian soils, but to retain soil organic matter levels such that Indian soils are not grossly deficient in N. Methods such as alkaline permanganate hydrolysable N were developed for assessing N availability in Indian soils (Subbiah and Asija, 1956) but provide very high values. More realistic values of N release from soil organic matter are provided by mild calcium hydroxide hydrolysis of soil (Prasad, 1965), but this method has not been widely tested in India and deserves attention.

Thus, Indian scientists have greatly contributed to our knowledge on the N dynamics in Indian soils. However, quantifications of N budget have largely remained elusive and empirical. Agronomists are greatly benefitted by the knowledge so far created for their ultimate objective of enhancing N-use efficiency by crops.

Nitrogen use efficiency in India

Nitrogen use efficiency (NUE) in Indian agriculture is very low. Various estimates, using apparent N recovery methods and ^{15}N techniques, show that the N recovery by wheat is less than 40% and that of rice even lower (Yadvinder -Singh *et al.*, 2007). Clearly, this scenario is unsustainable both for the economy and environment. Scientists have been working on methods to improve NUE by crops. On an average, the recovery of fertilizer N in India ranges from 20 to 50% for rice (Prasad *et al.*, 1998a).The global average recovery efficiency of fertilizer nitrogen (REN) by cereals is 55% (Ladha *et al.*, 2005), although it could be as low as 21% for rice in some cases (Katyal *et al.*, 1985). As reviewed by Ladha *et al.* (2005), average recovery efficiency of ^{15}N for cereal crops was 44% in the first growing season and total recovery of ^{15}N fertilizer in the first and 5 subsequent crops was only around 50% worldwide.

The NUE for cereal crops is about 33% (Ladha *et al.*, 2005). Ladha *et al.* (2016) constructed a top-down global N budget for maize (*Zea mays* L.), rice, and wheat for a 50-year period (1961 to 2010). Cereal grains and above-ground straw contained a total of 1,551 Mt of N, of which 48% was supplied through fertilizer-N. The N output was estimated to be 3,306 Mt, of which the crop harvested 47%, whereas the remaining 53% or 1,755 Mt of N input was lost. In addition, soil-N declined by about 68 Mt. In order to economize N fertilizer use in Indian agriculture while minimizing adverse environmental effects, Prasad (2007) suggested the following measures:

1. Reducing N losses from farm fields,
2. Developing and using more efficient N fertilizers,
3. Adopting integrated nutrient management (INM) or supplying N through sources other than chemical fertilizers,
4. Balanced fertilizers, and
5. Better agronomy of crops.

Better agronomy of crops includes such measures as good crop husbandry, proper methods of N application as placement, foliar and proper time of N application which include N applications based on right crop physiological stages, using such methods as chlorophyll meter, leaf colour chart.

Prasad *et al.* (1971) reviewed research on the use of slow-release N fertilizers and nitrification inhibitors in agriculture. Subsequently, many researchers have published the merits of nitrification inhibitors and modified urea materials such as urea supergranules, in crops like rice. However, most of these materials have not been adopted by farmers due to reasons of cost and availability.

In countries like India, traditional knowledge such as, traditional plant types and varieties, traditional sources of nutrients and pest-control measures, use of waste materials and products, use of locally available plants, minerals and animals have a great potential to address the issues of agriculture. It is in this context that scientists in India started searching for indigenous materials which have a potential to improve NUE. Bains *et al.* (1971) discovered that neem-cake obtained from the seeds of *Azadirachta indica* neem or margosa increased the efficiency of urea. Rajendra Prasad and group of researchers pioneered the work on the nitrification inhibitory action of neem products and their role in increasing NUE in crops. Thus started the quest of Indian scientists to search and evaluate indigenously available materials for enhancing NUE by crops.

In this article, we focus on some groups of indigenously available materials on which research has been conducted and also, products derived for large-scale adaptation in the country. The different classes of indigenous materials for nitrification-inhibitory properties and their use in enhancing NUE are broadly listed as:

1. Neem and pongamia products
2. Pyrites
3. Essential oils and terpene compounds

Neem and pongamia

Reddy and Prasad (1975) were the first to report nitrification-inhibiting property of neem; urea treated with neem-cake inhibited nitrification by 40 and 74 % at the end of 1 and 2 weeks of incubation, respectively.The nitrification-inhibitory properties of neem were confirmed by several studies done later across the country. As regards neem-cake coated urea (NCU), data are available from a large number of experiments on different crops and have been summarised by Prasad *et al.* (1993). The average increase in yields of wheat, potato (*Solanum tuberosum* L.), sugarcane, cotton (*Gossypium* sp.) and finger millet were 6.9, 10.5, 15.5, 10.3 and 5.3%, respectively. Prakasa Rao *et al.* (1985) reported that neem-coated urea increased herb and essential oil yields of an aromatic plant, citronella (*Cymbopogon winterianus*) in a 2-year field study carried out in a sandy-loam soil of semi-arid tropical region. Prasad *et al.* (2007) described the evolution of neem-coated urea research in India and its efficiency in increasing NUE in a variety of crops in India. Singh and Singh (1984) from Pantnagar reported that cummulative loss in 20 days as ammonia from N applied @ 150 ppm as urea was 22% and was reduced to 19% when urea was blended with neemcake (1: 1 w/w). Prakasa Rao (1996) has shown that neem coating of urea has reduced NH_3 volatilization losses in a citronella field; from 38% with ordinary urea to 29% with NCU (Fig 1). Prakasa Rao and Prasad (1980) found that leaching as nitrate was reduced from 11% to 8.7% of applied urea-N when urea was coated with neemcake. Research at the IARI under the leadership of Rajendra Prasad (Prasad *et al.,* 1993; 1999a,b; 2002; 2007; Shivay *et al.,* 2001) led to the development of neem-coated urea (NCU), its on-farm confirmation by others (Thind *et al.*, 2010) and feedback by the famers has led to its manufacture of NCU in India on a large scale (Table 1).

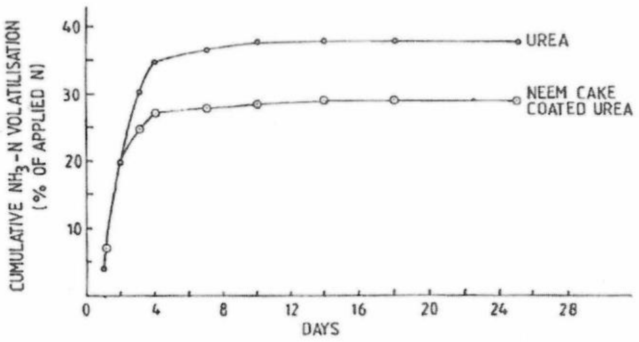


Fig 1. NH_3 volatilization losses from urea and neem coated urea applied to soil (Prakasa Rao,1996)

Research to identify the active constituents responsible for the nitrification-inhibitory properties in neem was initiated at the Division of Agricultural Chemicals, IARI, New Delhi. Devakumar (1986) found that a group of compounds known as meliacins were responsible for inhibition of nitrification by neem. Of the 5 meliacins screened, desacetylnimbin caused uniformly higher ammonium-N concentration and lower nitrate-N production. The general order of nitrification-inhibiting potency was: desacetylnimbin, salanin, desacetyl salanin > azadarachtin, nimbin. Kumar *et al.* (2007b) found in a soil-incubation experiment that the meliacins content in neem oil directly affected the nitrification-inhibition. Among neem-oil components, coating of prilled urea with meliacins proved beneficial over the other neem oil components – FFA, pure oil, saturated and unsaturated fractions – especially in respect of growth, yield attributes, grain and straw yields, agronomic efficiency and apparent N recovery in lowland rice. Across all the neem-oil components, a coating thickness of 500 mg/kg on to prilled urea was sufficient to realize the higher yield and NUE of lowland irrigated rice (Kumar *et al.*, 2011).

In order to develop a product from neem, collaborative efforts were made by scientists and industry (Devakumar, 2016). Division of Agronomy, IARI, first developed neemcake-coated urea using coal tar solution in kerosene (1 kg in 1 litre, enough for 100 kg urea) as sticker to hold the finely powdered neemcake. This technique could not go to the industrial level due to high requirements of neemcake; a factory producing 1,000 tomes urea per day would need 200 tonnes of neemcake per day (Prasad *et al.*, 2002). Production of (bulky) neemcake-coated urea in factories required 0.1–0.2 tonne neemcake per ton urea, which involved lots of transport and application costs and hence could not be used by the farmers eventually. Quality assurance of the neemcake-coated urea is another problem. As an alternative of neemcake, use of 0.5–5.0 kg neem-oil per tonne urea can serve the purpose and may be used successfully for coating of urea. Also, the Indian fertilizer industry was poised to take up neem-oil-coated urea(NOCU) as a value-added fertilizer and the Government of India was interested to formulate quality standards for NOCU. Considering the advantages of NOCU, the Government of India wanted to include it in Fertilizer Control Order (a government document which contains the specifications of fertilizer materials) and then subsidize its price to the farmers. Research has shown that coating of prilled urea (PU) with 1,000 mg neem-oil/kg PU was a better source than uncoated PU or PU coated with higher concentration of neem-oil, i.e. 2,000 mg neem-oil/kg PU (Kumar *et al.,* 2011). Suri (1995) developed primary equipment for coating urea prills with neem emulsion on the conveyer belt carrying prills from the prilling tower to the storage unit. Suri *et al.* (1998) reported improving urea storage and handling quality including anti-caking by coating of urea with a neem microemulsion. A technique involving neem-oil microemulsion was then developed at the IARI and patented (Saxena *et al.*, 2003) for coating urea, and this technique was tested at KRIBHCO's Hazira plant (Suri *et al.*, 2000) and later at Shriram's Kota plant. Recently, Government of India has allowed the urea manufacturers to convert their entire urea production as neem coated urea (GoI, 2015).

Thus, persistent efforts of agronomists to translate research into practice, the support of chemists to identify the active constituents of neem and efforts of the fertilizer industry to develop a scalable technology for the neem-coated urea product have resulted in the launching of the neem-coated urea in India. Policy support of the Government of India to make neem-coating mandatory for urea

Table 1. Grain yield and apparent nitrogen recovery (ANR) increase by using neem-coated prilled urea products in rice under different field studies conducted at Indian Agricultural Research Institute (IARI), state agricultural universities and at farmers' field

Neem-coated prilled urea products	Coating thickness	Place of field study (rice)	Increase in grain yield over prilled urea alone (%)	Increase in ANR[a] over prilled urea alone (%)	References
Neemcake-coated urea	200 g neemcake powder/kg urea	[b]IARI Research Farm	5.4	15.2	Prasad and Prasad (1980)
Neemcake-coated urea	200 g neemcake powder/kg urea	IARI Research Farm	14	19.4	Sharma and Prasad (1980)
Neemcake-coated urea	200 g neemcake powder/kg urea	IARI Research Farm	No increase	13.5	Prakasa Rao and Prasad (1982)
Pusa neem golden urea	Urea + neem-oil "adduct" analyzed 35% N and 12% neem-oil	IARI Research Farm	36	Not reported	Prasad *et al.* (1998b)
Pusa neem golden urea	Urea + neem-oil "adduct" analyzed 35% N and 12% neem-oil	IARI Research Farm	7.5	Not reported	Prasad *et al.* (1999b)
Pusa neem microemulsion- coated urea	0.5 kg neem-oil/tonne urea	IARI Research Farm	12-13	Not reported	Prasad *et al.* (2001)
Neem oil emulsion-coated urea	0.5 kg neem-oil/tonne urea	Farmers' field IARI Research Farm	6-12 7.7-10.9	11.75	Shivay *et al.* (2001)
Pusa neem microemulsion-coated urea	0.5 kg neem-oil/tonne urea	IARI Research Farm	4.5	5.6	Singh and Shivay (2003)
Pusa neem golden urea	Urea + neem-oil "adduct" analyzed 35% N and 12% neem-oil	IARI Research Farm	Not available	8.2	Kumar and Prasad (2004)
Pusa neem golden urea	Urea + neem-oil "adduct" analyzed 35% N and 12% neem-oil	IARI Research Farm	11.9	Not reported	Kumar *et al.* (2007a)
Neem-oil coated urea	0.5 kg neem-oil/tonne urea	IARI Research Farm	12.5	22.7	Kumar *et al.* (2010 and 2011)
Neem-oil coated urea	1.0 kg neem-oil/tonne urea	IARI Research Farm	15.7	27.7	Kumar *et al.* (2010 and 2011)
Neem-oil coated urea	5.0 kg neem-oil/tonne urea	IARI Research Farm	15.1	15.5	Kumar *et al.* (2010 and 2011)
Neem-oil coated urea	0.5 kg neem-oil/tonne urea	PAU Ludhiana Research Farm	5.6	6.7	Thind *et al.* (2010)

[a]Apparent Nitrogen Recovery (ANR) = 100 [N uptake in N treatment (kg/ha)–N uptake in control (kg/ha)] / Amount of nitrogen applied (kg/ha).
[b]Indian Agricultural Research Institute, New Delhi, India.

production and setting in place the quality standards through the FCO have made it possible for wide use of this technology. Government allowed fertilizer firms to produce 100% neem-coated urea – a move aimed at helping farmers boost income and reducing subsidy bill by up to Rs 6,500 crore (Business Standard, 7 January 2015). The Government of India on 12 May 2003, issued a notification indicating FCO Amendments to include specifications of neem-coated urea to be produced by M/s National Fertilizers Ltd. (NFL). However, it was clarified that Government of India has decided to permit all the manufacturers who wish to manufacture neem-coated urea at their factories (Baboo, 2014).

Other natural product, Karanjin, from *karanja* (*Pongamia glabra*) etc. has been tested for its efficiency as nitrification inhibitor (Sahrawat *et al.*, 1974). However, due to lack of extensive field evaluations and a product suitable for field application, this material has not found favour with our farmers.

IRON PYRITES

Iron pyrite is chemically known as iron disulphides (FeS_2) and is commonly called as '*fool's gold*'. Large quantity of iron pyrite (22% S) deposit is found in Bihar and is used to reclaim alkaline soils (Verma and Abrol, 1980). Furthermore, it is used to overcome S deficiency which is widespread in the country (Biswas *et al.,* 2004).

For the first time, Blaise and Prasad (1993) reported nitrification-inhibitory activity of iron pyrites. However, significant nitrification inhibition comparable to the commercial nitrification inhibitors was observed at high rates of application (Blaise *et al.,* 1997). Besides the nitrification inhibition, pyrites retarded NH_3 volatilization from fertilizer urea (Blaise and Prasad, 1995; Blaise *et al.,* 1997). In separate laboratory experiments, Reddy and Sharma (2000) and Shivay *et al*. (2005) reported reduction in NH_3 loss by mixing urea and pyrite compared to urea alone. Mixing 1 part of urea with 4 parts of pyrite brought down NH_3 loss from 29.3 to 14.5% of the applied fertilizer-N (Fig. 2). Reddy and Sharma (2000) also observed mixing urea with pyrites increased the apparent N recovery of sunflower in a pot culture experiment.

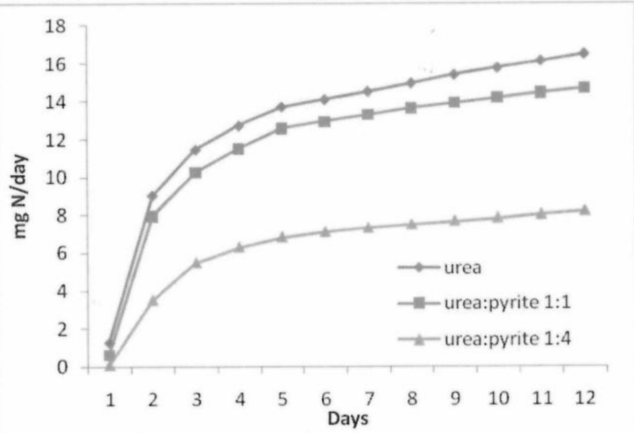


Fig. 2. Effect of pyrite on NH_3 loss from urea Source: Adapted from Shivay *et al.* (2005)

Most of the urea fertilizer is broadcast applied, in the country, especially to the grain crops grown at close row spacing. When urea is broadcast applied, potential for NH_3 loss is the highest. Under such situations, mixing urea with pyrite and broadcast application lowers the potential for NH_3 volatilization (Fig. 3). Placement is the best option compared to surface broadcast or incorporation. The acidity produced on oxidation of pyrites remains within the vicinity of the urea with the placement method of urea-pyrite mixture (Blaise *et al.*, 1996b). On the other hand, when the mixture is incorporated into the soil, there is a possibility of physical separation. Besides retarding NH_3 loss, iron pyrites reduces denitrification losses under waterlogged conditions (Blaise *et al.*, 1996a).

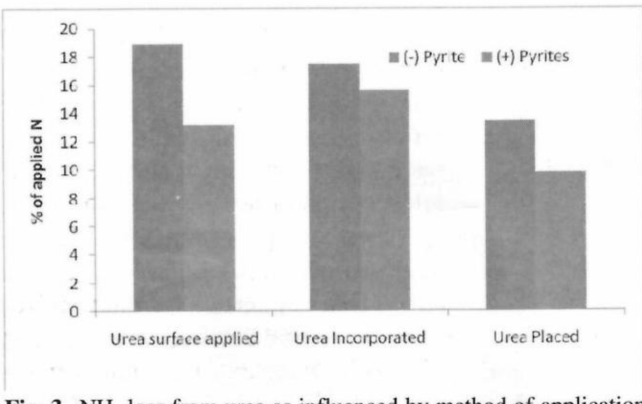


Fig. 3. NH_3 loss from urea as influenced by method of application and pyrite addition (Source: Adapted from Blaise *et al.*, 1996b)

Most of the commercially available nitrification inhibitors enhance NH_3 volatilization loss due to accumulation of NH_4^+ (Prasad and Power, 1995). On the other hand, iron pyrites have a dual advantage: *(i)* nitrification inhibition and *(ii)* NH_3 loss reduction. Pyrites on oxidation produce H_2SO_4 which prevents the rise in *p*H in the urea microsite and favours high exchangeable NH_4^+ concentration. Similarly, elemental S inoculated with *Paracoccus verutus* with urea was reported to reduce NH_3 loss ranging from 3.8 to 46.4% in the sandy calcareous soils of the United Arab Emirates (Soaud *et al.*, 2011). However, elemental S is quite expensive and iron pyrites can be considered as a cheaper alternative. Furthermore, it can be used in organic farms wherein commercial nitrification or urease inhibitors may not be acceptable. The dual advantage of pyrites, inhibiting nitrification and reducing NH_3 volatilization, can be achieved only with a high level of application (Blaise *et al.*, 1997).

Pyrites hold promise for increasing NUE in Indian agriculture. However, more field evaluations are necessary to confirm their efficacy. Considering the bukiness of the product, further efforts are required to develop a usable product of iron pyrites-urea and perhaps, its use is easy in the geographical regions of its availbility. Logistical and economic evaluation by the industry in collaboration with scientists may help to bring this product to field use.

ESSENTIAL OILS AND THEIR BY-PRODUCTS

Essential oils are obtained by steam distillation of aromatic plants; a wide variety of aromatic crops are grown in different parts of India (Prakasa Rao, 2009). Essential oils have a variety of applications in perfume, fragrance and pharmaceutical industries. Basically, essential oils contain terpene compounds which are responsible for their activity. A number of terpenes such as menthone, isomenthone, carvone, thymol, terpene, puleagone etc. present in essential oils were found to posses antimicrobial properties (Patra *et al.*, 2001).

Patra *et al.* (2002) evaluated the performance of 2 natural products, *Mentha spicata* oil and Nimin® (tetranortriterpenoids), an alcohol extract of neem (*Azadirachta indica*) cake as nitrification inhibitor in comparison with DCD as coatings on prilled urea for their performance in Japanese mint (*Mentha arvensis*) (Table 2). The natural products significantly increased the herb and essential oil yield of mint compared to prilled urea and were found as effective as DCD.

Kiran and Patra (2002) compared the nitrification inhibition potential of DCD coated urea, *Mentha spicata* oil, dementholised oil (DMO) and terpene-coated urea and their performance in wheat. Significant increase in grain and straw yield, N uptake and apparent N recovery, was

Table 2. Influence of different treatments on dry-matter yield, N accumulation, apparent N recovery in Japanese mint

Treatments level of N (kg/ha)	Coating material	Dry-matter yield (Mg/ha)	N uptake (kg/ha)	Apparent N recovery (%)
Control (0)	-	5.48	87.64	-
100	None	7.53	120.4	32.76
	MS oil	8.01	128.2	40.56
	Nimin	8.73	140.0	53.06
	DCD	9.88	161.1	73.46
200	None	9.90	135.01	23.72
	MS oil	11.86	166.0	39.21
	Nimin	12.82	192.3	52.33
	DCD	16.24	227.4	69.88
300	None	10.58	148.6	20.31
	MS oil	12.09	185.3	32.54
	Nimin	12.63	209.5	40.62
	DCD	12.49	212.9	41.75

MS, *Mentha spicata*
Source: Patra *et al* (2002)

observed with the application of the natural materials. All the 3 coating materials retarded nitrification of urea applied to soil significantly, throughout the growth period of wheat as compared to DCD-coated urea as well as uncoated urea. Apparent N recovery in wheat with the application of these materials was 39.61, 37.27 and 32.3% with DMO, *Mentha spicata* oil and terpene, respectively.

Patra *et al.* (2002) in laboratory and greenhouse experiments observed that *Artemisia annua* had both urease and nitrification-inhibitory properties. Ethanol extract of *Artemisia annua*, a natural source of artemisinin, a herbal precursor of anti-malerial drug, acts as both nitrification inhibitor and urease inhibitor. Field experiments to evaluate the relative performance of *Mentha spicata* oil and *Artemisia annua* oil in comparison with DCD have shown increased fertilizer-use efficiency in Japanese mint (*Mentha arvensis*) and succeeding crop of Indian mustard [*Brassica juncea* (L.) Czernj. & Cosson] (Kiran and Patra, 2002). The nitrogen-use efficiency was in order of *Artemisa annua* oil-coated urea > DCD-coated urea > uncoated urea.

De-mentholized oil is a by-product in mentha oil industry where menthol is the main product. Greenhouse and field experiments were conducted to elucidate the nitrification-inhibitory properties of mint oil and DMO (Patra *et al.*, 2001). The DMO has been observed to enhance the nitrogen-use efficiency in rice and wheat by 30-55% indicating that more economical urea products could be developed for their agronomic efficiency. Studies to evaluate the performance of raw medicinal and aromatic plant materials (*Mentha spicata, Artemisia annua*) in comparison with Nimin® and DCD have shown that these materials significantly increased the herb and essential oil of *Mentha arvensis* and N-use efficiency (Kiran and Patra, 2003).

Thus, the research has thrown open some possibilities of utilizing raw matrials of some medicinal and aromatic plants, essential oils and their products and by-products for inhibition of nitrification of urea in soils and for increasing NUE. Extensive agronomic evaluations of such materials in diverse agro-climatic regions and crops, economic formulations, product development to suit field applications are needed to utilise these natural products in agriculture.

CONCLUSION

Future for the use of indigenous materials for improving NUE in Indian agriculture holds a great promise considering the success story of neem-coated urea. However, consistent efforts in the following areas are needed to exploit the benefits of indigenous materials for higher NUE in agriculture:

- Fundamental research to isolate and characterize active consituents of promising plant/animal materials
- Agronomic evaluation of identified materials following uniform protocols of experimentation in diverse agro-climatic regions and crops/ cropping systems
- Meta-analysis of field data from such studies to derive region / crop-specific recommendations to facilitate product launch
- Product development and industrial upscaling through scientists-industry collaborations
- Policy support by government
- Role of media and extension agencies in propagation of technologies
- Screening of indigenous materials for enhancing N-use efficiency

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