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Neem and the Environment

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Abstract

Neem (*Azadirachta indica* Juss) can play a key role in C-sequestration, reducing nitrous oxide (N_2O) production from the agricultural fields, checking desertification and reducing nitrate eutrophication of surface and groundwater due to fertilizer nitrogen. Neem is a shady tree and reduces temperature of the micro environment under it. Neem also contains a large number of volatile organic chemicals (VOCs) that may purify the air around the tree; this is in addition to production of oxygen during the day as most trees and plants do.

1. Introduction

The environment encompasses everything around us including air, water, land, and biota. Deteriorating environment has been a major global concern and to prevent it the Inter-Governmental Panel on Climate Change (IPCC) was formed by two United Nations Organizations, namely, the World Meteorological Organization (WMO) and the UN Environmental Program (UNEP) in 1988 with headquarters at Geneva, Switzerland. IPCC provides internationally accepted authority on climate change through its reports; the first one was published in 1990, while the fifth report was published in 2014. The major issue addressed by IPCC has been “global warming”. In addition there is also global concern for water and air pollution, and the World Pollution Control Association has been formed. In India the Central Pollution Control Board (CPCB) of India, a statutory organization under the Ministry of Environment, Forest and Climate Change (MoEF&CC), was established in 1974.

Neem (*Azadirachta indica* Juss) is an indigenous tree and derives its name from Sanskrit 'Nimba', while the generic name is derived from Arabic words “azad” meaning free and “darakht” meaning tree, referring to its hardiness in arid and semi-arid environments. This paper briefly reviews the role of neem in mitigating environmental pollution.

2. Global Warming

A portion of solar radiation reaching the earth is absorbed, while the rest is reflected back. The reflected solar radiation can get trapped in the atmosphere due to the presence of gases, such as, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), water vapour and chlorofluorocarbons (CFCs). These so called 'greenhouse gases' work as a blanket and by increasing the heat retention contribute to global warming. These gases are technically known as Global Warming Gases (GWG). Atmospheric CO_2 concentration has increased from 280 ppmv (parts per million on volume basis) in the pre-industrial era of 1750s to 400 ppmv in 2015, however, a major increase was observed in 20^{th} century, which is the highest for the past 800,000 years (UESPA, 2017). Global warming is increasing at fairly fast rate in the 21^{st} Century since all but one of the 16 hottest years in NASA's 134-year record have occurred since 2000 (MacMillan, 2016). Methane level has also increased two and a half times, while nitrous oxide level has increased nearly 20 times that of pre-industrial level. This increase is ascribed to human activities of industrialization, increased use of locomotives and increased intensive farming involving high rates of fertilizers and other agro-chemicals. Global warming (GW) can lead to floods and cyclones (Ashley and Ashley, 2008; Ramsay and Sobel, 2011) and sea-shore cities and towns making up the world's important ports, such as New York, London, Tokyo, Mumbai, Chennai, Calcutta etc. are at the greatest risk, due to rise in atmospheric temperature, fast melting of glaciers and rise in sea level. On the other hand, GW can also lead to droughts (Dai, 2013; Trenbath *et al*., 2014). Therefore serious attempts are being made to put a break on global warming.

3. CO_2 Absorption or Carbon-Sequestration

Reducing CO_2 levels in the atmosphere has received considerable attention. Plants, especially trees, because of their large mass and high cellulose in stem and roots can play a major role in absorbing CO_2 from the atmosphere and storing it, a process known as "carbon sequestration" (Lal *et al*., 2015). A recent study by the Gujarat Ecological Education Research Centre at Ahmedabad (Kaushik, 2016) has shown that while teak sequestrated the most CO_2, neem was also effective in this regard (Table 1). In its lifetime, a neem tree could sequester 145,000 tons of CO_2. Of course the values for C-sequestration will vary with the age and the size of crown of a tree.

Of the various tree species mentioned in Table 1, neem deserves special attention, because it is a multipurpose tree, including the widespread use of its twigs in rural areas as tooth brush, leaves as forage for goats, sheep etc., timber for housing and seeds and oil for insecticidal, fungal and nematicidal values (Prasad *et al.*, 2007). Also neem grows well under arid and semiarid conditions, where C-sequestration is needed the most. Although soil organic carbon (SOC) content in arid soils is low, the total SOC present in arid soils of the world is 241 Pg (1 Pg=10^{15}g=1 billion metric ton), which is 15.5% of the total world's SOC in the top 1 m soil (Lal, 2004). Méndez-Bautista *et al.* (2009) reported that neem extract amendment of soil reduced the production of CO_2 and the oxidation of methane (CH_4).

4. Reduction on N_2O Production

Nitrous oxide (N_2O) has 265-298 times more global warming power than CO_2 and has a longer life in the atmosphere (USEPA, 2017). It has therefore received considerable attention in recent years (Synder, 2010). It is produced by denitrification of nitrates in oceans (Freig *et al.*, 2012), rice paddies (Mosier *et al.*, 1990; Bhatia *et al.*, 2013; Wang *et al.*, 2017) and even in fields of upland crops, such as maize and wheat etc. (Bogoi and Baruah, 2012; Burzaco *et al.*, 2013) by a large number of organisms belonging to genera *Pseudomonas, Bacillus, Chromobacteria, Thiobacillus* and others (Prasad and Power, 1997). It is estimated that globally, about 38% of nitrous oxide in the atmosphere is of anthropogenic origin, out of which agriculture may account for about 67 to 84%, and out of the total contribution of agriculture, fertilizer N may contribute about one-fourth (6.36% of total anthropogenic contribution) (IPCC, 2007; Smith, 2010). Global estimates of terrestrial N_2O emissions are at 12.52 ± 0.74 million tons per year (Tian *et al*., 2014), while the estimates from agricultural systems are about 4.2 to 7.0 million tons per year (Reay *et al.*, 2012).

A group of chemicals known as nitrification inhibitors are being used to inhibit or retard nitrification (Prasad and Power, 1995). Neem seeds and oilseed cake have nitrification inhibiting biochemicals and Reddy and Prasad (1975) reported that neem cake coated urea (NCCU) was 50% as effective as Nitrapyrin

Table 1: Relative CO_2 sequestration by some trees in India.

Botanical name of tree species	Common name of tree species (Local Indian names in parenthesis)	Tons of CO_2 fixed in life time by a tree of a girth of 20-30 cm
Tectona grandis	Teak (*Sangwan*)	370,000
Eucalyptus globulus	Eucalyptus (*Nilgiri*)	247,000
Prosopisjulifera	Mesquite (*Vilayati babool*)	167,000
Azadirachta indica	Margosa (*Neem*)	145,000
Casuarina equisetifolia	Beach oak (*Sheru*)	128,000
Acacia tortilis	Acacia (*Israeli babool*)	104,000

Source: Kaushik (2016)

Table 2: Nitrification rate of urea and neem cake coated urea (NCU) after 4 weeks of incubation.

Soil type	NH_4-N (mg kg^{-1})		NO_3-N (mg kg^{-1})		Nitrification rate* (%)	
	Urea	NCU	Urea	NCU	Urea	NCU
Alluvial	4.8	28.2	80.1	62.5	90.7	68.9
Black cotton	1.6	29.9	75.3	58.8	97.9	66.5
Laterite	11.6	32.5	71.3	62.2	86.0	66.4
Acid sulphate	7.0	23.6	64.3	60.6	90.2	72.0

*Nitrification rate = 100 [NO_3-N / NH_4-N + NO_3-N]
Source: Thomas and Prasad (1983)

(an established nitrification inhibitor) blended urea for about 2 weeks. Thomas and Prasad (1983) reported from a laboratory study that after four weeks of incubation nitrification rate in four rice growing soils of India varied from 86.0 to97.9% for urea and 66.4 to 72% for neem coated urea, showing the nitrification inhibiting property of neem (Table 2). Once the nitrification is inhibited, N_2O emission gets reduced. Majumdar *et al.* (2000, 2002) reported that N_2O emission in rice-wheat cropping system was more in wheat (750-1430 g N_2O-N ha^{-1} over a period of 90 days) than in rice (34.3-59.8 N_2O-N g ha^{-1} over a period of 70 days). They also reported that in rice, neem cake coated urea (NCCU) reduced N_2O emission by 11.2% as compared to 4.8% with Nimin (a commercial product containing neem bitters), while in the case of wheat, the reduction in N_2O emission was 63% with Nimin and only 9% with NCCU. Thus neem can play a role in reducing N_2O losses from the soil and in reducing global warming due to N_2O.

5. Arid Environments

Arid environments result in desertification, which may be defined as a land degradation process caused by the virtual absence of rain resulting in sparse xerophytic vegetation. Desertification leads to dust storms, massive wind erosion and formation of sand dunes. Neem has deep roots and an extensive lateral root system while being a strong competitor for soil moisture, and thus can survive better than other trees under arid conditions (Toky and Bisht, 1992). To prevent the spread of the Sahara Desert, neem windbreaks were created in Africa (Singh *et al.*, 2009). Neem was first introduced in Africa in Ghana from India by Brigadier-General Sir. Frederick G. Guggisberg, Governor of the then Ivory Coast during 1919-1927 and probably from there to Nigeria in 1928 and later to other countries of Africa (NRC, 1992). About 3.5 million neem trees were planted in Nigeria by Dr Newton Jibunoh, an engineer and environmentalist and this has helped not only in preventing the desertification, but also in providing many jobs and creating revenue (Orakpo, 2012). In Ghana, Neem plantations are being recommended for the production and marketing of neem oil (Addae-Mensah, 1999). Neem plantations were also made in Haiti for the same reason (Lewis and Elwin-Lewis, 1983). Neem plantation is also being encouraged in the northern dry region of Peru in South America to combat desertification (Hamann, 2013). An international convention for checking the desertification was held in New Delhi in September 2001 (GOI, 2001), in which importance of planting trees including neem was emphasized. Neem tree windbreaks can result in increased crop yields. In Africa, the millet yield was 1094 kg ha^{-1} in between the neem windbreak zone as compared to 854 kg ha^{-1} outside the windbreak zone; an increase of 23% (Catterson *et al.*, 1989). This was possibly due to lower temperatures in windbreak zones resulting in lesser loss of soil moisture by evapotranspiration.

With respect to shading and reducing temperatures, the best example is from Arafat plains in Saudi Arabia, where 50,000 neem trees were planted in a 10 km^2 area, that provide shade and cooler environment to about 2 million Haj pilgrims (Ahmed *et al.*, 1989). Botanists in India in collaboration with the Indian Meteorological Department, Government of India, need to generate information on the temperature and humidity at different heights under the tree and in the crown of neem and other shady trees, such as, *Ficus religiosa* (*peepal*), *Ficus racemosa (gular*) and *Syzygium cumini (jamun*) and as a contrast under less-shady trees, such as, *Populus* sp. (poplar) and *Eucalyptus* sp. (*safeda*).

6. Plant Micro-Environment

While C-sequestration and production of oxygen are major beneficial effects of plants and trees, crop plants also emit ammonia (Francis *et al.*, 1993; Tripathi

Table 3: List of districts showing localized occurrence of nitrate (>45 mg $litre^{-1}$) in ground water in different states of India.

S.N.	State	Districts (parts) having groundwater with >45 mg nitrate $litre^{-1}$
1.	Andhra Pradesh	Adilabad, Anantpur, Chittoor, Cuddapah, East Godavari, Guntur, Hyderabad, Karimnagar, Khammam, Krishna, Kurnool, Mahbubnagar, Medak, Nalgonda, Nellore, Nizamabad, Prakasam, Ranga Reddy, Srikakulam, Visakhapatnam, Vizianagaram, Warangal, West Godavari.
2.	Bihar	Aurangabad, Banka, Bhagalpur, Bhojpur, Kaimur(Bhabua),Patna, Rohtas, Saran, Siwan.
3.	Chattisgarh	Bastar, Bilaspur, Dantewada, Dhamtari, Jashpur, Kanker, Kawardha, Korba, Mahasamund, Raigarh, Raipur, Rajnandgaon.
4.	Delhi	Central Delhi, New Delhi, North Delhi, North West Delhi, SouthDelhi, South West Delhi, West Delhi.
5.	Goa	North Goa.
6.	Gujarat	Ahmadabad, Amreli, Anand, Banaskantha, Bharuch, Bhavnagar, Dohad, Jamnagar, Junagadh, Kachchh, Kheda, Mehsana, Narmada, Navsari, Panchmahals, Patan, Porbandar, Rajkot, Sabarkantha, Surat, Surendranagar,Vadodara.
7.	Haryana	Ambala, Bhiwani, Faridabad, Fatehabad, Gurgaon, Hissar, Jhajjar, Jind, Kaithal, Karnal, Kurukshetra, Mahendragarh, Panchkula, Panipat, Rewari, Rohtak, Sirsa, Sonepat, Yamuna Nagar.
8.	Himachal Pradesh	Una.
9.	Jammu & Kashmir	Jammu, Kathua.
10.	Jharkhand	Chatra, Garhwa, Godda, Gumla, Lohardaga, Pakaur, Palamu, PaschimiSinghbhum, PurbiSinghbhum, Ranchi, Sahibganj.
11.	Karnataka	Bagalkot, Bangalore, Belgaum, Bellary, Bidar, Bijapur, Chikmagalur, Chitradurga, Davangere, Dharwad, Gadag, Gulburga, Hassan, Haveri, Kodagu, Kolar, Koppal, Mandya, Mysore, Raichur. Shimoga, Udupi, Uttara Kannada.
12.	Kerala	Alappuzha, Idukki, Kollam, Kottayam, Kozhikode, Malappuram, Palakkad, Pathanamthitta, Thiruvananthapuram, Thrissur, Wayanad.
13.	Maharashtra	Ahmednagar, Akola, Amravati, Auragabad, Beed, Bhandara, Buldana, Chandrapur, Dhule, Gadchiroli, Gondia, Hingoli, Jalgaon, Jalna, Kohlapur, Latur, Nagpur, Nanded, Nandurbar, Nashik, Osmanabad, Parbhani, Pune, Sangli, Satara, Solapur, Wardha, Washim, Yavatmal.
14.	Madhya Pradesh	Anuppur, Ashok Nagar, Balaghat, Barwani, Betul, Bhind, Bhopal, Burhanpur, Chhatarpur, Chhindwara, Damoh, Datia, Dewas, Dhar, Gwalior, Harda, Hoshangabad, Indore, Jabalpur, Jhabua, Katni, Khandwa, Khargaon, Mandla, Mandsaur, Morena, Narsimhapur, Neemuch, Panna, Raisen, Rajgarh, Ratlam, Rewa, Sagar, Satna, Sehore, Seoni, Shahdol, Shajapur, Sheopur, Shivpuri, Sidhi, Tikamgarh, Ujjain, Umaria, Vidisha.
15.	Orissa	Angul, Balasore, Bargarh, Bhadrak, Bolangir, Baudh, Cuttack, Deogarh, Dhenkanal, Gajapati, Ganjam, J.Singhpur, Jajpur, Jharsuguda, Kalahandi, Kendrapara, Keonjhar, Khurda, Koraput, Malkangiri, Mayurbhanj, Nawapada, Nayagarh, Phulbani, Puri, Sambalpur, Sundergarh, Sonapur.
16.	Punjab	Amritsar, Bhathinda, Faridkot, Fatehgarh Sahib, Firozepur, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, Mansa, Moga, Muktsar.

Source: Central Government Water Board (2010)

et al., 2000) and even N_2O (Mosier *et al.*, 1990), which have harmful effects on the environment. In addition, trees also excrete a number of volatile organic compounds (VOC) that affect its micro-environment. The VOC's emitted by trees include organic acids, aldehydes, monoterpenes, isoprene etc. (Fall and Monson, 1992; Johnson, 1993; Guenther *et al.*, 1994; Gabriel *et al.*, 1999; Kesselmeier and Staut, 1999). Zeringue and Bhatnagar (1994) reported 68 VOCs from neem leaves, which included alcohols, hydrocarbons, Ketones, aldehydes and some miscellaneous compounds. In their studies microbe-free compressed air was passed continuously for a 3-day test period through an enclosed system containing fresh neem leaves and the resultant emitted volatiles were passed over the surface of submerged liquid cultures of a wild-type aflatoxigenic isolate of *Aspergillus parasiticus*. After a 3-day incubation period, there was a 90% reduction in aflatoxin production and a 51% reduction in fungal biomass in the fungal culture that received neem-derived volatiles, as compared with cultures that did not receive neem volatiles. More of such studies are needed to find out the effects of neem VOC on plant and human pathogens. It is a common practice in India to make the sick persons sleep under a neem tree and the beneficial effects could be due to some VOCs, which need to be identified to bring out the health advantages of neem in its micro environment.

7. Water Pollution/Eutrophication of Water with Nitrate

A considerable proportion of applied fertilizer nitrogen is lost along with surface soil slurry from the point of application, especially on sloping lands to lakes, rivers and finally to sea in far off places. These N losses do significant damage to the environment and aquatic life, since they lead to nitrate eutrophication of lake and sea waters as well as subsequent algal blooms, which are responsible for hypoxia (lack of oxygen) (Hietanen *et al.*, 2012) resulting in the death of fish, invertebrates, and amphibians (Camango *et al.*, 2005). In addition, excess fertilizer N is lost by leaching as nitrates to the groundwater, which is used for drinking purposes. The safe limit of nitrate in drinking water as per the US Environmental Protection Authority (EPA) is 45 mg nitrate litre^{-1} (10 mg NO_3-N L^{-1}). High nitrate concentration in drinking water leads to methaemoglobinemia or blue baby syndrome (Knobeloch *et al.*, 2000). A countrywide survey shows that water in shallow aquifers in a fairly large number of districts in India are having water above the safe limit for drinking (Table 3).

Situation is really bad in Punjab, where heavy use of nitrogen fertilizer is made in 'rice-wheat' cropping system. For example, Bharadwaj *et al*. (2012) reported that 28% of shallow well waters in Ludhiana district of Punjab in India contained 11-25 mg NO_3-N L^{-1} (49.5-112.5 mg nitrate L^{-1}), which is above the EPA safe limit. Similarly, Sharma *et al*. (2016) reported that nitrate in several ground waters of south Western Punjab was well above 90 mg L^{-1} with a mean value of 25 mg L^{-1}.

As already pointed out, neem cake/oil coating of urea can reduce nitrate formation and thus can reduce nitrate leaching to groundwater from the applied fertilizer N. Some data on this are Table 4. These data also show that leaching losses of N increased as the level of application was increased.

8. Crop Production

The major goal of agronomic research on neem has been to improve the efficiency of applied fertilizer nitrogen and to increase the crop yields especially in rice, where nitrogen efficiency is the lowest (Prasad, 1998) by using neem cake or neem oil coated urea. Some results from India and other countries are in Table 5, which show that neem cake or neem oil coated urea can increase the rice yield from 6.5 to 28.9%. These findings encouraged the development and use of neem coated urea.

Table 4: Relative nitrate-N leaching from urea and neem cake coated (NCCU) or mixed urea (NCMU).

Location	Soil type	Rate of N application	N leached (% of applied)			Reference
			Urea	NCCU	NCMU	
New Delhi	Alluvial	120 kgNha^{-1} (Field study)	8.3	-	-	Pathak *et al.* (2006)
		300kgNha^{-1} (Field study)	12.5	-	-	
New Delhi	Alluvial	92 mg kg^{-1}soil (pot culture study)	11.5	9.8	-	Prakasa Rao and Prasad (1980)
Pantnagar	Mollisol	120 kgN ha^{-1} (Lysimetre study)	12.0	-	8.0	Singh and Singh (1986)

Table 5: Relative efficiency of urea and neem coated urea (NCU) on the grain yield of rice.

Country	Location	Kg N ha^{-1}	Grain yield (t ha^{-1})		% increase	Reference
			Urea	NCU		
India[1]	New Delhi	Av 50-200	4.65	5.15	10.7	Sharma and Prasad (1980)
India[1]	New Delhi	Av 100-200	4.60	4.90	6.5	Prasad and Prasad (1983)
Bangladesh[1]	Dhaka	120	6.01	7.36	22.5	Chowdhury *et al.* (2010)
Egypt[2]	Cairo	60 mg pot^{-1}	49.4 g pot^{-1}	63.7 g pot^{-1}	28.9	Arafat *et al.* (1999)

[1]Field studies, [2]Pot-culture studies

Basic technology for coating urea with a neem oil-urea-water micro emulsion [(Pusa Neem Micro Emulsion (PNME)] was developed at the Indian Agricultural Research Institute, New Delhi (Prasad *et al.*, 1999) and an Indian Patent to this product was granted. PNME coated urea is generally referred to as Neem Coated Urea (NCU). The use of PNME for coating over urea prills was then thoroughly standardized, which involved designing of an appropriate nozzle, pump and storage tank, etc. (Suri *et al.*, 2000). Industrial level demonstrations of the production of NCU using IARI technology were carried out at the Hazira plant of KRIBHCO (June 1999 & December 1999) by producing over 1000 metric tons and later in other urea plants (Devakumar, 2016). Laboratory studies showed higher N use efficiency of NCU over urea (Prasad *et al.*, 2000) and NCU produced 6.3-11.9% (mean 9.2%) higher rice grain yields over uncoated urea on the farmers' rice fields in the state of Delhi (Prasad *et al.*, 2001). A number of researchers have reported the advantage of NCU over urea (Mangat, 2004; Kumar *et al.*, 2007; Thind *et al.*, 2010). A recent report suggests about 5-6% increase in crop yield with NCU over uncoated urea (Singh, 2016). A summary of some trials on the farmers' fields in India is given in Figure 1.

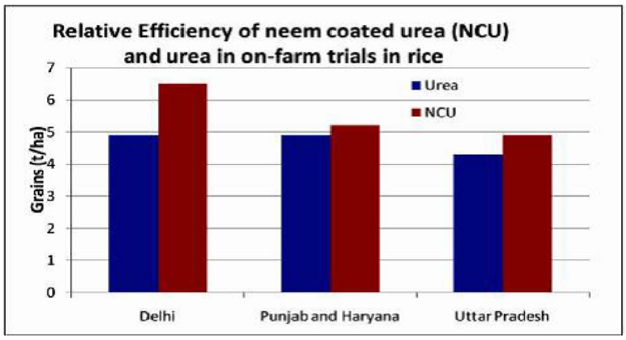

Fig. 1: Relative efficiency of neem coated urea (NCU) and urea in on-farm trials on rice in some states in India. (Source: Prasad, 2013).

Based on successful results with neem coated urea, the Government committed to a policy decision that all urea manufactured in the country, and even that imported from abroad, has to be coated with neem (PTI, 2015). Neem coated urea is now also manufactured in Pakistan (Ahsan and Ayub, 2017).

8. Epilogue

Neem is a tree that can grow well in arid and semi-arid environments and can greatly help in cooling the air, checking the desertification, C-sequestration, and reducing nitrous oxide production and nitrate leaching from agricultural fields. Thus neem can greatly help in overall improvement of the environment. In depth studies are needed to find out volatile organic compounds produced by neem and their effects on human, animal and plant pathogens. Neem does not fit in the Agroforestry programmes, because its shade adversely affects crop growth, but it should receive priority as a road-side tree on the existing as well as planned expressways in India. In addition to providing shade to the travelers, it will also help in producing and collecting neem fruits for extracting neem oil for medicinal purposes and for manufacturing neem coated urea.

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