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Farm Practices and Policies for Mitigating N Leaching and Run-Off: A Review

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Abstract: Leaching of fertilizer N as nitrate pollutes groundwater. Further, surface-applied fertilizers can be lost through run-off following water erosion and contaminates surface water bodies. Quantity of N lost through leaching and surface run-off would depend on the agro-ecosystem. The probable safe limit of nitrates in groundwater based on available literature is 45 to 50 mgL^{-1}. The present practices and their influence of N loss, the strategies to mitigate leaching and run-off in order to improve nitrogen use efficiency and challenges are discussed.

Keywords: *N leaching, ground water, agro-ecosystem, mitigation strategies, policies*

Introduction

Fertilizer-N has been one of the key production inputs that resulted in enhancing crop productivity. Fertilizer use increased 135 fold during 1950-51 to 2014-15. One of the major reasons for a quantum jump in yields with fertilizer application especially N was that the soils were deficient in N. Thus, supplying fertilizer-N led to yield increase in the initial phase of the green revolution. However, widespread usage of fertilizer-N mainly in the form of urea resulted in deficiencies of other nutrients that were not applied. Compared to other nutrients, N is easily dissolved and remains in the solution form making it susceptible to leaching and also surface run-off. Surface applied fertilizer is also subject to loss mechanisms by way of ammonia volatilization and de-nitrification.

Fertilizer-N that is applied to soil is rapidly transformed and primarily exists in two forms (ammonical and nitrate-N), of which nitrate-N is highly mobile and vulnerable for leaching. Soil moisture is a critical factor that facilitates leaching (Ochsner *et al.* 2018). Nitrate N can be easily leached into the deeper layers of the soil profile polluting the ground water which poses a threat to human health (Grizzetti *et al*. 2011). Livestock health is also adversely affected if fed with nitrate-rich water. Apart from fertilizers, other sources that contribute to nitrate pollution of ground water are manures and crops (Wick *et al.* 2012) geological sources and precipitation (Viets and Hageman 1971).

Nitrates in ground water

The Environmental Protection Agency USA fixed 45 mg nitrate-N l^{-1} as the safe limit while the

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European Union accepted 50 mg nitrate-N l^{-1} as the safe limit of nitrate in the groundwater**.** The World Health Organization also set a standard of 45 mg nitrate l^{-1} more importantly because of a huge consumption of groundwater in the arid and semi-arid regions of developing countries. We accepted the limit set by the WHO.

Presence of nitrate in the water makes it unsafe for drinking purposes (Grizzetti *et al*. 2011; Ward *et al.* 2018). Recently several studies across the country have established high proportion of groundwater samples contaminated with nitrate levels more than the safe limit of 45 mg nitrate l^{-1} (Table 1). Not surprisingly, the first report about high nitrate in ground water originated from the sandy loam soils of Punjab (Arora *et al*. 1980; Bajwa *et al*. 1993). Singh *et al*. (1995) observed two to seven-folds increase in nitrate concentration over the study period ranging from 1975 to 1993. The most surprising of the studies were the disclosure of high nitrate pollution of groundwater in the wells of samples collected from Maharashtra (Gupta *et al*. 2011). The proportion was smaller in the southern states of India (Table 1). However, it should be noted that at some places nitrate content in the tube wells is alarming.

Table 1. Proportion of samples with high nitrate-content in groundwater

State	No. of Samples	No. of samples (NO_3^->45 mg l^{-1})	Reference
Punjab	470	71	Malik (2000)
Haryana	352	68	Malik (2000)
Rajasthan	64		Suthar *et al.* (2009)
Uttar Pradesh	61	37	Chaudhary (2011)
Maharashtra	1407	544	Gupta *et al.* (2011)
Nalgonda, Telangana	46	6	Brindha *et al*. (2012)
Karnataka	6	1	Vinod *et al.* (2015)

N leaching loss in major agro-ecosystems

Major intensive cropping systems in the country are rice (*Oryza sativa*)-wheat (*Triticum aestivum*), rice-rice, cotton (*Gossypium hirsutum*)-wheat, maize (*Zea mays*)-based, potato (*Solanum tuberosum*)-based and sugarcane (*Saccharum officinarum*)-based cropping systems. Most of these cropping systems are grown on well-endowed lands and is predominantly irrigated and heavily fertilized. Fertilizer use in these cropping systems is in excess of what the crop removes. Furthermore, nitrogen use efficiency ranges from 35 to 60 per cent and the remaining is either lost by volatilization or leaching or remains in the soil.

Present practices and policies - impact on N loss

Farm practices

Rice cultivation became popular in the non-traditional areas such as northwest India and further gained importance in the entire Indo-Gangetic Plains. Rice-wheat is now the most common intensive cropping systems in northwest and north India. The major soil types on which these systems are followed are Inceptisols and Entisols. These soil groups have low clay content and cannot be well puddled. Therefore, these soils are porous and have high infiltration rate. After irrigation, fertilizer-N moves down the soil profile making it conducive to nitrate enrichment of the groundwater (Singh *et al*. 1995). Further, wheat follows rice in this region which is also highly fertilized. Therefore, the rice-wheat system contributes greatly to nitrate pollution of groundwater. Chabbra *et al*. (2010) opined that this region contributes maximum to the groundwater pollution through nitrate leaching. The northwest India and the Indo-Gangetic plains of north India contributes approximately 0.3 million tonnes of nitrate-N is added to the ground water every year (Table 2). A conservative estimate of the nitrate loss by major cropping systems is 0.66 million tonnes. This would be much higher if the horticultural crops is accounted and the peri-urban agriculture.

Table 2. Estimated loss of nitrate-N by leaching in the major intensive irrigated cropping systems of India

Cropping system	Nitrate loss (‘000 tonnes)*
Rice-wheat	311.2[a]
Maize based systems	76.0[b]
Potato based systems	37.3[c]
Sugarcane based systems	189.8
Cotton based systems	44.5

*Estimated using leaching factors [a]Chhabra *et al*. (2010); [b]Dash *et al.* (2015); [c]Sharma (1999)

In central and south India, rice-rice is an intensive cropping system. However, the rice is grown under puddled conditions with fertilizers commonly broadcasted. Leaching is not a major issue under such situations. As nitrogenous fertilizers are readily soluble and are more susceptible to N loss through volatilization, nitrification-denitrification and run-off (De Datta 1995). Furthermore, fertilizer-N applied suppresses growth of cyanobacteria and biological nitrogen fixation (Ladha *et al*. 1989).

Cropping systems with a high nitrogenous fertilizer inputs are sugarcane, potato and maize based systems. These cropping systems also contribute sizeable amount of nitrate to the groundwater (Table 2). We obtained the estimates from the proportion of fertilizer-N lost by leaching given by Dash *et al*. (2015) for maize, Sharma (1999) for potato and multiplied with the average fertilizer-N use and the acreage. For sugarcane, the proportion of nitrogen lost by leaching for wetland rice was used and for cotton the values for maize because of their similar nature of habitat. Sugarcane fields are wet during most of the period of cane growth making it highly conducive to leaching of fertilizer-N. Potato has a shallow root growth and a heavy feeder. As a result, N is not efficiently scavenged from the soil and the N that has moved below the root zone can be lost by leaching. Cotton is a deep rooted crop and can utilize the nitrate present in the lower layers.

Nitrate loss is also a function of the soil type and the management practices followed. A summary of the data for the various locations on which potato was grown is presented in table 3. It is clear that from the sandy loam soils nearly one-third of the applied fertilizer-N is lost whereas on the silty loam soils it is half of that observed on the sandy loams. However, the trend is reverse for contribution of losses by surface run off.

Table 3. Leaching and surface run-off of nitrogen from different soil types under potato

Soil type	Nitrate leached (kg ha^{-1})	Surface run-off
Silty loam	14.2	5.8
Loam	16.5	5.5
Sandy loam	30.3	4.0

Source: Sharma (1999)

Policies

Cultivation of rice-wheat cropping system became popular in the northwest and the IGP of north India with the availability of irrigation water, cheap electricity and fertilizer subsidy. Food security concerns were the prime issues and environmental concerns were at the backstage. A combination of all these factors aggravated nitrate pollution of the river basins and the groundwater. Similarly, availability of irrigation water made the rice-rice cropping system a possibility in the southern river plains of Godavari, Cauvery *etc*. In the mid 90's, de-control of fertilizer pricing resulted in an imbalanced use of fertilizers and greater amounts of nitrogenous fertilizers applied. Urea is the only fertilizer with the prices controlled due to political reasons and thus because of its low cost compared to the other fertilizers, nitrogen is applied in larger amounts.

Strategies and Policies to mitigate leaching and surface run-off

Strategies

Once N enters into the soil either through fertilizer or other sources, it is inevitable that the N on transformations creates a situation for the leaching of excess N. Therefore, efficient management systems and strategies are needed to prevent ground water pollution. An important aspect to be considered is to reduce the N use during high intensity rainfall events to minimize the nitrate transport to ground waters.

Crop rotation, catch crops and diversification

This strategy should be designed in a manner that has differential N requirement and high capacity to utilize N from the deep layers. For instance potato is heavily fertilized and has a shallow rooting system. It is also grown on soils that are more porous. For such a situation, growing a subsequent crop having a deep root system and a reduced N supply would be a pragmatic approach. In high N application regions, N loss due to leaching can be reduced by growing catch crops or cover crops (Prakasa Rao and Puttana 2006). Growing of crops with low N demand such as the pulses or crops with low water requirement such as trees are options for reducing N use and ultimately N loss to the environment. Singh *et al*. (2005) reported that pigeon pea could substitute for rice in the rice-wheat cropping system of north India. Adopting agro-forestry systems can also minimize nitrate leaching (Khajanchi-Lal *et al*. 2015).

Split application

Singh *et al*. (2005) suggested split application of fertilizer N than single application. This is a cheap option to reduce nitrate leaching to ground waters.

Nitrification inhibitors

Use of nitrification inhibitors can be another alternative to reduce conversion of the ammonium form of N to nitrate (Wick *et al.* 2012). Neem cake is an indigenous nitrification inhibitor (Singh *et al.* 2006, 2011) and is now a component of the fertilizer urea available on the market. There is a sizeable scope of reducing nitrate leaching by the use of such fertilizers.

Deep placement

In the rice-based cropping systems, the strategy for mitigating surface loss of fertilizer-N is avoiding broadcast application and adopting the deep placement method of application. Recycling of crop residues along with fertilizer-N in the rice systems will potentially reduce the total fertilizer N requirements. This would lead to a reduced load on the environment.

Policies

Policy changes include regulatory approaches and legislative measures making it mandatory for bringing about changes in fertilizer N use. Subsidy given to fertilizers could also be one of the policy options to be considered. Some changes that may be necessary are briefly discussed below.

Identifying nitrate vulnerable zones

Once a nitrate vulnerable zone is identified it can be considered for making the region manure/fertilizer free in order to reduce ground water pollution. This can be considered as a priority around the periphery of the regions close to major river water bodies, such as the Ganga, Yamuna, Godavari river basins *etc.* In such areas, one can opt for low N requiring crops or adopt a reduction in manure and fertilizer usage which will lessen the pollution of the water bodies.

Reducing fertilizer-N usage

The first and easiest option that is available to minimize leaching loss is to reduce the fertilizer-N input. However, this is to be done carefully as a reduction in N input may lead to yield reductions that may not be acceptable to the farmer. Therefore, the associated cost of yield loss should be estimated compared to the other technologies that are available.

Removal of subsidy

Subsidy may be restricted to regions with low fertilizer use whereas regions with excess fertilizer-N application may either be taxed or subsidies offered may be removed. Thus excess N application can be minimized with an indirect benefit of reduced point and non-point pollution. Nutrient based subsidy can be provided to the fertilizers (NAAS 2012). This way customization and value added fertilizers produced will benefit. Coating of nitrogenous fertilizers with nitrification inhibitors or slow release materials will gain momentum and pave the way for reduced N loss and improved use efficiency. De-control of the prices of urea and other N fertilizers can further pave for reduced input and adoption of better agronomic practices.

Introducing value added fertilizers

Some value added products such as urea super granules may need to be re-introduced. This fertilizer may be of use in the southern states where rice is cultivated under puddled conditions. USG was widely tested in northwest India when the fertilizer product was developed. The product was considered as ineffective in improving use efficiency. Low cation exchange capacity and high percolation rates (Katyal *et al.* 1988). On the sandy soils, USG may not perform well, but the same may not hold true for the other soil types.

Treatment of well waters

Wells that are high in nitrate content should either be treated to remove the nitrate or discontinued from use as drinking water or providing water to livestock. Instead, it should be considered as irrigation purpose and restrict use of fertilizer-N.

Challenges ahead

The irrigated agriculture systems such as the north and northwest have a high potential of leaching because of the combined factors of the permeable soil type, high N input use. Thus these regions are likely to contribute most to the nitrate leaching. Information on the fertilizer rate that causes nitrate pollution of ground water in the different soil types and cropping systems are far too limited. This has led to several assumptions in the calculation of nitrate in surface and ground water. Therefore, network research programmes should be conducted to validate strategies and identify the critical fertilizer application rates that would result in the pollution of ground water.

Policy changes can be effective only by comparing social costs and societal benefits. No such studies are available for our country at present. Identifying regions that are nitrate vulnerable and making them as manure/fertilizer free, may be in direct contrast to the food security and farm profitability.

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