International Journal of Applied Earth Observation and Geoinformation 12 (2010) 190–200

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

Non-point source pollution in Indian agriculture: Estimation of nitrogen losses from rice crop using remote sensing and GIS

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ARTICLE INFO

Article history:
Received 6 October 2009
Accepted 12 February 2010

Keywords:
Nitrogenous fertilizers
Rice crop
Leaching loss
Ammonia volatilization loss
Indo-Gangetic plain region

ABSTRACT

The paper presents a detailed understanding of nitrogenous fertilizer use in Indian agriculture and estimation of seasonal nitrogen loosses from rice crop in Indo-Gangetic plain region, the '*food bowl*' of the Indian sub-continent. An integrated methodology was developed for quantification of different forms of nitrogen losses from rice crop using remote sensing derived inputs, field data of fertilizer application, collateral data of soil and rainfall and nitrogen loss coefficients derived from published nitrogen dynamics studies. The spatial patterns of nitrogen losses in autumn or '*kharif*' and spring or '*rabi*' season rice at 1 × 1 km grid were generated using image processing and GIS. The nitrogen losses through leaching in form of urea-N, ammonium-N (NH_4-N) and nitrate-N (NO_3-N) are dominant over ammonia volatilization loss. The study results indicate that nitrogen loss through leaching in *kharif* and *rabi* rice is of the order of 34.9% and 39.8% of the applied nitrogenous fertilizer in the Indo-Gangetic plain region. This study provides a significant insight to the role of nitrogenous fertilizer as a major non-point source pollutant from agriculture.

1. Introduction

Agriculture has been identified as the largest contributor of non-point source (NPS) pollution of surface and ground water systems globally (Thorburn et al., 2003). Fertilizers, which are used as important inputs in agriculture to supply essential nutrients like nitrogen (N), phosphorus (P), and potassium (K) also serve as a major non-point source pollutant. They undergo transformation through various physical, chemical, and biological processes in soil. From the beginning of green revolution, nitrogen fertilizer use has been a success story for Indian crop production. The increase in nitrogenous fertilizer application in the last four decades (0.05 Mt in 1950–1951 to 11.7 Mt in 2004–2005) has resulted in unprecedented increase in agricultural production in the northwestern India leading to food security of the country (NAAS, 2005). Recently, concerns have been raised regarding consequences of fertilizer use more particularly nitrogenous fertilizers, since fertilizer recovery efficiency of nitrogen seldom exceeds 50% and a major portion of applied fertilizer is lost from plant–soil system by various soil processes. Therefore, the losses of reactive nitrogen from agricultural systems are a serious cause of concern for both economic and environmental reasons (Raghuram et al., 2007). Assessing the environmental impacts of non-point source pollutants at a localized and regional scale is of prime importance to achieve sustainable agriculture.

Rice is the most dominant food crop of India. Nitrogen is the single most important nutrient element that has a profound effect on the growth and yield of rice. Most of the Indian soils are deficient in available N, and rice crop invariably respond to the application of fertilizer-N in almost all the Indian soils (Panda et al., 2007). Among the different forms of fertilizer nitrogen, nitrate (NO_3^-) is highly mobile and most susceptible to leaching, ammonium (NH_4^+) the least and urea-N is moderately susceptible. Urea is the most common form of nitrogenous fertilizer applied to rice crop in India. When urea is applied to aerobic or flooded rice soil, it hydrolyses to ammonium carbonate by the enzyme urease, principally produced by soil microbes. Depending upon the alkalinity and pH buffering capacity of soil, ammonium carbonate decomposes and ammonia gas escapes to the atmosphere resulting in ammonia volatilization loss. Urea hydrolysis is maximum in soils with high organic carbon or added organic manure or green manure, pH around 8.0, moisture status at field capacity, and temperature around 35 °C (Panda et al., 2007). The ammonium ion resulting from urea hydrolysis also undergoes biochemical oxidation (nitrification) in aerobic soil as well as at three sites in submerged rice soil system viz. top oxidized soil layer, rice rhizosphere, and flood water. The diffusion of nitrate into the anaerobic zone in the submerged soil also results to denitrification loss (N_2O, N_2) of nitrate (NO_3^-) formed. Nitrate leaching is dominant when both soil nitrate content and water movement are high. The NO_3^- anion is very soluble in water,

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doi:10.1016/j.jag.2010.02.007

not influenced by soil colloids and unless intercepted and taken up by plant roots, leach down in the soil along with irrigation or rainwater or carried away by run-off. Nitrate leaching from field soil must be carefully controlled with its associated environmental impacts. High nitrate levels in surface run-off and water percolating through the soil can pollute drinking water resources and stimulate unwanted plant and algae growth in lakes and reservoirs (Panda et al., 2007). A detailed study was made on nitrogen fertilizer use and various forms of gaseous N emissions including N_2O, NO_x and NH_4 volatilization from rice based cropping systems in India (Adhya et al., 2007). Ammonia volatilization is not only a major loss of N primarily from rice cultivation but also a cause of environmental pollution. From the atmosphere NH_3 is washed out by clouds and redeposited on the terrestrial ecosystem. In the atmosphere, it is oxidized to N_2O which is a potential greenhouse gas and responsible for the destruction of stratospheric ozone layer.

1.1. Objectives of the study

Various studies have been carried out to understand nitrogen dynamics in soil with varying management practices for applied nitrogenous fertilizer. However, soil type is one of the most important factors in affecting fertilizer use efficiency and soil productivity. The spatial patterns of extent and intensity of different forms of nitrogen losses in soil and their variations with soil characteristics need to be captured using remote sensing and GIS tools. Indo-Gangetic plain (IGP) is the agriculturally dominant region and also known as the major '*food bowl*' of the Indian sub-continent. Rice is the dominant food crop of Indo-Gangetic plain region occupying about 32% of the gross cropped area and consumes ∼49% of the total agricultural nitrogenous fertilizer used in the region. Urea is the major source of fertilizer-N for rice crop in Indian agriculture. The present study was aimed at a spatio-temporal analysis of agricultural nitrogenous fertilizer use in India and a detailed estimation of various forms of nitrogen losses from applied urea N-fertilizer in rice crop in the Indo-Gangetic plain states using remote sensing and GIS tools, other collateral and field data. The major objectives of the study include:

i) Statistical analysis of N-fertilizer consumption in India and deriving the spatio-temporal patterns at district level by linking the administrative boundaries in GIS.
ii) Estimation of extent and intensity of different forms of nitrogen losses (leaching and volatilization) from applied N-fertilizer in kharif and rabi rice crops for different soil types in the Indo-Gangetic plain (IGP) states using remote sensing derived inputs and GIS.

2. Materials and methods

2.1. Study area

The detailed spatial analysis of nitrogenous fertilizer use in Indian agriculture was carried out at the district level. However, a detailed estimation of nitrogen losses through leaching and volatilization from applied N-fertilizer in kharif and rabi rice crops was carried out only for Indo-Gangetic plain region of India which includes five states viz. Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal (Fig. 1).

2.2. Data used

2.2.1. Statistical data

A detailed district level statistical database of nitrogenous fertilizer use was prepared using fertilizer statistics (FAI, 2004) available online at http://www.indiastat.com. A detailed database of location, soil texture, pH, organic carbon, season, crop, year, applied N fertilizer (kg ha^{-1}), N-fertilizer type, N uptake (kg ha^{-1}), N use efficiency (percent), N uptake efficiency (percent), apparent N recovery (percent), leaching losses (urea-N, NH_4-N, NO_3-N percent) NH_4 volatilization and gaseous N_2O emission was prepared using published literature studies (Appendix A). The study database included published nitrogen dynamics studies of different crops viz. rice, wheat, maize and cotton. The present study was focused on rice crop only as few studies on N-losses with different soil types were available, as compared to very limited data available for other crops.

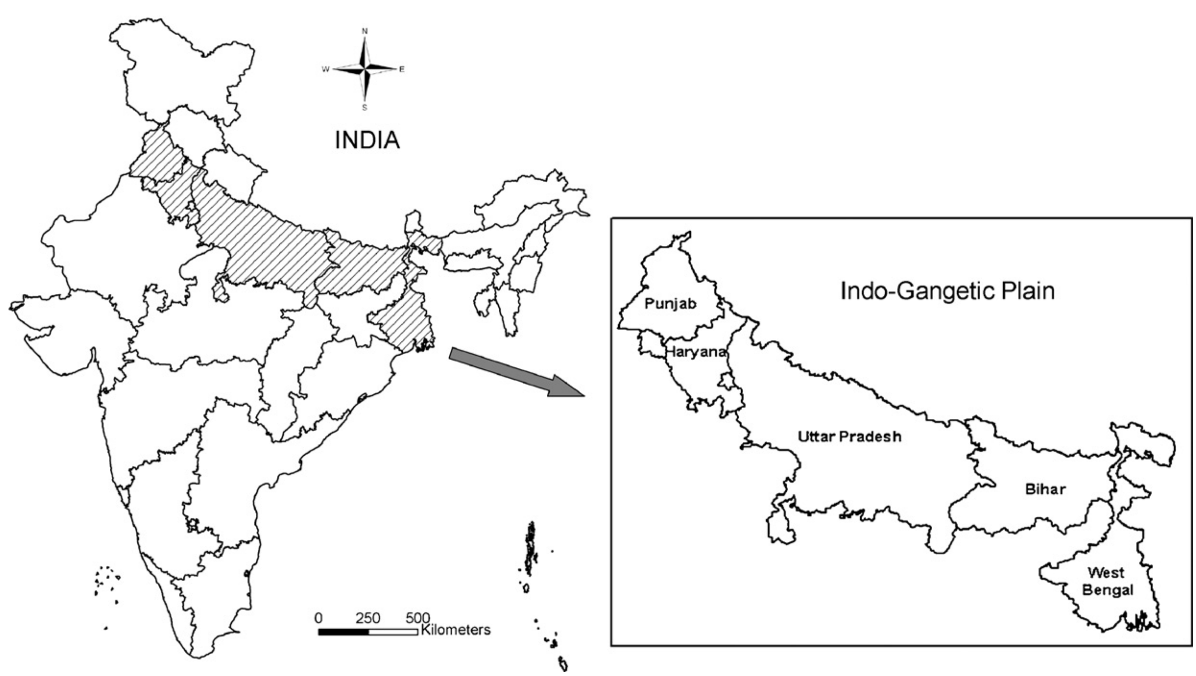

Fig. 1. Indo-Gangetic plain region of India constituting five study states.