

Spatially Explicit Assessment of Nutrient Demands for Promoting Efficient Regional Fertilizer-use Management in Vietnam

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Abstract

To transition to efficient fertilizer use for promoting food production, a wide range of stakeholders need to know nutrient demands for meeting crop yield potentials over an agricultural region. Knowledge about spatial patterns of these demands, however is often deficient in developing countries. This study (1) assesses the nutrient demands of potential crop productions in two intensive agricultural regions in Vietnam (Dong Nai and Bac Ninh provinces), and (2) provides public access to the output. We calculated the nitrogen (N), phosphorus (P) and potassium (K) demands for reaching crop yield potentials over the farmlands in the two provinces, taking soil nutrient balances into account. The balance calculations considered the effects of natural nutrient supplies (*e.g.*, from soils), and different natural nutrient losses (*e.g.*, by volatilization, erosion, leaching, runoff and crops' uptake with different fertilizer use efficiencies). The results were spatially explicit, presented at a map scale of 1:100,000, and managed by a Web-based Geographic Information System (GIS). The web-based GIS allows lay users to query the results at different levels of aggregation (*i.e.*, farm, commune, district and province) in a responsive and iterative manner.

Key words: nutrient supply and demand, potential crop yield, soil nutrient balance, Web-based GIS

1. Introduction

Over the period of 1965-1990, the global cultivated area increased by only 9.4% while the global population increased by 68.5%, thus the cultivated area per capita decreased by 35.1% (Nguyen Van Bo *et al.*, 2003). In Vietnam, from 1930 to 2000 the farming area per capita dramatically decreased from 2,548 m² to 675 m². To meet the increasing requirements for foods and fuels while national farm land is limited, increasing crop yield is essential for national food security. So far, increases in the crop yield in Vietnam have mainly depended on mineral fertilizers. The use of mineral fertilizers has rapidly increased: the fertilizer input per areal unit in 2007 was 5.8 times the rate in 1985 (SFRI, 2011). At present, mineral fertilizer use in Vietnam is around 6–7 million tons per year and 50% of it is imported (SFRI, 2011), being a costly input factor for the country's agricultural production. Furthermore, fertilizer use efficiency is still low—around 30–45% for nitrogen, 15–25% for phosphorus and 40–50% for potassium (Nguyen Van Bo *et al.*, 2003).

There has been much research on soil characteristics, fertilizer application and related spatial data that are use-

ful for guiding improvement of mineral fertilizer use efficiency. Stakeholders' access to information, however, is limited because it lacks viable assessment frameworks and user-friendly operational tools. Recently the availability of spatial information system technology, together with the availability of spatially explicit agronomic data, offers new opportunities to fill the gap (Kalogirou, 2002; Roetter *et al.*, 2005; Jianting Zhang, 2012). In this paper, we introduce an approach and a case study in Vietnam that applied IT techniques and spatially explicit assessment to:

- (1) assessing the nutrient demands of potential crop production in two intensive agricultural regions in Vietnam (Dong Nai and Bac Ninh provinces – Fig. 1), and
- (2) providing public access to the output. The study is expected to provide a wide range of stakeholders (*e.g.*, farmers, producers and policy makers) with necessary information on due fertilizer demand that should be useful for optimizing their farming management and policies.

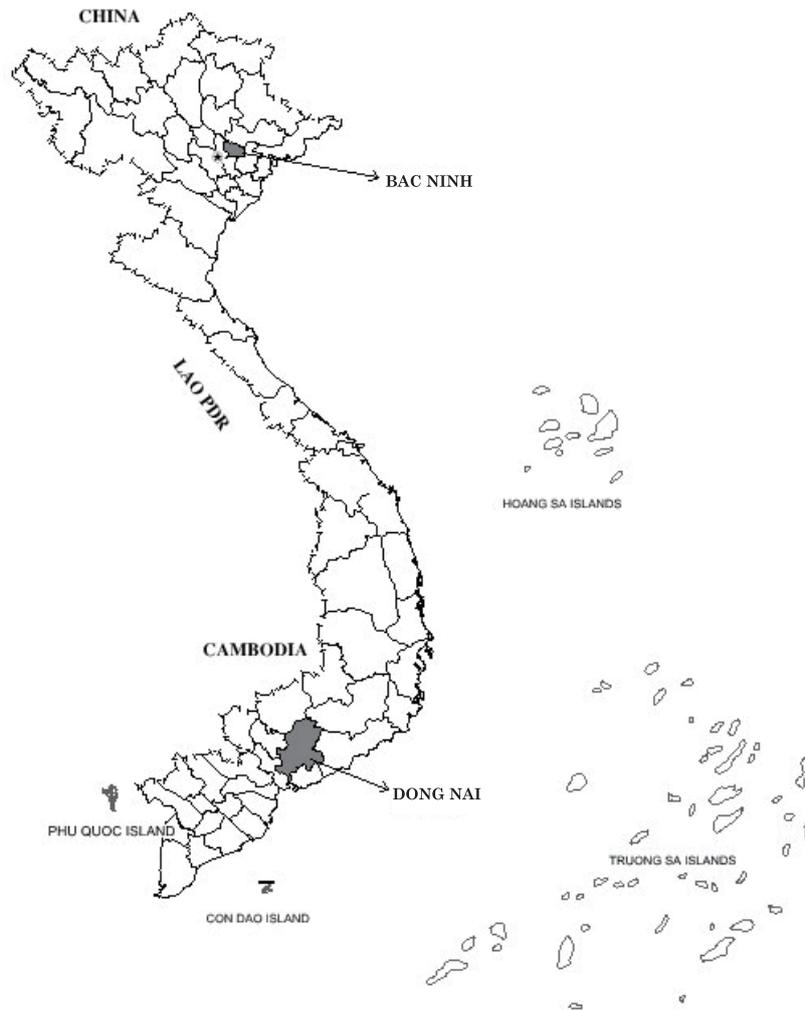


Fig. 1 Location of Bac Ninh and Dong Nai provinces on a map of Vietnam.

2. Methods

2.1 Assessment of nutrient demands for potential crop production

Nutrient demands for obtaining potential crop production are calculated by the difference between (1) nutrient release from soil and fertilizers and (2) nutrient losses by runoff, leaching and crop uptake. The information sources and calculation procedures are illustrated in Fig. 1.

The calculation of nutrient demand for a given farmland location is as per Equation 1:

$$M_{use} = \frac{M_E + M_{ca} - M_S}{HS} \times 100 \quad \text{Eq. 1}$$

where M_{use} is the nutrient demand (kg ha^{-1}) to be calculated. M_E refers to nutrient losses by soil erosion and leaching (kg ha^{-1}). Given that the amount of soil eroded is calculated by the Universal Soil Loss Equation (USLE), the amounts of nutrient losses by soil erosion are estimated using current spatial soil type-specific data (soil maps) of nutrient contents in soils. The amount of nutrient losses by leaching are approximated from relevant literature and leaching studies across various conditions of soil type, topography and weather. M_{ca} expresses the

amounts of nutrients up-taken by crops (kg ha^{-1}) that are calculated on the basis of field experiments and/or reviewing relevant literature. M_S accounts for the nutrient supplies to crops from the soil (kg ha^{-1}), which are estimated based on soil characteristics (soil bulk density, soil depth and available nutrients in soil) and the crop's nutrient uptake ability. These soil and crop parameters are spatially distributed as they are calculated using the maps of soil types and land/crop uses. HS is the mineral fertilizer use efficiency index (% of fertilizer-driven nutrient uptake by crops) that is estimated from field experiments and/or relevant literature. The data flow in the calculation of soil-crop-specific nutrient demands is summarized in Fig. 2.

2.2 Mapping crop-soil-specific nutrient demands and Web-based Geographic Information System (GIS)

Given basic Equation (1) and available spatial data, we applied Geographic Information System (GIS) technology to calculate and map the nutrient demand for crop groups in every commune in the study provinces. The maps were built based on site condition data (*e.g.*, soil data, present land use, rainfall, slope and altitude) and crop data (*e.g.*, crop type, crop area). The GIS

synthesis procedure is shown in Fig. 3.

Based on the above-described calculation procedure and the database of related variables, a Web-based GIS was developed for responsive assessment and visualization of soil-crop-specific nutrient demand in the study provinces. We used the ASP.NET technique and SQL server to provide public access to the output of the research.

3. Results

3.1 Nutrient demands for potential crop production

For demonstrative purposes, we spatially calculated the nutrient demand (N, P₂O₅ and K₂O) per area unit for main crops, and then aggregated the results for main crop groups (*i.e.*, industrial, fruit and cash crops) for each administrative unit (*i.e.*, district) in Dong Nai Province

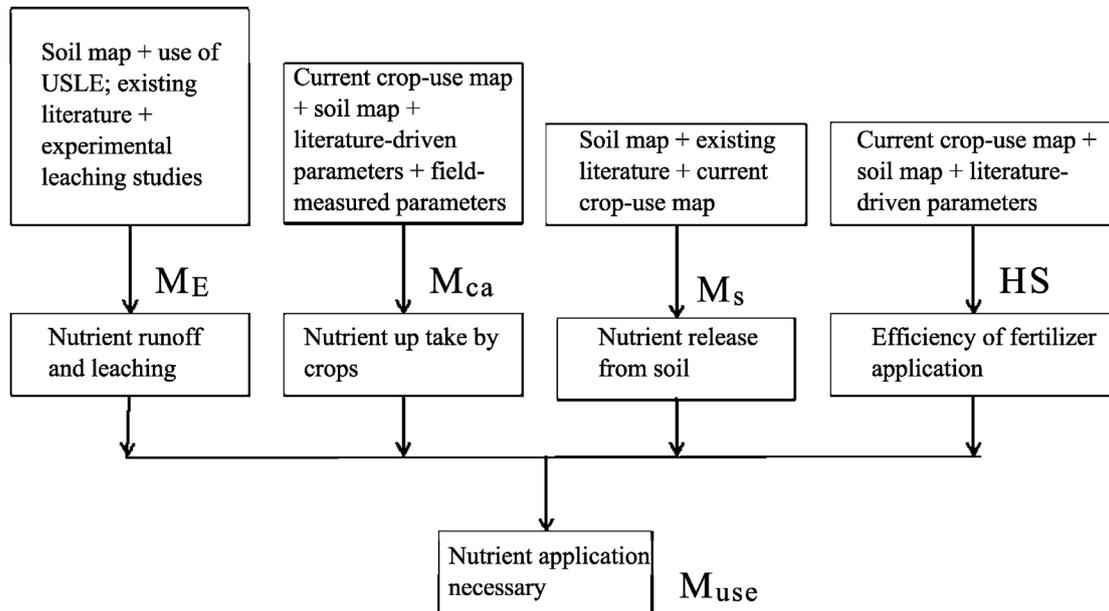


Fig. 2 Steps for determining crop-specific nutrient demands.

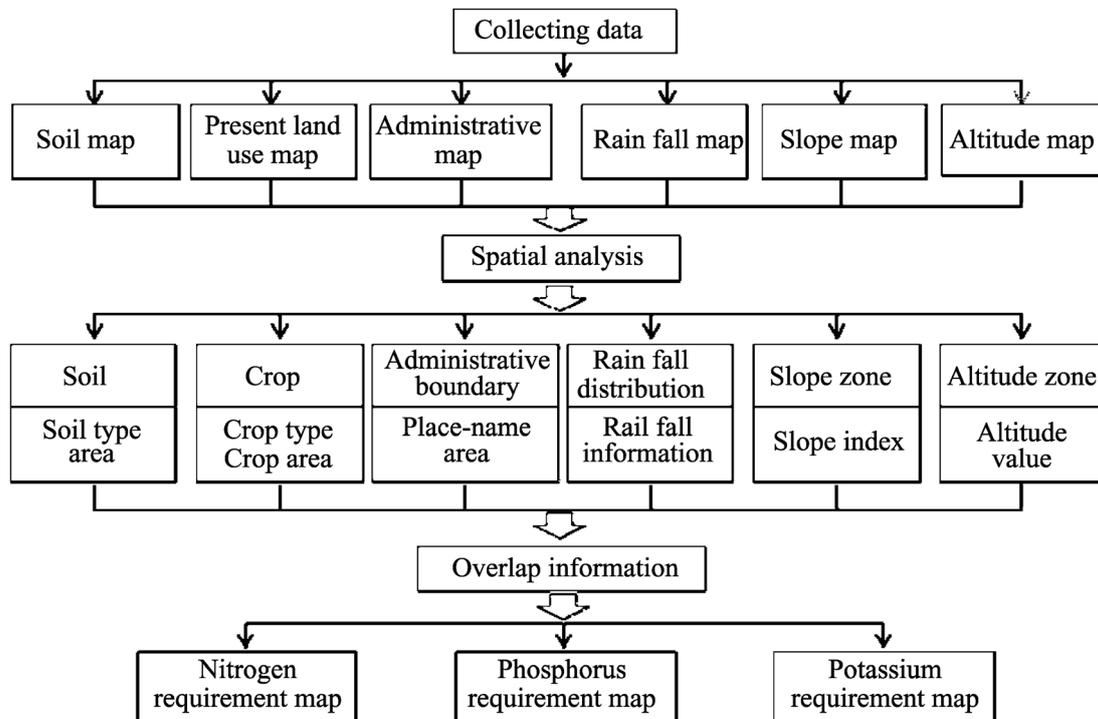


Fig. 3 Process of building nutrient maps.

(Fig. 4), but in Bac Ninh Province, we spatially calculated the nutrient demand for all crops for each administrative unit (Fig. 5) because the main crop in this province was cash crops. By looking at the district-wise distribution of nutrient demands per area unit of the three main crop groups (*i.e.*, in Dong Nai Province), provincial and district agencies can realize what nutrient types are most urgently needed in what areas to minimize the yield gaps of different crop groups.

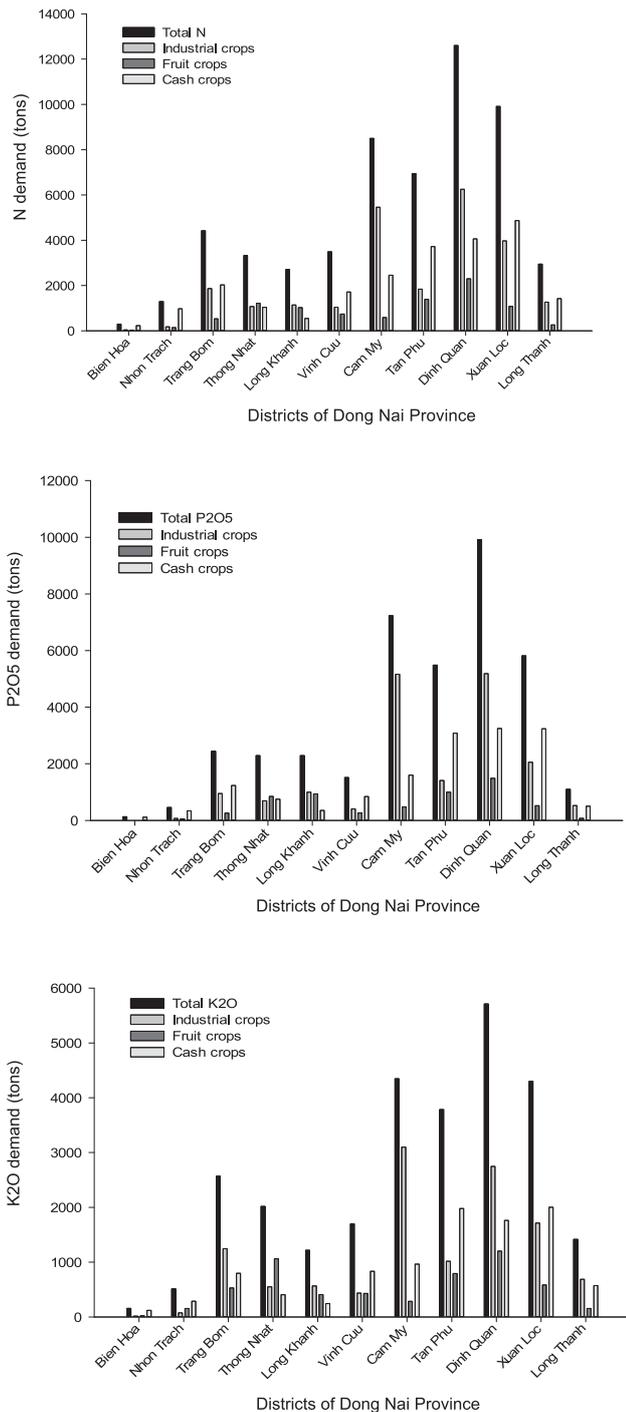


Fig. 4 Annual demand (tons) of N, P₂O₅ and K₂O for three main crop groups (industrial, fruit and cash crops) in different districts of Dong Nai Province.

3.2 Spatially explicit navigation of crop-specific nutrient demands using Web-based Geographic Information System (GIS)

We developed a Web-based GIS for depicting crop-specific nutrient demands that includes:

- (i) a home page and catalogue for information on soil, crops and administrative units (snapshot shown in Fig. 6).
- (ii) input data for calculating nutrient demands (*e.g.*, climate, soil characteristics, total area in communes/districts, cropping areas, mineral fertilizer use efficiency indices and nutrient demands of crops) and some user-defined data/parameters such as those illustrated in Fig. 7, and
- (iii) software to calculate nutrient demands in specified administration units (here districts) for each crop group, as demonstrated in Figs. 4 and 5.

4. Conclusions and Recommendations

This study assessed the nutrient demands of potential crop production in two intensive agricultural regions in Vietnam, and provided public access to the output. We calculated the N, P and K demands for reaching crop yield potentials over the farmlands in the two provinces, taking soil nutrient balances into account. The balance calculations considered natural nutrient supplies (*e.g.*, from soils), and different natural nutrient losses (*e.g.*, by volatilization, erosion, leaching, runoff and crops' uptake with different fertilizer use efficiencies).

The results were spatially explicit, presented at a map scale of 1:100,000, and managed by a Web-based Geographic Information System (GIS). The web-based GIS allows lay users to query the results at different levels of aggregation (*i.e.*, farm, commune, district and province) in a responsive and iterative manner.

Key parameters and components of the Web-based GIS model presented, however, still need calibration. These parameters include the soil erosion model used, crop nutrient uptakes and mineral fertilizer use efficiencies. This will require the performance of field experiments over the soil-crop matrix found in the study area.

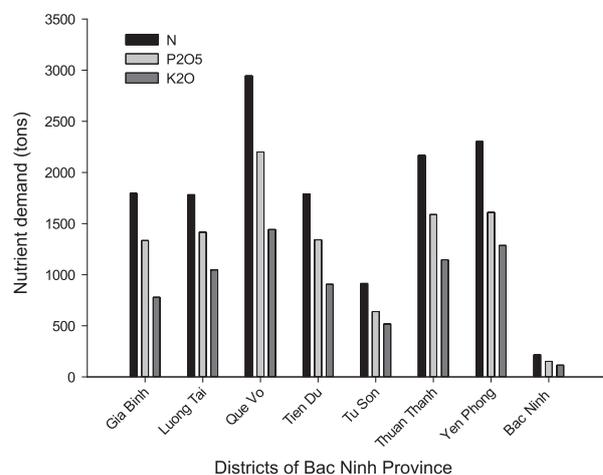


Fig. 5 Annual N, P₂O₅ and K₂O demand (tons) of crops in different districts of Bac Ninh Province.

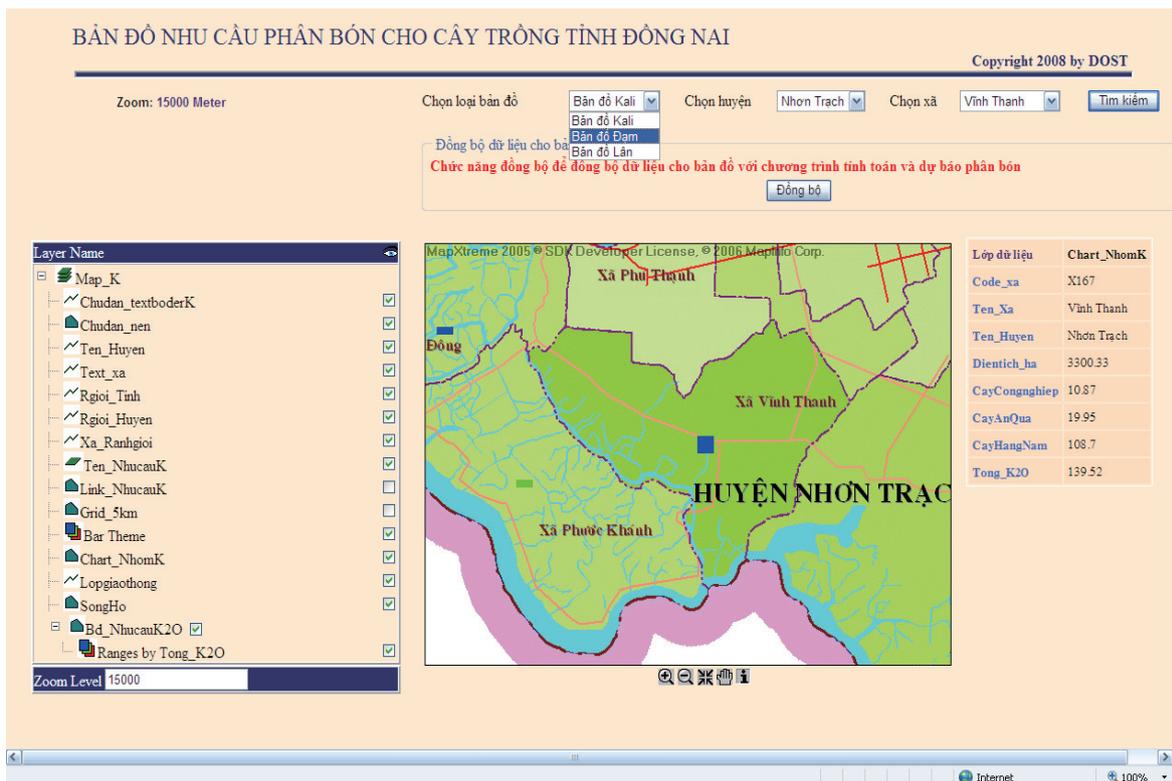


Fig. 6 Map and data on the Web.



Fig. 7 Form for farmer input data on the Web.

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Thu Thi Minh TRAN is a researcher at the Soils and Fertilizers Research Institute (SFRI), Ha Noi, Vietnam. She received her engineering degree from the Vietnam National University of Agriculture in 2000 in the field of land resource management. Since 2000, she has been employing as a researcher by the Soils and Fertilizers Research Institute. Mrs. Tran received her master's degree in 2005 from the Vietnam Academy of Agricultural Sciences in soil classification and land evaluation. Now, she is working on her PhD in agricultural sciences in soil fertility and plants at the Vietnam Academy of Agricultural Sciences. Her research focuses on soil surveys land evaluation, soil map production, and geographical indications for agricultural product in Vietnam.

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Quang Bao LE was appointed senior scientist at the CGIAR Research Program in Dryland Systems from January 2015. He earned his engineering degree in forestry from Hue University (1993) and his M.Sc. in environmental science from Chiang Mai University (1998). In 2005 he received his Ph.D. in geography, ecology and natural resources management from the University of Bonn. Dr. Le started his career as a junior lecturer at Hue University in 1993. After completing his doctorate he worked at the Center for Development Research (ZEF), University of Bonn as a postdoctoral researcher until 2009. He was a senior scientist at the Swiss Federal Institute of Technology (ETH), Zurich for the previous five years (2009–2014). Dr. Le's research has focused on the development and application of human-environmental system methodologies – with both qualitative and quantitative frameworks, indicators and models (*e.g.*, farming systems' nutrient flows and balances, bio-economic multi-agent system models) – to integrate his scientific expertise in different disciplines with societal decision processes fostering sustainable human-environmental systems at different levels and in various regional contexts.

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