Impacts of Site-Specific Nutrient Management in Irrigated Rice Farms in the Red River Delta, Northern Vietnam

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ABSTRACT

This study estimates the impact of the adoption of SSNM practices on rice production of smallholder farmers in Vietnam using cross-section household data (n = 371) gathered from the provinces of Ha Nam and Ha Tay in the Red River Delta. Specifically, it investigates the economic impact of SSNM, focusing on SSNM-induced changes in the yield, profit, nitrogen use and pesticide use of farmers. The instrumental variables (IV) approach is used to achieve this objective because it deals with endogeneity and self-selection bias present in the study. SSNM improves the paddy yield of farmers by 0.6 tons per hectare and profit by $150 per hectare. It has no statistically significant effect on the amount of pesticide and nitrogen use of farmers. The higher profits for adopters versus non-adopters of SSNM arise from increased grain yield rather from reducing fertilizer costs and pesticide costs. Results of the impact analysis identified several directions that can be pursued to improve further the adoption of SSNM.

Key words: Site-specific nutrient management, instrumental variables, nitrogen, Red River Delta, smallholder farmers

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I. Introduction

Rice is an important staple food for about 70 percent of the Asian population (nearly 3 billion people). More than 75 percent of rice worldwide is produced in irrigated rice lands and 90 percent of these irrigated lands are paddy rice production found predominantly in Asia (Bouman *et al.*, 2006). In irrigated rice grown under favorable tropical conditions, rice requires essential nutrients such as nitrogen that are typically not present in the soil in sufficient amounts to meet crop needs. Nitrogen is the most important nutrient because it significantly affects tillering, leaf area growth, biomass production, and grain yield (Yang *et al.,* 2003). It is also the most limiting agent in almost all soils (Balasubramanian *et al.,* 1999). Rice production alone uses 16 percent of total nitrogen fertilizer and 15 percent of fertilizer worldwide (Heffer, 2008). Fertilizer accounts for about 20 percent of input costs in rice production – the biggest after labor (Clayton, 2010). Because fertilizer is such an important input, it is essential for agricultural sustainability to develop effective management of nutrients important for plant growth (IFPRI, 2000). In this regard, rice production must become more efficient in the use of fertilizer and essential plant nutrients.

Fertilizer recommendations provided to farmers typically do not consider field, climate, and management-specific effects on the nutrient needs of the crop (Buresh, 2006). Indeed, factors affecting crop yield and quality are site-specific (Reets and Fixen, 2000). Therefore, to ensure that nitrogen and other essential plant nutrients are provided in optimal amounts, and are readily available during crop-growth periods, site- specific nutrient management (SSNM) was developed in Asia by the International Rice Research Institute (IRRI) [1]. SSNM is a low-tech, plant need-based approach for optimally applying nitrogen, phosphorus, and potassium fertilizers to rice when they are needed (IRRI 2006). As a result, wider farmer adoption of SSNM will increase land productivity, yield, and profitability of farmers, and decrease fertilizer-related pollution in the environment.

In Vietnam, researchers from IRRI and Soil and Fertilizer Research Institute (SFRI) initiated SSNM in five provinces in Red River Delta (RRD) in 1997. They developed specific SSNM recommendations tailored to soil conditions/fertility and the cropping seasons of different sites in the region. Given the large investments in the SSNM approach by international agencies (e.g. Swiss Agency for Development and Cooperation), various stakeholders and policy makers in Vietnam are interested in the magnitude of its impacts and currently, SSNM is not yet approved as an "advanced technology" in the country[2]. Hence, this study is conducted.

In this paper, I assess the impacts of SSNM on yield, profit, fertilizer use and pesticide use of Vietnamese farmers. Cross-sectional data from a 2007 farm-level survey conducted by IRRI in the provinces of Ha Nam and Ha Tay in the RRD form the basis of the analyses. To my knowledge, the survey was the first farm-level survey on the impact of SSNM conducted in Southeast Asia. I mainly rely on methods based on comparison of groups (i.e. comparison of SSNM adopters versus non-adopters, rather than comparison of before and after SSNM adoption or a combined panel data approach). Given that

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[1] The optimal amount of nitrogen and other essential plant nutrients is defined as the amount of nitrogen and other essential plant nutrients that will maximize yield. To focus on the SSNM itself, allocations under profit maximization which account for relative input and output prices are not considered since the effect of different rice prices and input prices is not large.

[2] The SSNM is not yet approved as an "advanced technology" since a project called "Three Reductions, Three Gains" (3R3G) which aims to reduce production costs, improve farmers' health, and protect the environment in irrigated rice production in Vietnam through the reduced use of seeds, nitrogen fertilizer, and pesticides, has already been approved and disseminated in the country.

cross-sectional data do not permit analysis of the dynamics of technology adoption (Doss, 2005), I use regression-based techniques to deal with selection issues typically present in impact analysis that utilizes comparison of groups. In particular, I use instrumental variables (IV) methods to solve the problem of missing or unknown controls. The IV methods can deal with the self-selection bias in observational data collected through household survey (Rosembaun and Rubin, 1983; Heckman and Vytlacil, 2005) and hence can identify the causal effect of adoption. Results indicate that SSNM technology improves farmers' yield and profit. However, pesticide and nitrogen use are found to be unaffected.

Analyses of this study will provide information to determine whether or not SSNM is effective in raising the productivity and profitability of rice. Confidence and consensus building on the developed SSNM technology is vital considering that other less efficient nutrient technologies are being promoted in the area. Policy makers will then be able to assess whether or not the research investment in developing this technology is worthwhile. More importantly, results of this study, if found to be positive, may help convince the Ministry of Agriculture and Rural Development (MARD) in Vietnam to approve the SSNM technology as an "advanced technology" and hence can be further disseminated in the RRD in particular, and in the whole country, in general. Moreover, upon SSNM approval, this study may guide them in future priority-setting decisions and help to focus dissemination efforts aiming to make an impact on farmers' lives. Although this study focuses on RRD area of Vietnam, the conditions in the study area are typical for rice farming in the intensive cropped lowlands of Southeast Asia.

Hence, findings from this study may have broader implications for other rice producing countries in the region.

II. Literature Review

Numerous studies exist that investigate adoption and impact of various agricultural techonologies (Griliches, 1957; Feder, Just and Zilberman, 1985; Feder and Umali, 1993 for a detailed survey of the adoption literature). Pandey (1999) enumerates that a farmer's decision to adopt nutrient technology depends on the following: (1) whether or not the fertilizer cost is greater than the marginal cost of acquiring and using efficient nutrient management technology; (2) added labor cost in using the technology; and (3) ease in applying the technology. Balasubramanian (1999) indicates that many technical factors and management practices constrain the adoption of efficient nitrogen management techniques. These include (1) poor water control; (2) low plant population; (3) partial nutrient application[3]; (4) insufficient weed control; (5) untimely sowing, transplanting, weeding, and/or harvesting; and (6) poor postharvest processing. Akinola *et al*. (2007) add a number of factors such as (1) access to credit, (2) farmers' perception of the state of land degradation, and (3) assets ownership. Ouma *et al*. (2002) look at the adoption of improved seed and fertilizer in Embu District in Kenya where they find that gender, agro-climatic zone, manure use, hiring of labor and extension services are significant determinants of adoption.

The potential impacts of these nutrient-management techniques are also studied by Duflo *et al*. (2005). They run controlled experiments in Western Kenya over five years to measure returns from fertilizer use and find that the average net rate of return for

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[3] When farmers are faced with cash constraints, they tend to buy and use mostly N fertilizers. This selective application of nutrients in intensive systems leads to soil mining of elements not supplied from external sources.

investing in top-dressing fertilizer is between 28 percent and 134 percent for an eight-month investment. In addition, there are several studies that specifically examine the impact of the SSNM approach on fertilizer use and/or paddy yields primarily using field experiments.

Doberman *et al*. (2002) conduct on-farm experiments to develop and test a new SSNM approach for eight key irrigated rice production domains of Asia located in six countries from 1997 to 1999. They hypothesized that rice yields, profit, plant nutrient uptake, and nitrogen use efficiencies can be significantly increased by applying fertilizers on a field-specific and cropping season-specific basis, i.e. through SSNM. They find that average grain yield increased by 0.36 Mg per hectare with SSNM as compared to current farmers' fertilizer practice in their study in cropping systems in Asia. Their results also show than SSNM led to significant increases in nitrogen use efficiency. Average agronomic efficiency applied nitrogen (kg grain yield increase per kg nitrogen applied) under SSNM was 15 kg kg^{-1}, apparent recovery efficiency of applied nitrogen (kg nitrogen taken up per kg nitrogen applied) 0.40 kg kg^{-1}, and partial factor productivity of applied nitrogen (kg grain per kg nitrogen applied) 52 kg kg^{-1}. Compared to the farmers' fertilizer practice, average agronomic efficiency applied nitrogen and recovery efficiency of applied nitrogen increased by almost 30 percent, partial factor productivity of applied nitrogen by six percent.

In terms of profitability, on average, across all sites, there was an increase in profitability of US$46 ha^{-1} through the use of SSNM. This increase is attributed to the following: (1) SSNM technology was gradually improved and more effective at increasing yields in the second year; and (2) the SSNM strategy involved re-capitalizing soil phosphorus and potassium applied in the first year.

Son *et al*. (2004), particularly analyze the SSNM in irrigated rice systems of the Red River Delta. A SSNM plot was established on each of the 24 farm fields as a comparison with the farmers' fertilizer practice. Using simple comparison of means, SSNM results in a small yield increase of 0.19 tons per hectare on winter-spring season over the farmers' fertilizer practice, which is not statistically significant. They also look at the effect of SSNM on fertilizer use and profit. Results of their study reveal that SSNM decreased the total fertilizer cost by about \$2 per hectare in 1998 and by \$22 per hectare in 1999. The average profit increase over farmers' fertilizer practice is \$41 per hectare in 1998 and \$74 per hectare in 1999.

Pampolino *et al*. (2007) explore the environmental impact and economic benefits of SSNM in irrigated rice systems in Asia, particularly in the Philippines, southern India, and southern Vietnam. Using on-farm trials research data, their results show that SSNM leads to higher efficiency of nitrogen use. While the annual nitrogen use was the same for SSNM and farmers' fertilizer practice farmers in India, the reductions in fertilizer use with SSNM averaged 10 percent in the Philippines, and 14 percent in Vietnam. In all three locations, the estimated grain yields were significantly higher in SSNM than in farmers' fertilizer practice fields. In addition, the partial factor productivity of nitrogen increased significantly with SSNM in the Philippines and Vietnam. This increase can be associated with increased plant use of nitrogen and reduced loss of nitrogen. SSNM decreases the percentage of total nitrogen losses from applied fertilizers, thus reducing the nitrous oxide emissions and global warming. Economic performance of SSNM ad and adopters and non-adopters are also compared using economic data through focus group discussions. Gross revenue and gross return above fertilizer costs are higher for SSNM than non-SSNM farmers across the three countries. Although the practice of SSNM does not reduce the total input costs, it raises the net benefits of farmers by US$168, US$106, and US$34 per hectare per year in India, the Philippines, and Vietnam, respectively. Dawe et al. (2004) find in their study in China, Southern India, and the Philippines the profitability in SSNM ranged from $57 to $82 per hectare. They also find out that the sites in Vietnam (southern and northern) exhibited intermediate levels of profitability at $38-39 per hectare. Studies of Khurana et al. (2007) in northwestern India and Wang et al. (2007) in China find similar results.

Most of the studies mentioned above typically are based on controlled field experiments and focus group discussions data that use simple "with SSNM and without SSNM comparisons" without controlling for a number of econometric problems that may have affected inferences (i.e. endogeneity and selection). These studies do not utilize farm-level survey data to examine actual behavior of farmers (who face constraints that experiment participants do not) and impact of the SSNM approach. Also, it is likely that farmers with more human capital are more likely to participate in the farm-trials. In addition, no study (as far as I know) has specifically examined the impacts of SSNM on pesticide use of farmers.

This paper contributes to the literature by (1) providing an analysis of SSNM impact on yield, profit, nitrogen use, and pesticide use based on actual practice of farmers since farmers' perceptions of the effectiveness of SSNM will be an important factor affecting adoption, and the visibility of yield gains will be an important factor influencing those perceptions and (2) using regression-based approaches that control for endogeneity and selection bias in the impact analysis of the SSNM technology.

III. Background, Survey Design, and Data Description

A. SSNM Technology in Vietnam: Overview and Dissemination Approach

Rice production in RRD accounts for about 20 percent of total rice output in Vietnam. The RRD has an area of about 1.5 million hectare spread over 10 provinces including Hanoi, the capital. It is probably one of the most intensively cultivated agricultural areas in the world, in terms of both cropping intensity and the cumulative amount of grain produced per year (Son *et al*., 2004). The total agricultural land in 2007 was 756,000 hectares account for 51 percent of the total land area of the region. RRD is the second largest rice area in the country next to Mekong River Delta and is considered as the rice bowl for the north.

From 1990 to 2003, the total land area cultivated to rice in Vietnam increased 1.4 times while nitrogen, phosphorus, and potassium applied per hectare increased 2.97 times, 4.76 times, and 14.3 times, respectively (Hien, 2005). Various studies (Hien, 2005; UNEP, 2005; Dung *et al*., 2003) report unbalanced and excessive use of chemical fertilizer, especially nitrogen in the RRD. Inappropriate rates and timing of fertilizer applied to rice lead to losses in income and negative environmental impacts.

To help address this problem, the IRRI and the SFRI developed specific SSNM recommendations in RRD in 1997. The SSNM recommendations are based on the following principles: (1) estimation of nitrogen-potassium-phosphorus requirements for the target grain yield[4]; (2) determination of indigenous nitrogen-potassium-phosphorus supply; (3) calculation of nitrogen-potassium-phosphorus fertilizer rates; and (4) use of dynamic nitrogen management using leaf color charts (LCCs)[5].

The SFRI then collaborated with the Plant Protection Division and the provincial extension center in RRD. During the period 1997-2000, on-farm research was focused in giving preliminary recommendations on nutrient management for alluvial and degraded soils in the provinces of Ha Tay and Vinh Phuc. From 2001-2004, SSNM was validated for intensive rice systems in five provinces of RRD namely, Nam Dinh, Ha Nam, Ha Tay, Vinh Phuc, and Hai Phong. In these five provinces, SSNM evaluation and nutrient omission plot experiments were conducted in five soil types of RRD. Pilot trials, training of trainers, farmer field school, and field demonstrations were conducted. A curriculum for training of farmers was developed and revised over four consecutive cropping seasons (2003-2004). In 2005, wider-scale evaluation and promotion of SSNM began in 11 provinces of the RRD (Figure 1). In eight of eleven provinces, activities in 2005 included both research (LCC demonstration, nutrient omission plots) and training of trainers. In the three provinces remaining, the activities focused only on training of trainers.

The National Extension Center and the Plant Protection Division provided extension information directly to farmers through mass media, such as television, radio, and newspapers. The provincial extension center and sub-Plant Protection Divisions also

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[4] The grain yield target for a given location and season is the estimated grain yield attainable with farmers' crop management when nitrogen, phosphorus, and potassium constraints are overcome. It therefore indicates the total amount of nutrients that must be taken up by the crop.

[5] LCC is an easy-to-use and inexpensive diagnostic tool for monitoring the relative greenness of a rice leaf as an indicator of the plant N status, and then enabling farmers to apply fertilizer N whenever leaves reach a critical N status determined by their yellowish-green color (Alam et al. 2005). The standardized LCC is five inches long, made of high-quality plastic consisting of four-color shades from yellowish green (No.2) to dark green (No. 5). The color strips are fabricated with veins resembling rice leaves.

disseminated information through local television channels and publications. Note, however, that information was broadcasted on limited occasions at the project sites.

SSNM was also introduced to farmers through extension networks in a limited number of communes in the project sites. Extension workers held trainings, workshops, and field visits. The National Extension Center and Plant Protection Division also had demonstration model plots in the project sites. During the introduction of new rice varieties or seed production, SSNM was incorporated in some communes as a required practice. It is important to note that these activities were only feasible in areas where there was enough budget/funding for SSNM development. So far, SSNM has not been approved as an "advanced technology" by the Scientific Committee of Ministry of Agriculture and Rural Development of Vietnam. Thus, it is not yet considered as a technology that can be officially disseminated through the wide network of extension systems, and hence, limited funds from extension departments (national and provincial) are provided for the diffusion of SSNM.

B. Data Description and Sampling Approach

Primary survey data were obtained from both the SSNM farmer-adopters and non-SSNM farmer-adopters in the provinces of Ha Nam and Ha Tay. The Ha Nam province was selected for the following reasons: (1) presence of demonstration plots in farmer fields (omission plots to determine the amount of fertilizers nitrogen, phosphorus, and potassium required for attaining a yield target); use of a LCC to assist farmers to decide whether the rice plant requires nitrogen fertilizer began in 2002 in one village in each of its two districts; (2) a farmer field day was held in 2003 with coverage by the local television channel; (3) training of trainers and farmer field days have been held each year from 2004-2007 which involved local government officials, including extension specialists from each district within the province, and key farmers; and (4) strong support for extension of the technology from the provincial Department of Agriculture. Ha Tay province was selected because: (1) it was one of the five provinces where SSNM evaluation and nutrient omission plot experiments were conducted on five soil types from 1998-2004; and (2) activities such as LCC demonstration and training of trainers where conducted from 2005 onwards.

A three-stage sampling approach was then employed in the selection of farmer-respondents. The first stage was the non-random selection of two districts within each province based on the quality of the soil to account for soil-specific fixed effects. In Ha Nam, these districts were Bin Luc District representing poor soil and Thanh Lien District representing good soil[6], while in Ha Tay, Thuong Tin (good soil) and Thach That (poor soil) were chosen. Second, two or three villages from each district were then randomly chosen. The villages selected within a district had similar characteristics with regard to the topography of soil and climate. Third, a random selection of farmer respondents was conducted for each village. After the survey, considering time and budget constraints, there were 371 farmer-respondents in the study. Sixty-one percent of the respondents were classified as SSNM adopters and 39 percent as SSNM non-adopters. SSNM adopters are those farmers who currently practice SSNM; otherwise they are SSNM non-adopters.

The data were collected from 2006 winter-spring season which consist of on-farm fertilizer management strategies of the farmers, various input and output data for rice

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[6] In the context of this study, poor soil is high lime content, whereas good soil is the alluvial type of soil. Alluvial soils are generally rich in mineral nutrients. This is the best soil in the delta, with humus content of two percent, total nitrogen of 0.1 to 0.25 percent, and medium phosphorus and potassium.

production, such as input use (i.e. labor, seed, etc.), rice production output, input costs, and rice revenues[7]. In addition, information about pertinent socio-demographic characteristics of the farm like the household size, tenure status, and exposure to SSNM training were collected.

IV. Empirical Approach and Estimation Procedures

A. Estimation Strategies

The following estimation measures the impact of SSNM adoption on the following outcome variables: paddy yield, profits, nitrogen use, and pesticide use. In the context of this study, the equation to estimate the outcome variables can be expressed using the following Ordinary Least Squares (OLS) regression:

$$y_i = \boldsymbol{x_i \beta} + SSNM_i \alpha + \varepsilon_i \qquad (1)$$

where y_i is the outcome of interest of farmer i, $\mathbf{x}_\mathbf{i}$ is the vector of farm/farmer characteristics, $SSNM_i$ is a binary variable representing whether or not farmer adopted SSNM, $\boldsymbol{\beta}$ is a vector of parameters to be estimated, α_i is the impact parameter of interest, and ε_i is a random error term. A crucial assumption of OLS is that the random error term is uncorrelated with independent variables in the model. In the context of my study, the samples are not randomly selected; therefore SSNM dummy variable and the amount of fertilizer use may be endogenous because of unobserved covariates (i.e. unobserved management ability) that affect the decision to adopt SSNM, amount of fertilizer use, and the outcome variables of interest. That is, SSNM and amount of fertilizer use are likely to be correlated with ε_i.

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[7] I only use the data from winter-spring season because the summer-autumn season is often affected by heavy rainfall or storms.

I control this endogeneity problem using instrumental variables (IV) for treatment (Imbens and Angrist, 1994; Imbens, 2004; Heckman and Vytlacil, 2005). Let the SSNM adoption now be defined as follows:

$$SSNM_i = \mathbf{z}_i \boldsymbol{\pi}_i + v_i \qquad (2)$$

where $\mathbf{z}_i$ is a vector of explanatory variables that affect SSNM adoption, $\boldsymbol{\pi}_i$ is a conformable parameter vector to be estimated, and v_i is a random error term. The endogeneity problem exists if there are unobserved factors in ε_i and v_i that make these errors correlated (See Heckman, 1978; Burrows, 1983). To ensure proper identification, there should be at least one instrument that is correlated with SSNM status but does not affect the outcome once the effects of the covariates are controlled for. Using my sample, I can now regress (2) using probit model and then use the predicted probability $\left(\widehat{SSNM}\right)$ as an instrument for the actual SSNM dummy variable, i.e.,

$$y_i = \boldsymbol{x_i}\boldsymbol{\beta} + \widehat{SSNM_\imath}\,\alpha + \varepsilon_i \qquad (3).$$

Equation (3) can then be estimated using OLS regression and the parameter estimate α is more accurate impact measure of the SSNM approach. I use also IV for the amount of fertilizer use (nitrogen, phosphorus, and potassium) that may also be endogenous. However, instead of using the predicted probability as an instrument, I use the predicted values of nitrogen, phosphorus, and potassium. One possible problem in using IV approach is heteroskedasticity because it can make the standard errors inconsistent. To address this problem, I implement Generalized Method of Moments (GMM) estimation that generates efficient estimates in the presence of heteroskedasticity.

B. Empirical Specification

The outcome/dependent variables of interest (y_i) are farmer's nitrogen use, paddy yields, profits, and pesticide cost[8]. Nitrogen use is tested to see whether SSNM adoption reduce or increase the quantity of nitrogen use. SSNM eliminates waste of fertilizer by preventing excessive rates of fertilization and by avoiding fertilization when the crop does not require nutrient inputs. Reduction in nitrogen use may be possible in some areas without any sacrifice in yields (Wang *et al*., 2001). This would in turn improve farm profitability to some extent (lower input costs); perhaps even a large extent in areas where fertilizer use is very high. More so, optimal use of fertilizer will lead to increased paddy yield. Hence, yield and profitability of farmers are of interest. A given percentage increase in yield will do much more for profitability than a similar reduction in nitrogen use, because the ratio of nitrogen costs to gross revenue from paddy is typically eight percent or less (Dawe, 2000). Lastly, since improved nitrogen management makes crop less attractive to pests, it is interesting to see whether SSNM adoption reduces the cost of pesticide use for irrigated rice.

To estimate the impact of SSNM on yield, profit, and pesticide cost (equation 3), the following covariates are used in my specification: education, years of farming experience, land ownership dummy, household size, whether or not the soil is good, nitrogen use, phosphorus use, potassium use, whether or not farmer has access to credit, seed use, and labor use. Education and farming experience are proxy variables for knowledge, farming ability, and experience. Land ownership dummy and household size variables account for wealth and scale effects and good soil dummy variable accounts for

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[8] Pesticide costs includes insecticide, fungicide, herbicide, molluscicide, and rodenticide. I could not find a common measurement index for these pesticide, thus cost is used in the analysis.

soil-specific effects. The credit dummy variable is included to see whether a farmer has access to credit because the lack of such access may constrain farmers from using technologies that require the initial investments (Doss, 2005). The nitrogen, phosphorus, potassium, seed, and labor variables account for other essential inputs of production and these explanatory variables are consistent with previous empirical impact studies of technology (Pampolino *et al.*, 2007; Wang *et al.*, 2007).

To predict probability of *SSNM* in the first-stage probit (equation 2), I use as explanatory variables ($\boldsymbol{z_i}$) education, years of farming experience, land ownership dummy, household size, whether or not the soil is good, amount of nitrogen use, amount phosphorus use, amount potassium use, whether or not farmer has access to credit, amount of seed use, and amount of labor use. The instruments I use are whether or not the farmer is married, a dummy for training, whether or not the farmer has seen a LCC, a province dummy and a male dummy. A priori, a married farmer is expected to adopt SSNM since he needs to feed more mouths (i.e. he has more incentives/motivation to increase his profits). The training dummy pertains to the SSNM training where farmers are trained on the techniques and guidelines to use effective nutrient management practices for their specific rice-growing conditions. The LCC dummy is also included to account for the awareness of farmers on the relative greenness of a rice leaf as an indicator of the leaf nitrogen status. The province dummy serves as a proxy for provincial agricultural extension agents' effectiveness in the conduct of SSNM training while male dummy variable is specified to account for the female household heads participation. In RRD, females are usually the one who buys fertilizer, and who decides when and what fertilizer to buy while applying fertilizers is largely perceived as men's role. Note that married, training, LCC, province, and male dummies are the explanatory variables in the selection equation but not in the impact equation to ensure identification. An over-identification test indicates that these instruments are valid for both SSNM and fertilizer use. The predicted probability of SSNM using these instruments is then used to estimate the yield, profit, and pesticide cost in the second stage. Since fertilizer use may also be endogenous, the estimated values of nitrogen use, phosphorus use, and potassium use are also computed using these instruments[9].

Since the amount and timing of fertilizer decision is the major component of SSNM, the SSNM approach will not only affect yield, profit, and pesticide cost of farmers, but also the nitrogen use. To estimate the impact of SSNM on nitrogen use, the following explanatory variables are used: training dummy, LCC dummy, education, years of farming experience, land ownership, household size, good soil dummy, amount of seed and labor, and pesticide cost. The following are the explanatory variables to predict the probability of SSNM and the estimated values of phosphorus and potassium use in the first stage: education, years of farming experience, land ownership dummy, household size, whether or not the soil is good, amount of nitrogen use, amount phosphorus use, amount potassium use, whether or not farmer has access to credit, amount of seed use, amount of labor use, whether or not the farmer is married, a dummy for training, whether or not the farmer has seen a LCC, a province dummy and a male dummy. The credit, married, male, and province dummies are the instruments used in the selection equation but not in the impact equation. The over-identification test indicates that the instruments used are valid. A detailed description of all the variables used in analysis is shown in

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[9] Usually nitrogen, phosphorus, and potassium are applied together by farmers. However, in this study I analyze these three nutrients separately since farmers usually apply different formulations of nitrogen, phosphorus, and potassium to the farm.

Table 1. The summary statistics for all the explanatory variables in the impact and first stage equations are presented in Table 2 by treatment category.

V. Results and Discussion

A. First Stage Model Results

The results of the first stage regression models are presented in Table 3. For the SSNM adoption model, I find the attendance in the SSNM training, awareness of the availability of LCC, and seeds use (kg/ha) to be statistically significant. Farmers who are likely to adopt SSNM are those who have the technical knowledge to use the SSNM method. The SSNM approach requires that farmers are aware about the nutrient needs of rice crop at its different growth stages and know how to use the LCC as a guide in determining the timing and rate of fertilizer that needs to be applied. This technical knowledge is provided in the SSNM training. Farmers are also taught of using the LCC. A higher seeding rate tends to reduce the probability of adopting SSNM. Vietnamese farmers, who practice wet seeding, use high seed rates in order to reduce risk and control weeds. The high seed rate might increase yield in the absence of fertilizer nitrogen and across all rates of fertilizer nitrogen. Hence, the probability of farmers adopting the SSNM approach is lower.

As the amount of nitrogen, phosphorus, and potassium use may be endogenous, I also instrument farmers' fertilizer use. Note that SSNM approach does not specifically aim to either increase or reduce fertilizer use rather it aims to apply nutrients at optimal rates and times in order to achieve high paddy yield and high efficiency of nutrients use by rice, leading to high cash value of yield per unit of fertilizer invested (Buresh *et al.*, 2005). In the nitrogen equation, the factors that are found to be statistically significant are SSNM training, LCC, province dummy, education, and pesticide cost. The attendance in training increases the use of nitrogen by 8 kg/ha. This suggests trained farmers are aware of the importance of nitrogen in rice. Nitrogen is applied to crop to increase height, promote production of tillers, and increase the sizes of leaves and grains. On the other hand, LCC tends to decrease nitrogen use by 14 kg/ha. Farmers used to think that green leaves are always a good indicator of high yield and try to apply as much nitrogen as possible. However, with the use of LCC, farmers are able to monitor the nitrogen status of plants and only apply nitrogen fertilizer whenever leaves reach a critical nitrogen status determined by their yellowish-green color. With the use of LCC, they are able to maintain optimal leaf nitrogen content. With the training and awareness of LCC, they learned that nitrogen should not be applied at anytime and at any amount to achieve "green leaves". However, only one-fifth of the SSNM adopters own a LCC. Other adopters do not own and use LCC because they are able to observe leaf color and already know when and how much nitrogen should be applied. Also, when village leaders and/or extension workers visit, they use LCC and recommend farmers on fertilizer application.

Further, if a farmer lives in Ha Nam, the amount of nitrogen fertilizer is reduced. The province dummy serves as a proxy for the level of skills or effectiveness of provincial extension workers. The effective uptake by farmers of a relatively knowledge intensive technology such as SSNM necessitates the communication of consistent and clear messages to farmers. This requires ensuring the extension workers who provide information to farmers are familiar with the SSNM guidelines and how they can be used by farmers to develop improved practices for specific rice fields through trainings. However, since there is a very limited fund for SSNM in Vietnam, it is possible that the quality of training given to local extension workers and eventually the quality of training workshops, and information given to farmers by the former might be affected by the budget constraint. The reduction of nitrogen use might suggest that extension workers in Ha Tay are more effective in teaching farmers the importance of essential plant nutrients, especially nitrogen, phosphorus, and potassium to the development of rice crop. Meanwhile, higher education level of farmer tends to decrease its nitrogen use. This suggests more educated farmers tend to avoid using excessive amount of nitrogen. Perhaps with their education level, these farmers are aware that excessive use of nitrogen does not necessarily translate to higher yield and is harmful to the environment. On the contrary, the higher the pesticide use, the higher is the nitrogen use of farmers. To compensate for the loss in yield due to presence of pests, farmers tend to apply more nitrogen. Recent studies (Potera, 2007; Fox, *et al*., 2007) also show that pesticide disrupts nitrogen fixation[10]. When this happens, increased dependence on synthetic nitrogenous fertilizer occurs.

In the phosphorus equation, I find that having access to credit, living in Ha Nam province, and increasing the seed rate have a negative statistically significant effect on the amount of phosphorus use in the field. Although fertilizer accounts for almost 20 percent of farm expenditure, farmers usually do not borrow money to spend on fertilizers. Vietnamese farmers usually access credit to pay for farm labor requirements (e.g. land preparation). More so, access to credit is used for other household expenditure (e.g. education of children). Like in the case of nitrogen use, the province dummy has negative relationship on phosphorus use. This may suggest that extension workers in Ha

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[10] Plants produce chemicals that attract *Rhizobium* soil bacteria to their root systems to form nodules for nitrogen fixation (Potera, 2007). Nitrogen-fixing *Rhizobium* bacteria convert atmospheric nitrogen to ammonia and other sources utilizable by plants.

Nam province may have not fully explained and emphasized the importance of phosphorus to rice to farmers. Phosphorus stimulates root development, tillering, and early flowering. It also helps in the grain development.

The statistically significant factors that affect the use of potassium are the following: LCC, access to credit, province dummy, and farming years. Like the effect in nitrogen use, LCC, access to credit, and province dummy have negative relationship on the amount of potassium use. In contrast, the more years of farming experience of farmers tends to increase the amount of potassium used and this has to be interpreted with caution. One way to interpret this result is that more experienced farmers are the ones who are more knowledgeable in farming. They know that potassium plays an important role in physiological process of rice, and contributes to greater canopy photosynthesis and crop growth. Potassium also increases the number of spikelets per panicle (flowers per grain bunch) and percentage of filled grain. Another way to interpret this is it is possible that old farmers are once told to use potassium in their rice field using blanket recommendation and thus, they just apply potassium fertilizer because they are told to do so. It does not necessarily mean that more experienced farmers are more aware of the importance of potassium in the plant.

In the previous discussion, results show that pesticide increases the amount of nitrogen applied. It follows that pesticide also increases the amount of potassium used since in most cases, farmers are applying fertilizer in a nitrogen-phosphorus-potassium (NPK) formulation. These three nutrients are usually the basic components in fertilizer.

B. Impacts on paddy yield

The estimated impact of SSNM on yield (kg/ha) using OLS procedure and a two-stage procedure are shown in columns 3 and 4, respectively, of Table 4. The results from the two-stage least square regression method indicate that there is a statistically significant difference between the SSNM adopters' and SSNM non-adopters' rice yield (at the 1 percent level). My mean comparison shows that SSNM adopters have 615 kg/ha (0.6 ton/ha) more yield. This suggests farmers who adopt SSNM approach tend to increase their yield level conditional on other factors that affect yield. Without controlling for endogeneity and selection, the magnitude of impact of SSNM is underestimated (only 0.14 tons per hectare). This is consistent with the study of Son *et al.* (2004), which reports SSNM only increases yield by 0.19 ton per hectare and is not statistically significant. The instrumental variable heteroskedasticity test reports a Pagan-Hall general test statistics of 0.949, failing to reject the null hypothesis of homoskedasticity. Given this, the Sargan test statistic for over-identifying restrictions is the appropriate test. The Sargan test statistic indicates validity of the chosen instruments.

The three other factors that have positive relationship with yield are access to credit, good soil dummy and amount of potassium use. When farmers have access to credit, yield increases by 300 kg/ha. This is because it will be easier for farmers to procure seeds and fertilizers at the start of the growing season, rent machinery, and hire labor. Planting in a good soil increases yield by 750 kg/ha. This is not surprising since alluvial soils are generally rich in mineral nutrients. Yield also increases by approximately 40 kg/ha when additional kilogram of potassium is used. The SSNM approach encourages farmers to apply phosphorus and potassium within 14 days after transplanting and apply potassium at panicle initiation stage of the crop growth. Since potassium plays an important role in increasing the size and weight of the grains, it follows that yield increases.

One statistically significant factor that has a negative effect on yield is the number of years of farming experience of farmers. This result is counter-intuitive. More years of experience is often hypothesized to increase the yield. However, it is also possible experienced farmers tend to shy away from training opportunities and not willing to innovate but rather rely on their experience in farming to increase yield. Given this, younger farmers are more receptive to new information and that they apply nitrogen, phosphorus, and potassium fertilizer at the right time and thus, they have higher yield than those more experienced farmers.

C. Impacts on profit

Using the two-stage least square regression, SSNM increases farm profit by almost $150/ha (Table 4). A large part of this increase results from the positive impact of SSNM on yield. Compared to the results from the study of Pampolino *et al.* (2007), this amount is almost four times larger. This indicates that the method used by Pampolino *et al.* (2007) underestimates the impacts of SSNM on profit. The difference in the magnitude of profitability may significantly affect the decision of farmers to adopt the SSNM approach. Financial profitability of a technology is a necessary condition for widespread adoption by farmers.

The Pagan-Hall test statistic of 0.769 suggests failing to reject the homoskedasticity. The Sargan statistic supports the validity of the instruments used. Table 4, Column 4 also shows that increasing the amount of phosphorus applied significantly increases profit. Phosphorus helps increase the size and weight of grain. This increase converts to higher yield and thus, higher profit.

In contrast, the relationship between profit and nitrogen use is negative and statistically significant. That is, a kilogram increase in the nitrogen use decreases profit by roughly $6/ha. For farmers in RRD, this is practically a significant amount. Increasing the amount of nitrogen applied to rice does not necessarily convert to neither increase profit nor yield. This supports the idea of SSNM, i.e. increasing the amount of nitrogen applied to crop will not surely increase yield and/or profit but it is important that the fertilizer is applied at the right time when the plants need it.

Increasing the amount of labor used and ownership of rice farm also has negative impact on farmer's profit. A one-manday increase in the labor use decreases profit by almost $12/ha. Labor in Vietnam are usually hired and in great demand during land preparation, planting, and harvest season. Interestingly, if a farmer owns a land, his profit will significantly decrease by almost $130/ha. Additional explanatory variables capturing wealth effects on farming would have perhaps explain such counter-intuitive results. Location factors of the land - such as climate and availability or access to information - can also influence the profitability of farmers.

D. Impacts on pesticide cost

The adoption of SSNM has a negative impact on pesticide cost although it is statistically insignificant. The negative relationship may indicate SSNM approach makes rice less attractive to pests because of better nitrogen management. Balanced application of fertilizer for rice plants improves crop health, hence crop resistance to insects and other diseases, especially those related to nutrient management such as blast, bacterial blight, stem borer, brown plant hopper (Son, 2006).

Using the OLS regression model, the factors that affect pesticide cost are potassium use, amount of seed use and labor. Results show that an additional kilogram increase per hectare of potassium use increases the pesticide cost by \$0.05. When over-applied, fertilizer can increase insect and disease problems. However, the increase in pesticide cost is minimal and economically insignificant. Meanwhile, as farmer increases the amount of seed used, the pesticide cost decreases. This is because farmers also treat seeds from pest. Labor and pesticide cost have negative relationship. Labor and pesticide can be substitute inputs to control pests. For example, instead of spraying molluscicide, farmers can just pick up the snails in the farm. Although these variables are statistically significant, like the increase in pesticide cost, the numbers are not practically significant. When endogeneity is controlled for, no explanatory variable is found to have a significant relationship on pesticide cost (Table 4, Column 7). This may indicate that pesticide, as an input, is no longer constraint to paddy yield.

E. Impact on nitrogen use

The impact of SSNM adoption on nitrogen use is presented in Table 5. Using the OLS procedure (Column 2), SSNM adoption has a negative effect on the level of nitrogen use of farmers although this is not statistically significant. Even when endogeneity and selection problems are accounted for (Column 3), this relationship between SSNM adoption and nitrogen use still holds true. This result suggests that SSNM neither reduces or increases the nitrogen use of farmer but rather it makes farmers to apply nitrogen at optimal rates and times in order to achieve high rice yield and high efficiency of nitrogen use by rice. This result is in contrast with the findings reported by Pampolina *et al.* (2007), which shows SSNM significantly reduces the nitrogen application of farmers.

To check for the presence of heteroskedasticity, a Pagan-Hall test statistic is computed that gives a value of 4.845 and is not significant. Thus, I fail to reject the null hypothesis of homoskedasticity. Given this result, the Sargan statistic is presented with a value of 0.69 with a p-value of 0.40, indicating the instruments used in the analysis are valid. Similar to the results in the first stage regression, educational level is statistically significant factor that affect the nitrogen use of farmers.

VI. Conclusion and Policy Implications

This study estimates the impact of the adoption of SSNM practices using cross-section household data gathered from the provinces of Ha Nam and Ha Tay in RRD, Vietnam. I use the instrumental variable approach to control for endogeneity and selection bias. In general, my results suggest that SSNM does have a positive impact; it increases farmers' yields and profits. SSNM improved the paddy yield of farmer by 0.6 ton/ha, and the profit by approximately $150/ha. It is important to note, however, that higher profits attributed to SSNM arise from increased grain yield rather from reducing fertilizer and pesticide costs. It appears that SSNM farmers improved their fertilizer management and increase fertilizer nitrogen efficiency. Results suggest that increasing the amount of fertilizer use, particularly nitrogen, does not guarantee increase yield and profit but what important is that essential nutrients, such as nitrogen, phosphorus, and potassium are applied to crops when they are needed. The implication of this result for my study area is that SSNM approach can help address the excessive use of chemical fertilizer in the area, especially nitrogen (and perhaps for most major rice producing regions in Asia) because nitrogen use can potentially be reduced without the adverse effect of lowering rice producers' yield and profit. On average, rice producers who adopt SSNM can help reduce nitrogen runoff and gaseous nitrogen losses into the environment.

Results of the study also show that attendance in SSNM training and knowledge on the use of LCC are important factors that positively impact the likelihood of SSNM adoption. Extension programs that provide specific information regarding SSNM and the manufacture and distribution of LCCs can potentially encourage further adoption of this nutrient management technique. Therefore, benefits of SSNM to environment and to farmers can be realized if SSNM technology will be approved by the Scientific Committee of MARD. This is a key factor for the sustainable widespread diffusion of SSNM technology on a larger scale. Once it is approved, funds will be available and the technology can then be officially disseminated through the wide network of extension systems, which is important for the technology diffusion.

A challenge ahead is limited capability of extension staff, especially at grass root level. The dissemination of SSNM starts with the training of researchers, local extension workers, fertilizer retailers, and farmer leaders on techniques and guidelines for enabling rice farmers to use effective nitrogen management practices for their specific rice-growing conditions. SSNM requires good understanding and motivation of the extension staff. Different rice areas, different farmers/farmers-groups require different SSNM recommendation. To address this issue, the *Nutrient Manager for Rice*, a decision software, can facilitate extension workers and technical staff in guiding farmers with SSNM. This software gives comprehensive fertilizer guideline that is tailored to specific conditions in rice fields. With this software installed in computer, technical staff only needs to ask farmers several simple questions about their rice production then a printable SSNM recommendation paper can be provided for farmers. Therefore, in this regard, there is a need to build capacity of extension workers and technical staff, especially computer skill and managing the software upon its release.

Lastly, previous recommendations of SSNM on fertilizer application have not taken into account other sources of nutrient such as farmyard manure, crop residues carried over, and quality of (i.e. water from Red river have higher content of sediments which provide nutrient for crop). Future development of SSNM as well as *Nutrient Manager for Rice* should consider these sources of nutrient supply.

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Table 1. Variable definitions

Variable name	Definition
Independent	
SSNM	=1 if adopt SSNM; =0 otherwise
Educ	Years of education for household head
Farm_yrs	Years of farming experience
Male	=1 if male; =0 otherwise
Married	=1 if married; =0 otherwise
Province	=1 if Ha Nam province; =0 if Ha Tay province
Own Land	=1 if own land; =0 otherwise
HHsize	Number of household members
Goodsoil	=1 if good soil; =0 otherwise
Training	=1 if attended SSNM training before; =0 otherwise
Labor	Total labor used in production (manday per hectare)
Seed	Total seed used in production (kg/ha)
Credit	=1 if fertilizer payment by credit; =0 otherwise
Nitrogen	Fertilizer N use (kg/ha)
Phosphorus	Fertilizer P use (kg/ha)
Potassium	Fertilizer K use (kg/ha)
LCC	=1 if seen LCC; =0 otherwise
Dependent	
Pesticide use	Total cost of pesticide use ($/ha)
Nitrogen use	Total amount of fertilizer N use
Yield	Paddy yield in kg/ha
Profits	Profits (income less variable costs)

Table 2. Summary statistics: Full sample

Variable	SSNM Adopter (n=228)		non-SSNM adopter (n=144)	
	Mean	Std.	Mean	Std.
Hhsize (number)	3.917	1.283	3.806	1.334
Male Dummy	0.149	0.357	0.160	0.368
Married Dummy	2.110	0.638	2.056	0.350
Training Dummy	0.575	0.495	0.063	0.243
Farm_yrs (years)	27.355	11.500	26.410	11.078
Educ (years)	9.259	12.094	8.590	8.308
Good soil Dummy	0.956	0.205	0.931	0.255
Credit Dummy	0.307	0.462	0.431	0.497
Own_Land Dummy	0.908	0.289	0.839	0.369
Profit ($/ha)	568.885	299.676	499.007	296.732
Yield (tons/ha)	5.58	848.123	5.28	938.392
Pestcost ($/ha)	18.873	12.266	21.735	12.989
Nitrogen(kg/ha)	79.072	24.346	83.310	27.949
Phosphorus(kg/ha)	22.200	11.806	19.300	11.582
Potassium(kg/ha)	60.278	28.534	65.315	27.639
Seed(kg/ha)	41.573	17.976	45.731	20.821
Labor(manday/ha)	14.589	12.200	12.999	10.950

Table 3. First stage model results on SSNM adoption and nitrogen, phosphorus and potassium use (n=371)

VARIABLE	SSNM adoption	Nitrogen use (kg/ha)	Phosphorus use (kg/ha)	Potassium use (kg/ha)
(1)	(2)	(3)	(4)	(5)
Married Dummy	0.03	-3.87	-0.76	4.39
	[0.0948]	[5.918]	[2.696]	[6.210]
Training Dummy	0.347***	8.578***	0.56	3.56
	[0.0518]	[3.233]	[1.473]	[3.393]
LCC Dummy	0.302***	-14.01***	-1.20	-6.697*
	[0.0547]	[3.416]	[1.556]	[3.585]
Credit Dummy	-0.05	-1.72	-2.727**	-7.631***
	[0.0447]	[2.794]	[1.273]	[2.933]
Province Dummy	0.01	-9.632***	-5.187***	-18.60***
	[0.0477]	[2.979]	[1.357]	[3.126]
Hhsize (number)	0.01	-0.91	-0.80	-0.99
	[0.0179]	[1.119]	[0.510]	[1.174]
Male Dummy	0.03	-2.29	-3.21	-0.65
	[0.0770]	[4.811]	[2.191]	[5.049]
Farm_yrs (years)	0.00	0.10	0.04	0.281**
	[0.00198]	[0.124]	[0.0563]	[0.130]
Educ (years)	0.00	-0.216*	0.01	-0.01
	[0.00201]	[0.126]	[0.0573]	[0.132]
Good soil Dummy	0.06	2.48	3.07	-8.18
	[0.0938]	[5.858]	[2.669]	[6.148]
Seed (kg/ha)	-0.00208*	-0.04	-0.0796**	0.05
	[0.00113]	[0.0704]	[0.0321]	[0.0739]
Labor (manday/ha)	0.00	0.03	0.00	0.09
	[0.00195]	[0.122]	[0.0554]	[0.128]
Own_Land Dummy	0.04	1.61	1.91	-2.58
	[0.0669]	[4.175]	[1.902]	[4.382]
Pesticide cost ($/ha)	0.00	0.200*	-0.03	0.276**
	[0.00170]	[0.106]	[0.0484]	[0.112]
Constant	0.373**	87.13***	26.81***	67.17***
	[0.174]	[10.88]	[4.955]	[11.42]
R-squared	0.35	0.10	0.10	0.17
Akaike Information Criteria	390.44	3458.10	2874.68	3493.92
Bayesian Information Criteria	449.18	3516.84	2933.42	3552.66

Robust standard errors in brackets

*,**,*** imply significance at 90%,95%, and 99% confidence intervals

Table 4. Impacts of SSNM on yield, profit, and pesticide use (n=371)

	YIELD (kg/ha)		PROFIT ($/ha)		PESTICIDE COST ($/ha)	
VARIABLE	One-Stage (OLS) Impact Model	Two-stage Impact Model	One-Stage (OLS) Impact Model	Two-stage Impact Model	One-Stage (OLS) Impact Model	Two-stage Impact Model
(1)	(2)	(3)	(4)	(5)	(6)	(7)
SSNM	143.10	615.2***	42.97	145.4***	-1.98	-4.18
	[105.9]	[166.5]	[35.24]	[55.25]	[1.653]	[2.616]
Credit Dummy	9.20	303.0***	8.75	52.54	1.75	2.45
	[89.87]	[103.6]	[29.92]	[34.37]	[1.403]	[1.658]
Hhsize	-45.32	-39.81	-10.71	4.04	0.82	0.64
	[35.47]	[40.90]	[11.81]	[13.57]	[0.553]	[0.666]
Farm_yrs (year)	-0.76	-10.98**	-1.10	-0.42	0.03	0.00
	[3.934]	[4.453]	[1.310]	[1.477]	[0.0615]	[0.0694]
Educ (year)	5.47	3.22	1.93	0.40	0.02	0.00
	[3.992]	[4.440]	[1.329]	[1.473]	[0.0624]	[0.0693]
Good soil Dummy	483.7***	751.5**	94.45	-65.51	2.53	4.19
	[185.7]	[346.1]	[61.80]	[114.8]	[2.901]	[5.143]
Nitrogen (kg/ha)	1.26	-9.08	-1.283**	-5.781*	0.04	-0.02
	[1.831]	[9.632]	[0.609]	[3.195]	[0.0286]	[0.150]
Phosphorus (kg/ha)	3.57	10.58	-1.43	34.50**	-0.04	-0.10
	[3.926]	[49.61]	[1.307]	[16.46]	[0.0614]	[0.770]
Potassium (kg/ha)	3.572**	41.45**	0.77	-5.67	0.0470*	0.22
	[1.662]	[16.42]	[0.553]	[5.447]	[0.0259]	[0.240]
Seed (kg/ha)	-1.17	-0.99	-1.387*	1.88	-0.0895**	-0.10
	[2.249]	[5.253]	[0.749]	[1.743]	[0.0349]	[0.0752]
Labor (manday/ha)	-2.53	-5.39	-11.97***	-11.21***	-0.0995*	-0.10
	[3.841]	[4.211]	[1.278]	[1.397]	[0.0598]	[0.0631]
Own_Land Dummy	211.70	302.80	-50.32	-131.2**	3.18	3.89
	[132.0]	[192.2]	[43.94]	[63.75]	[2.058]	[2.787]
Pesticide cost ($/ha)	2.97	-3.44	-1.20	2.75		
	[3.403]	[6.438]	[1.133]	[2.136]		
Constant	4,767***	2,538***	919.5***	716.3***	14.72**	7.74
	[389.1]	[712.8]	[129.5]	[236.4]	[6.036]	[10.98]
R-squared	0.26	0.23	0.27	0.25	0.08	0.05
Underidentification test		1.27[a]		1.27[a]		1.96[b]
Chi-sq(2) P-val		0.53		0.53		0.38
Overidentification test		1.85[c]		0.15[c]		1.37[d]
Chi-sq(1) P-val		0.17		0.70		0.24

[a] Anderson canonical correlation LM statistic

[b] Kleibergen-Paap rk LM statistic

[c] Sargan statistic

[d] Hansen J statistic

Robust standard errors in brackets

*,**,*** imply significance at 90%,95%, and 99% confidence intervals

Table 5. Impacts of SSNM on nitrogen use (n=371)

VARIABLES	One-Stage (OLS) Impact Model	Two-stage Impact Model
(1)	(2)	(3)
SSNM	-4.42	-38.84
	[3.069]	[52.37]
Training Dummy	8.863***	20.47
	[3.160]	[18.52]
LCC Dummy	-10.23***	0.89
	[3.280]	[16.35]
Hhsize (number)	-0.06	-0.40
	[1.031]	[1.289]
Farm_yrs (years)	0.00	0.01
	[0.114]	[0.148]
Educ (years)	-0.225*	-0.257**
	[0.115]	[0.129]
Good soil Dummy	2.46	7.19
	[5.397]	[11.15]
Phosphorus (kg/ha)	0.726***	0.24
	[0.107]	[1.530]
Potassium (kg/ha)	0.237***	0.40
	[0.0466]	[0.482]
Seed (kg/ha)	-0.01	-0.11
	[0.0654]	[0.198]
Labor (manday/ha)	0.01	0.01
	[0.112]	[0.131]
Own_Land Dummy	1.01	3.81
	[3.838]	[6.358]
Pesticide cost ($/ha)	0.14	-0.01
	[0.0986]	[0.266]
Constant	53.43***	64.88***
	[10.95]	[23.00]
R-squared	0.25	0.09
Underidentification test		1.172[a]
Chi-sq(2) P-val		0.56
Overidentification test		0.695[b]
Chi-sq(1) P-val		0.40

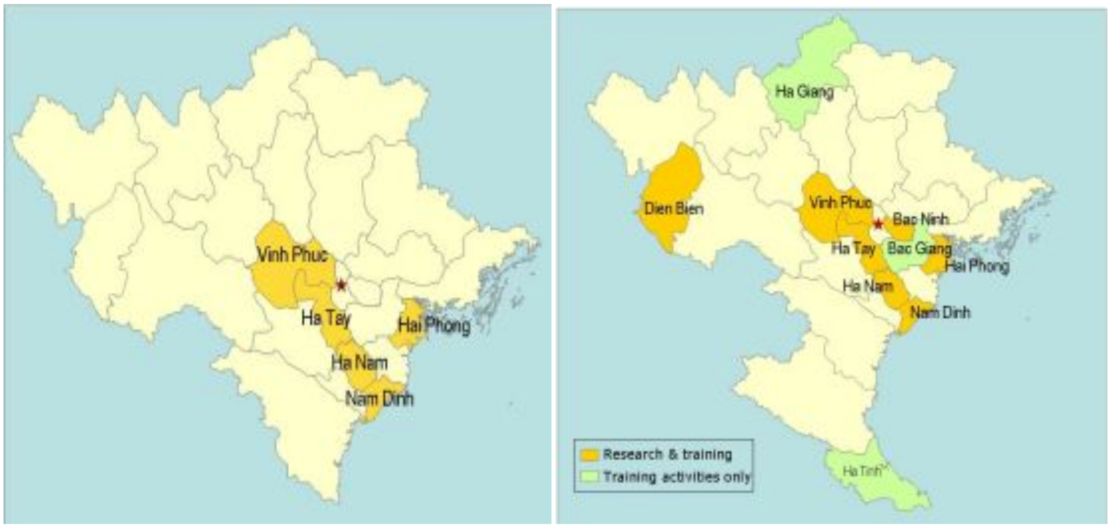
[a] Anderson canonical correlation LM statistic

[b] Sargan statistic

Robust standard errors in brackets

*,**,*** imply significance at 90%,95%, and 99% confidence intervals

Figure 1. Maps showing the provinces where SSNM was evaluated and promoted in RRD, North Vietnam.



Source: http://www.irri.org/irrc/ssnm/country%20sites/vietnam/North%20Vietnam.asp