LEVERAGING EVIDENCE FOR ACCESS AND DEVELOPMENT

AGRICULTURAL TECHNOLOGY ADOPTION INITIATIVE

# SOIL NUTRIENT MANAGEMENT PROGRAM:
## *Alleviating Constrains to Adoption of Improved Soil Fertility Management*

FINAL REPORT 2017

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# Executive Summary

Smallholder farmers in low income countries often invest a large proportion of their production costs in fertilizer, however returns on this investment can be highly variable and maximum potential productivity gains are very rarely achieved (Beaman et al. 2013; Duflo et al. 2008; Suri 2011). Experimental evidence points to the need for balanced nutrient application in order to maximize the efficiency of each synthetic compound (Das et al. 2009). However in order to effectively optimize fertilizer use efficiency, targeted advice needs to be generated at the plot level based on current soil fertility status as well as the nutrient demands of the cropping system (Das et al. 2009). At present, most farmers rely on blanket fertilizer recommendations which fail to account for this variability. Furthermore nitrogen based fertilizers, a known cause of greenhouse gas emissions, are inefficiently used by smallholder farmers (Garg et al. 2012; Tilman et al. 2002). As a result, site specific fertilizer recommendations have the potential to both increase farm level profitability and reduce greenhouse gas emissions intensity from the agricultural sector.

In this study we a randomized control trial of a new automated mobile system for delivering personalized fertilizer recommendations. This fertilizer decision support tool, Nutrient Expert (NE) for wheat, provides fertilizer input recommendations for specific fields and growing environments. The recommendations are generated through a user-friendly digital interface. Simple and easily attainable data on management practices, agro-ecological conditions, and farmer resources are input to calculate optimal nutrient management practices based on established algorithms.

# Abbreviations

CAPI: Computer Assisted Personal Interview

CSPro: Census and Survey Processing System

FAO-STAT: Food and Agriculture Organization Statistical Database

FYM: Farm Yard Manure

GPS: Geographic Positioning System

HH: Household

IFMR: Institute for Financial Management and Research

LEAD: Leveraging Evidence for Access and Development

MFI: Micro Finance Institute

MOP: Muriate of Potash

NE: Nutrient Expert

UC Berkeley: University of California Berkeley

## Introduction

Intensification of production systems in many parts of the African continent is following a similar pattern to that of the Indian green-revolution, which was driven by widespread adoption of synthetic fertilizer to replenish soils with nutrients required to increase and sustain high yields (Minde et al. 2008). However, the replenishment of soil nutrients through fertilization has focused primarily on nitrogen; the nutrient required in the largest quantities to achieve high yields. In contrast, application of phosphorus and potassium, as well as micro-nutrients has been chronically deficient. Roughly speaking, the nationwide proportion of nitrogen, phosphorus, and potassium (N:P:K) in India is 100:39:18 which is clearly scarce in both P and K when compared to the worldwide ratio of 100:44:28[1]. This has led to widespread human-induced soil nutrient mining[2], ultimately resulting in these essential elements becoming the limiting factor to productivity (Gupta 2005).

Rapid increases in population, meat and dairy consumption, as well as biofuel use are expected to roughly double the global demand for agricultural crops by 2050 (Tilman et al. 2011). As a result mounting evidence of widespread yield stagnation of major cereal crops including, wheat, maize and rice, is becoming a cause of major concern (Ray et al. 2012). This alarming trend has emerged across India, despite the persistence of large yield gaps in many parts of the country. Small-scale farms in Asia often only achieve 40-65% of their potential yield for common cereal crops (Lobell et al. 2009). This is largely hypothesized to be due to poor nutrient management that does not consider the crop's dynamic response to the environment (Cassman et al. 2002).

Government efforts to improve fertilizer management by providing targeted recommendations began as early as 1955-56, under the Indo-US Operational Agreement for “Determination of Soil Fertility and Fertilizer Use”. Under this program 16 laboratories were established which were later used to support the Intensive Agricultural District Programme (IADP) in selected districts. The need to reach out to millions of smallholder farmers across the country led to the introduction of 34 mobile soil testing vans in 1970 under the joint auspices of the Technical Cooperation Mission of USA, Indian Agriculture Research Institute, and Government of India. This network of soil testing laboratories has gradually expanded to 661 which include 120 mobile vans operating in 608 districts of the country with an annual sample analysis capacity of 8 million and an annual growth rate of 11% over the last two decades. Under the National Mission for Sustainable Agriculture (NMSA) there are plans to set-up another 500 stationary and 250 mobile soil testing labs, thus increasing the national analysing capacity by 7.5 million soil samples per annum. Despite this rapid expansion there still exists a larger disparity between the sampling capacity and the 110 million farm holdings in the country. Furthermore, even in districts with relatively good access to soil testing services, adoption of improved fertilizer management remains low.

Technology innovations capable of providing personalised soil fertility management practices to the millions of smallholder farmers spread across the developing world have started to emerge. One such innovation is the Nutrient Expert (NE)[3]; a fertilizer decision support tool, based on the principles of site specific nutrient management, which provides fertilizer input recommendations for specific plots and growing environments. The

[1] Data from FAO STAT.
[2] The un-replenished removal by crops of soil nutrients such as nitrogen, phosphorous, and potassium.
[3] NE was developed by the International Plant Nutrient Institute (IPNI) in close collaboration with the International Maize and Wheat Improvement Centre (CIMMYT) with the aim to increase nutrient use efficiency, reduce yield gaps while improving the welfare of smallholder farmers. The NE tool has been adopted by the CGIAR research program, Climate Change Agriculture and Food Security (CCAFS), within the Climate Smart Villages project in India, as tool for increasing nutrient efficiency and reducing greenhouse gas emissions.

recommendations are generated through a user-friendly computer based system. Simple and easily attainable data on agro-ecological conditions are entered into the Microsoft Access user interface which calculates an optimal nutrient management strategy based on established algorithms. The site-specific fertilizer requirement are estimated from the expected yield response to individual nutrients, which provides an estimate of the maximum attainable yield for that specific field. A country specific version of the NE has been developed for India, for both hybrid maize and wheat.

Field trials have demonstrated that NE recommendations result in increases in both yield and profits compared with current farmer practices and state recommendations (Pampolino et al. 2012; Sapkota et al. 2014). However, it remains unclear whether the more precise, but more expensive, soil testing approach performs significantly better. Additionally, regardless of the soil analysis method used, the procurement of required fertilizer at critical periods during the growing season may still represent a major constraint to adoption in many parts of the country. Fertilizer supply chains are aligned with the demand generated by state policies. As a result, procurement of fertilizer for practices that diverge from this norm is often impossible. In this pilot we propose to evaluate adoption rates of fertilizer recommendations from both NE and soil testing laboratories, both with and without time bound procurement of required fertilizers. This will allow us to determine the extent to which information or market inefficiencies act as a constraint to adoption of improved soil fertility management.

## Intervention

The intervention was carried out by the People's Action for National Integration (PANI) in two districts - Balrampur and Faizabad - in the state of Uttar Pradesh during the 2016-17 winter (Rabi) growing season (October-March). The districts were selected given the predominance of wheat as a major Rabi crop, as this is the target crop for the NE system. Villages where PANI have existing operations were eligible for selection in our study. From these eligible villages, 20 were selected for inclusion in the pilot.

The intervention included the provision of fertilizer recommendations using both the automated NE system and a soil testing laboratory facility with and without time bound procurement of fertilizer to wheat cultivating smallholder farmers during the Rabi growing season. Of the 20 study villages farmers in 8 were given NE fertilizer recommendations, and farmers in 8 other villages were given recommendations from a soil testing laboratories, and farmers in the remaining 4 villages were given no recommendations (this group will be used to determine current farmer practice). All the recommendations were delivered at least by the first week of October allowing farmers plenty of time to decide on a production strategy. Within each of the two treatment groups farmers in half the villages will be offered a guarantee of time bound fertilizer procurement. Recommendation were delivered free of charge, but farmers were responsible for purchasing the fertilizer.

There are costs and benefits to these two alternative recommendation systems which need to be better understood. The automated NE system, is cheap and easily deployed in the field or even through mobile phone extension services, and can therefore reach a lot more clients in a shorter period of time. However the system only focuses on the dynamic requirements of macro-nutrients (N:P:K) of a handful of widely cultivated target crops throughout the growing season, while neglecting potential significant deficiencies in micro-nutrients. It is also worth noting that the NE recommendations are adjusted to the size of the field under consideration. As a result, the farmers are not required to make any conversions which may result in unintentional erroneous adoption practices. Furthermore, the NE recommendations are spread across 2-3 applications during the growing season to coincide with peak periods of nutrient demand[4]. In contrast, the soil testing laboratories are able to provide extremely accurate nutrient requirement, including micro-nutrients. However, the reports only provide total fertilizer application rates on a per hectare bases thus abstracting from the dynamic nutrient demands of the crops. Furthermore, access to laboratories is limited and they are notoriously unreliable which has eroded farmer trust in the service. A cost-benefit comparison of these two alternative solutions will provide us with valuable information on potential adoption rates, as well as the relative benefits to productivity.

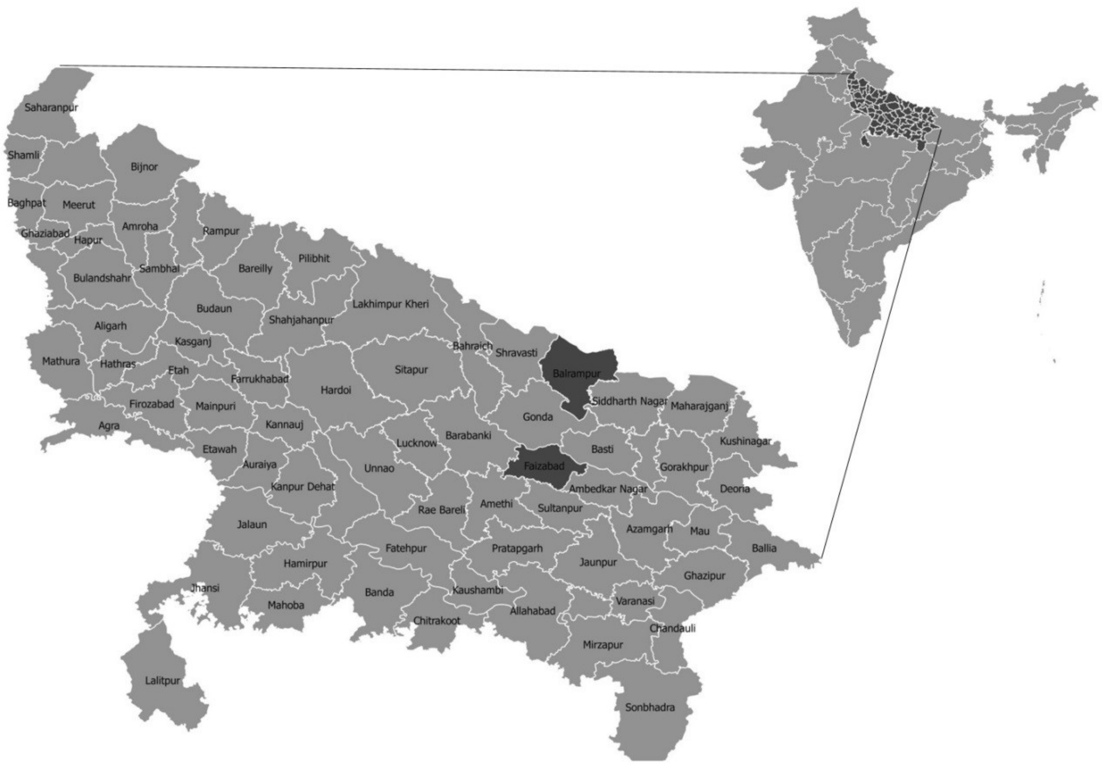


*Figure 1: Location of study districts (Balrampur and Faizabad) in the state of Uttar Pradesh.*

Farmers in Uttar Pradesh commonly take out loans from government cooperatives and purchase fertilizer within the same transaction. However, their choice of fertilizer is limited to those supplied at the cooperative outlet, which is in turn driven by coarse government recommendations. Therefore, supply chains may need to be realigned with more balanced fertilizer use resulting from site specific recommendations. Accordingly, at the time of delivering our recommendations farmers were given the option of having fertilizer procured in a timely manner in line with precise recommendations. Farmers will be required to pay prevailing market prices for fertilizer but will have the assurance of guaranteed supply, thus easing any existing market inefficiencies that may be restricting adoption. To achieve this goal local market outlets within a 5 km radius of the villages were monitored on a

[4] An example report of the Nutrient Expert can be found in Annex I.

fortnightly bases throughout the growing season using a fertilizer availability tracker. Any fertilizers that were not available on any given visit were procured by PANI and made available through that particular outlet.

## Household Survey

600 randomly selected households (25 households in 24 villages) were surveyed following the intervention using the household questionnaire, which was initially developed in English and later translated into Hindi for data collection. The survey was tailored to the sample during field piloting exercises in nearby villages not included in the study. Based on the findings of each phase of piloting, appropriate amendments and revisions were made before the final administration of the questionnaire. This process is important in order to ensure an appropriate design informed by local insights on measuring household characteristics.

The survey questionnaire includes questions on the following topics: household demographics, household agricultural production decisions (crop choices, labour allocation, input purchases, and fertilizer use), as well as household income, consumption, expenditure, asset accumulation. In addition, less-standard questions on preferences for trying out new products, and attitudes to risk were also included. The full questionnaire in English can be found in Annex II[5] (summarized in Table 1).

*Table 1: Outline of indicators for measuring key agricultural practices and household characteristics.*

| Outcomes | Characteristics | Indicators |
|---|---|---|
| **Agricultural Practices** | Land holdings | Plot wise surface area, irrigation status, and soil characteristics. |
| | Expenditure | Expenditure on chemical fertilizer, pesticides, seeds, labour, and machinery rental. |
| | Yield | Plot/crop wise yield in the previous growing season. |
| **Household Characteristics** | Demographics | Number of adults and children by sex, education of the household head. |
| | Wealth | Household income and consumption, assets |
| **Behaviour** | Risk | Attitude to different risk scenarios |
| | Time | Attitude to short versus long term preferences |

The household decision maker was the respondent for the household survey. The decision maker was defined as "*the one who took the major economic decisions in the household and was not just the oldest person in the household*". If the household decision maker could not be found, another household member knowledgeable about the agricultural production decisions of the household was interviewed. The module on female empowerment was addressed to the primary female in the household (normally the household head or wife of the household head).

### Training of surveyors and data collection

Interviewers and supervisors for this survey were recruited from Lucknow the capital city of Uttar Pradesh. All the surveyors were fluent in writing, reading, and speaking Hindi and aware of local agricultural practices and

[5] GPS coordinates were also collected for each household.

terminology. For the survey, the field personnel were organized into teams of 5 people (consisting of 1supervisor and 4 interviewers) and there were a total of 2 teams.

An intensive seven days training for interviewers and supervisors was conducted by the team of researchers from IFMR in Lucknow. The questionnaire was further improved from the inputs of the supervisors and interviewers during training. Training consisted of a question-by question review of the questionnaire, instructions on how to obtain the informed consent from the respondents and role playing.

In general, the supervisors were responsible for coordinating and supervising data collection and training, providing guidance and administrative support to the team, field checking and downloading the data at the end of each day. The relationship between the survey team and the community at large was also managed by the supervisors. Supervisors actively checked 10% of the administered surveys in the field. This entire process was monitored by the IFMR team, making visits to the field at regular intervals.

Upon arriving at a household selected for the study the interviewers determined the head of the household or representative, and explained the purpose of the study and how the household was selected. To reduce reporting biases, interviews were conducted privately so that the other members of the household or neighbours could not overhear or intervene.

As with all cross-sectional surveys, this survey is subject to response and recall biases. The survey responses on knowledge, attitude and behaviour questions may be influenced by the perceived desirability of answers to the experimenters. This was limited as much as possible by framing questions on past behaviour in a neutral manner: for example, leading questions were avoided. However some recall bias will remain and we henceforth indicate any specific questions where we think it was overly influential. Furthermore, some questions were not answered by some households, because the respondents were not willing to disclose the information and this was a right clearly explained to them during the process of informed oral consent[6].

This survey was conducted using Computer Assisted Personal Interview (CAPI) through the Census and Survey Processing System (CSPro); a public domain software package used by hundreds of organizations and tens of thousands of individuals for entering, editing, tabulating, and disseminating census and survey data. Responses were input using the CSPro android app CSEntry. The data were analysed using STATA statistical software package. Proportions, means, medians, frequency tables and cross-tabulations of important variables were used for data summaries and presentation.

# Results

## Descriptive statistics of sampled households

The average household (HH) in our sample was comprised of 6 members and headed by a male member in 86 percent of cases (see Table 2). On average less than 50 percent of the household heads are literate, i.e. they can read and write in a language. Given the average monthly per capita expenditure of INR 820, all the households

[6] The consent form can be found in Annex II.

in the sample fall below the poverty line[7]. Households own, on average, about INR 52,000 worth of assets which includes television, vehicles, mobile phone, agricultural tools such as tractors. An average household in the sample farms about 6 hectare of land of which 2.8 hectare is under wheat cultivation. On average 90 percent of households irrigate their plots, with tube well being the most commonly used source. While there exist some differences in means between treatment and control groups, these are not statistically significant, as can be observed from a balance test (see Table 7 in the Appendix A). These differences between the treatment and control groups prevail mainly due to the small sample size.

*Table 2: Descriptive statistics*

| | **Nutrient Expert** | **NE and fertilizer procurement** | **Soil testing** | **ST and fertilizer procurement** | **Control** | **Aggregate** |
|---|---|---|---|---|---|---|
| *Household demographics* | | | | | | |
| Household size | *6.452* | *6.043* | *6.000* | *5.246* | *6.373* | *6.087* |
| | *(0.430)* | *(0.330)* | *(0.306)* | *(0.236)* | *(0.278)* | *(0.146)* |
| HH head male | *0.808* | *0.871* | *0.899* | *0.986* | *0.803* | *0.861* |
| | *(0.046)* | *(0.040)* | *(0.037)* | *(0.014)* | *(0.034)* | *(0.017)* |
| HH head literate[1] | *0.479* | *0.371* | *0.377* | *0.609* | *0.451* | *0.456* |
| | *(0.059)* | *(0.058)* | *(0.059)* | *(0.059)* | *(0.042)* | *(0.024)* |
| Per capita monthly expenditure (INR)[2] | *749.301* | *694.897* | *847.826* | *926.278* | *851.297* | *819.478* |
| | *(111.437)* | *(100.436)* | *(133.303)* | *(117.141)* | *(100.727)* | *(51.166)* |
| Total HH assets | *54,574.656* | *18,446.000* | *64,731.160* | *42,783.332* | *65,522.844* | *52,004.523* |
| | *(12,390.324)* | *(2,779.108)* | *(18,326.426)* | *(9,525.854)* | *(16,666.598)* | *(6,912.601)* |
| *Agricultural Characteristics* | | | | | | |
| Cultivated land area (ha)[3] | *6.675* | *4.609* | *5.867* | *5.905* | *6.341* | *5.964* |
| | *(0.618)* | *(0.512)* | *(0.836)* | *(1.381)* | *(0.601)* | *(0.358)* |
| Irrigated area (ha) | *5.627* | *4.366* | *5.714* | *5.457* | *5.599* | *5.395* |
| | *(0.543)* | *(0.480)* | *(0.840)* | *(1.360)* | *(0.546)* | *(0.341)* |
| Wheat area (ha) | *2.351* | *2.663* | *3.205* | *2.936* | *2.993* | *2.853* |
| | *(0.408)* | *(0.438)* | *(0.688)* | *(1.180)* | *(0.322)* | *(0.266)* |
| Livestock Value | *26,006.850* | *25,545.715* | *27,550.855* | *21,077.102* | *24,555.641* | *24,891.088* |
| | *(2,813.534)* | *(3,562.014)* | *(3,443.259)* | *(2,810.511)* | *(2,215.780)* | *(1,286.648)* |
| Sample Size | 73 | 70 | 69 | 69 | 142 | 423 |

Source: Household survey (2017)

Notes: Standard errors are in parenthesis, [1]Literacy is measured as ability to read and write a sentence in any language, [2]Includes only expenditure for household items, [3]Cultivated land area is the total land area farmed by the household

## Soil nutrient status

We present results from the soil analysis used to generate fertilizer recommendations to farmers in the soil testing treatment branches. This data gives some indication of the prevailing nutrient status of the soil among our sample population. The macro-nutrient status of the soil reveals widespread deficiency in both nitrogen and potassium, while phosphorous levels were more adequate. Soil nitrogen however, appears to be adequately replenished with inorganic fertilizers on an annual basis by most farmers (see Figure 2). Of greater concern are

[7] International Poverty line is defined at $1.90 (PPP) which is approximately INR 130 per person per day.

the depleted levels of potassium accompanied by minimal usage of murate of potash fertilizer[8], as well as the micro-nutrient status of the soil as all nutrients are classified almost entirely as either *low* or *very low*. This is of particular concern as adoption of micro-nutrient fertilizers is almost zero among farmers in our sample.

*Table 3: Soil nutrient status classification*

| | Percentage of soil samples within each category | | | | |
|---|---|---|---|---|---|
| | Very Low | Low | Moderate | High | Very High |
| ***Macro Nutrients*** | | | | | |
| Nitrogen | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Phosphorous | 3.5 | 30.5 | 66.0 | 0.0 | 0.0 |
| Potassium | 1.0 | 50.0 | 49.0 | 0.0 | 0.0 |
| ***Micro Nutrients*** | | | | | |
| Sulphur | na | na | na | na | na |
| Zinc | 52.0 | 47.5 | 0.5 | 0.0 | 0.0 |
| Iron | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Manganese | 88.5 | 10.5 | 0.0 | 0.5 | 0.5 |
| Copper | 85.0 | 15.0 | 0.0 | 0.0 | 0.0 |

*Source: Soil laboratory reports for sample of farmers in the soil testing treatment branches*

## Fertilizer recommendations

In this section, we will make some initial comparisons of the fertilizer recommendations generated by the NE and soil testing laboratories and compare both methods to farmer practice. We convert all sets of recommendations to a total nutrient per hectare bases, allowing us to make direct comparisons, regardless of the specific fertilizer types used. It is strikingly apparent that on average farmers have assumed extremely unbalanced fertilizer usage. Currently, farmers are applying both excessive amounts of nitrogen and insufficient quantities of potassium. Interestingly there is also a certain degree of discrepancy between the two types of recommendations. On average the soil laboratories are promoting more inorganic nitrogen and phosphorous fertilizer and slightly less potassium relative to the NE recommendations. This is somewhat compensated for by endorsing more organic fertilizer usage where possible[9] (see Table 4).

Figure 2 graphs the kernel density functions for each of the soil macro nutrients which allow us to compare the farmer practice with recommendation under nutrient expert and soil testing. The sample for this graph includes all four treatment groups to which the recommendations were made. For farmer practice, we use the baseline data collected from the NE sample. Since treatment allocation was done randomly, we believe the baseline data for the NE group would be generally representative of the farmer practice in our study sample. The graph also contains the blanket government recommendation under timely sown rain-fed (vertical dashed-line) and timely sown irrigated scenarios (grey region).[10] The soil testing recommendations are different from the nutrient expert and seem to be in accordance with rain fed agriculture recommendation given by the government. The nutrient expert recommendation have various distinct peaks in the distribution indicating that farmers are being grouped together based on their individual characteristics and therefore provides a more customized recommendation.

[8] Potassium chloride (commonly referred to as Muriate of Potash or MOP) is the most common potassium source used in agriculture
[9] The NE system considers individual farmers access to different types of organic fertilizer and only endorses it if it is an option.
[10] The government recommendation can be found at the Directorate of Wheat Development.

Additionally, farmer practice has the largest variance indicating that many farmers are applying either excessive or insufficient macro-nutrients.

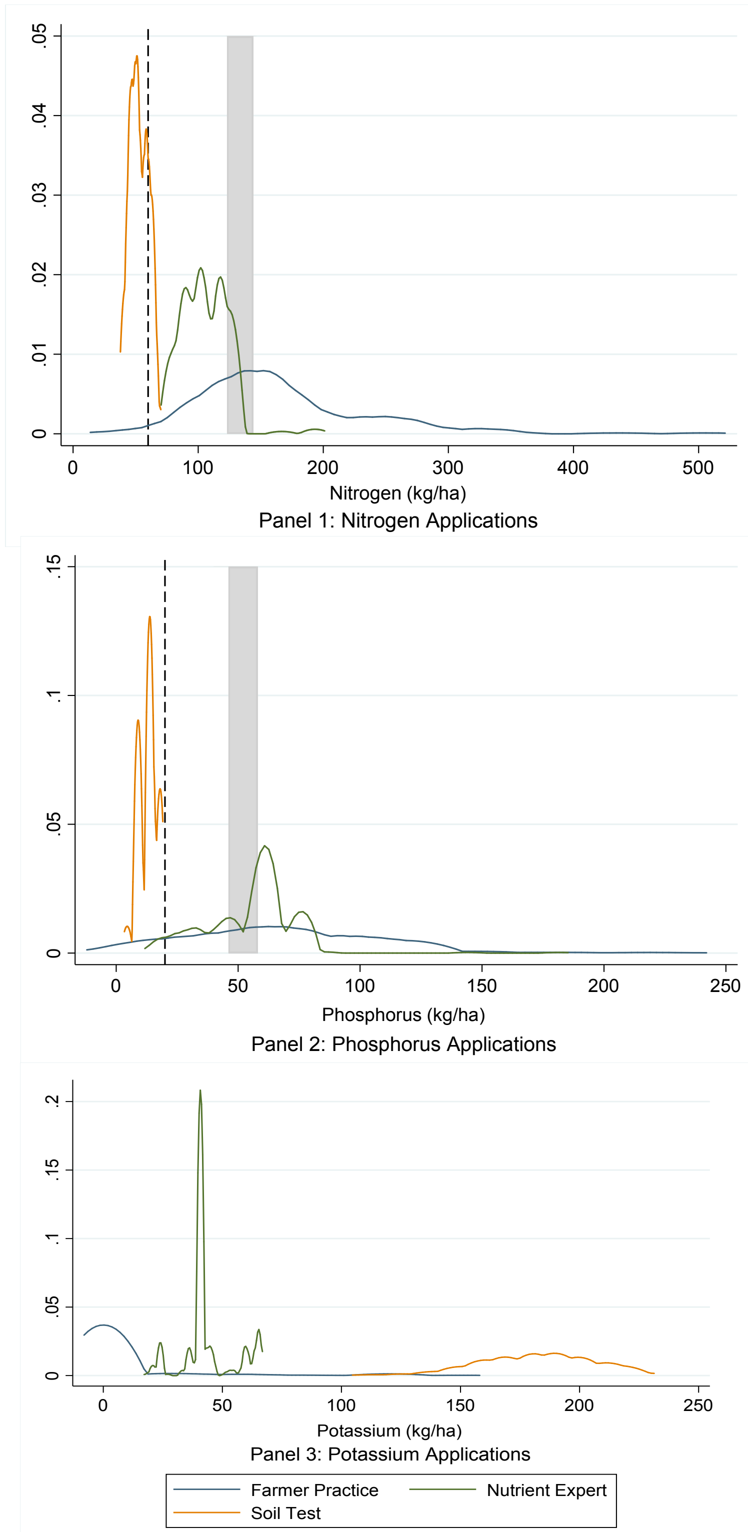


*Figure 2: Kernel density function of each soil macro nutrient comparing farmer practice and recommendation.*

*Table 4: Comparison of fertilizer recommendations with farmer practice*

| | NE | Soil Laboratory | Farmer Practice |
|---|---|---|---|
| ***Inorganic Macro-Nutrient Fertilizer*** | | | |
| Nitrogen (N kg/ha) | 105.4 (±18.6) | 131.4 (±14.3) | 165.6 (±68.4) |
| Phosphorus ($P_2O_5$ kg/ha) | 44.1 (±19.0) | 66.4 (±7.1) | 67.7 (±39.9) |
| Potassium ($K_2O$ kg/ha) | 46.5 (±15.0) | 40.8 (±0.2) | 7.7 (±25.9) |
| ***Organic Fertilizer*** | | | |
| Nitrogen (N kg/ha) | 18.2 (±27.2) | 7.0 (±2.1) | 11.3 (±21.1) |
| Phosphorus ($P_2O_5$ kg/ha) | 4.88 (±7.2) | 1.9 (±0.6) | 3.1 (±5.6) |
| Potassium ($K_2O$ kg/ha) | 12.1 (±18.1) | 4.8 (±1.5) | 7.6 (±14.1) |
| ***Inorganic Micro-Nutrient Fertilizer*** | | | |
| Sulphur (kg/ha) | - | 31.4 (±10.0) | 2.7 (±7.5) |
| Zinc (kg/ha) | - | 33.7 (±17.2) | 0.5 (±3.2) |
| Iron (kg/ha) | - | 35.3 (±15.7) | 0.0 (±0.0) |
| Manganese (kg/ha) | - | 16.3 (±4.4) | 0.0 (±0.0) |
| Copper (kg/ha) | - | 7.4 (±3.5) | 0.0 (±0.0) |

*Source: Soil Testing and Nutrient Expert reports, results based on a total sample of 199 cases.*

## Estimating Impact

In our evaluation of the above treatments, we focus on the effects of our treatments on recommendation uptake. However, unlike many technologies, adoption of fertilizer recommendations is not simply a binary outcome wherein farmers are faced with a take-it or leave-it decision. In practice, farmers compare their own practice with those of the recommendations and decide to what extent, if any, they want to conform.

The random allocation of recommendation type and ensured fertilizer procurement allows us to estimate the impact of these interventions on fertilizer usage by comparing the quantity of individual nutrient applied on a per hectare bases across different treatment arms. We test the village level interventions formally by estimating the intent to treat effect (ITT) as follows:

$$f_{ij} = \alpha + \beta_1 NE_j + \beta_2 NEF_j + \beta_3 ST_j + \beta_4 STF_j + \beta_5 d_{ij} + \beta_6 X_{ij} + \varepsilon_{ij}$$

where $f_{ij}$ is a measure of fertilizer usage (kg nutrient/ha) for individual i in village j, $d_{ij}$ is a district dummy taking the value 1 for Balrampur and 0 for Faizabad and $X_{ij}$ denotes a range of individual level control variables (including literacy and gender of the HH head), household level variables (including per capita expenditure, assets, and household size), agricultural variables (including land area, irrigated area, wheat area and livestock ownership). The coefficients of interest are $\beta_1$-$\beta_4$ which indicate the effect of receiving Nutrient Expert (NE) or Soil Testing (ST) recommendations as well as NE with fertilizer procurement (NEF) and soil testing with fertilizer procurement (STF).

Table 5, presents results on the impact of our four interventions on macro and micro nutrient fertilizer usage as well as on organic fertilizer. According to Table 4, if the farmers were to adopt either the NE or soil test recommendation, then the usage of inorganic soil macro-nutrients for nitrogen and phosphorus should reduce. We see that happening under both treatments for nutrient expert, but not for soil test. Similarly for organic macro nutrients, the recommendation should lead to an increase under nutrient expert treatments and decrease under soil testing treatments (Table 4). In the case of each nutrient, the average usage decreases under the soil testing treatments which is consistent with the recommendation. However, for the nutrient expert treatments, the average usage increases only under the nutrient expert with fertilizer availability treatment. We also find the micro nutrients (zinc and sulphur) decrease under the treatments when the recommendation is to increase their usage. None of these trends however, are statistically significant, which make their inference for measuring adoption very limited.

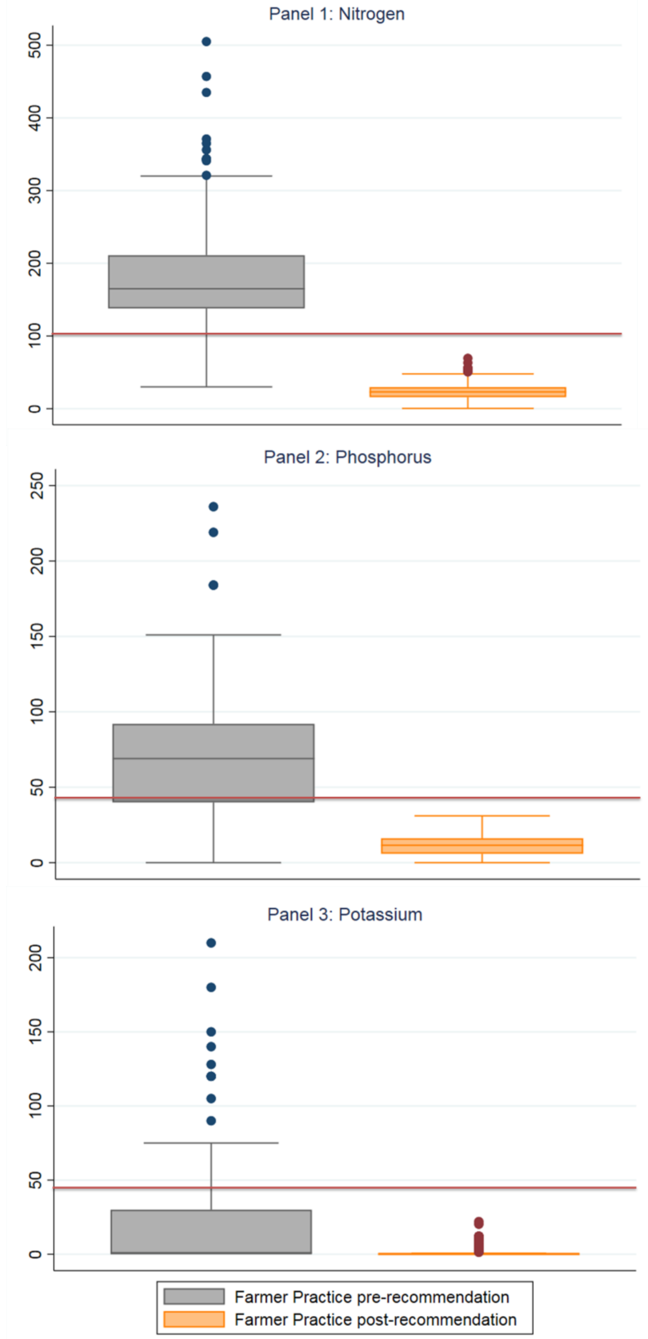


*Figure 3: Box Plots of each soil macro nutrient comparing farmer practice before and after recommendation for NE treatment*

While adoption of fertilizer recommendations is not a binary outcome, one of the objectives of this study was to present a rough estimate of 'binary' adoption for each treatment branch, allowing for a 10% deviation in reported

*Table 5: Impact of recommendations on macro and micro nutrient fertilizer usage*

| | Nitrogen | Phosphorous | Potassium | Organic Nitrogen | Organic Phosphorus | Organic Potassium | Zinc | Sulphur |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| *Nutrient Expert* | *-4.887* | *-3.159* | *-0.387* | *-1.175* | *-0.336* | *-0.839* | *-0.096* | *-0.159* |
| *(sd)* | *(5.507)* | *(4.466)* | *(1.097)* | *(1.016)* | *(0.290)* | *(0.726)* | *(0.066)* | *(0.236)* |
| *p-value* | *0.384* | *0.486* | *0.727* | *0.260* | *0.260* | *0.260* | *0.163* | *0.506* |
| *Nutrient Expert and Fertilizer Procurement* | *-0.591* | *-1.627* | *-0.340* | *3.920* | *1.120* | *2.800* | *-0.044* | *0.331* |
| *(sd)* | *(4.947)* | *(4.114)* | *(1.330)* | *(4.141)* | *(1.183)* | *(2.958)* | *(0.081)* | *(0.320)* |
| *p-value* | *0.906* | *0.696* | *0.800* | *0.354* | *0.354* | *0.354* | *0.596* | *0.311* |
| *Soil testing* | *27.449* | *27.313* | *-0.252* | *-0.893* | *-0.255* | *-0.638* | *-0.059* | *-0.095* |
| *(sd)* | *(23.886)* | *(22.786)* | *(0.993)* | *(0.862)* | *(0.246)* | *(0.616)* | *(0.068)* | *(0.185)* |
| *p-value* | *0.262* | *0.243* | *0.802* | *0.311* | *0.311* | *0.311* | *0.390* | *0.612* |
| *Soil testing and Fertilizer Procurement* | *-2.609* | *-4.145* | *-0.437* | *-1.738* | *-0.497* | *-1.242* | *-0.100* | *-0.081* |
| *(sd)* | *(5.240)* | *(4.610)* | *(1.058)* | *(1.185)* | *(0.339)* | *(0.846)* | *(0.072)* | *(0.168)* |
| *p-value* | *0.623* | *0.378* | *0.683* | *0.156* | *0.156* | *0.156* | *0.177* | *0.635* |
| *District FE* | *-4.758* | *-4.059* | *0.545* | *2.683* | *0.767* | *1.916* | *-0.070* | *-0.146* |
| *(sd)* | *(7.555)* | *(6.981)* | *(0.812)* | *(1.712)* | *(0.489)* | *(1.223)* | *(0.054)* | *(0.168)* |
| *Constant* | *29.679**** | *15.782*** | *1.571* | *-1.684* | *-0.481* | *-1.203* | *0.072* | *0.640*** |
| *(sd)* | *(8.242)* | *(7.452)* | *(0.926)* | *(1.465)* | *(0.419)* | *(1.047)* | *(0.062)* | *(0.294)* |
| Observations | *405* | *405* | *405* | *405* | *405* | *405* | *405* | *405* |
| R-squared | *0.080* | *0.070* | *0.017* | *0.034* | *0.034* | *0.034* | *0.023* | *0.030* |
| Controls# | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |

Notes: Standard errors adjusted for clustering at village level are in parentheses; *** p<0.01, ** p<0.05, * p<0.1. P-values are below the standard errors. #Controls for various demographic (such as household size, household head gender and literacy, household monthly per capita expenditure) and agricultural (such as irrigated land area, area under wheat cultivation, total value of livestock) characteristics.

fertilizer usage relative to the original given recommendations. This would have given us an indication of number of farmers that are changing their practice to some extent in order to follow the recommendations. However, upon analysing the data post intervention, we find that the farmers in all treatments apply nutrients in much lower quantities than that recommended across all treatment branches. Figure 3 depicts this trend, along with the variance in farmer practice at baseline and endline for each of the soil macro nutrients. Since the baseline data on farmer practice is available only for the NE treatment groups, the sample for this graph (both pre and post intervention) includes only the nutrient expert and nutrient expert with fertilizer procurement treatment groups. We see that the variance at farmer level is much lower at the endline compared to the baseline for all the three soil macro-nutrients. As can be also seen in the graphs, the farmer practice at endline is much lower than the average recommended by the intervention.

This drop in aggregate fertiliser usage across all study groups is likely to be a consequence of the demonetization policy[11] ordered by the Government of India in 2016. Demonetization came into effect right at the beginning of the sowing period for Rabi season and led to considerable panic and cash shortfall in the economy, especially in rural areas. This sudden liquidity constraint, at the onset of the agricultural season, has been found to have significantly reduced application of fertilizers.[12] According to the Ministry of Agriculture's fertilizer monitoring system, the fertilizer offtake during the Rabi season 2016-17 was 7 percent lower than the fertilizer offtake in the corresponding period during the 2015-16 season. Given only one round of data collection across all study groups, it is not possible to assess the differential impact of the demonetisation and recommendation treatments on the usage of fertiliser.

## Estimating cost saving in fertilizer expenditure

As previous research has demonstrated, Nutrient Expert recommendations result in higher profits as well as yield since the fertilizer application is customized to each farming field. In this section, we evaluate if our treatments have any impact on the per hectare expenditure on fertilizers, after controlling for total yield. The regression equation can be written as:

$$E_{ij} = \alpha + \beta_1 NE_j + \beta_2 NEF_j + \beta_3 ST_j + \beta_4 STF_j + \beta_5 p_{ij} + \beta_6 d_{ij} + \beta_7 X_{ij} + \varepsilon_{ij}$$

where $\mathrm{E_{ij}}$ is the expenditure on fertilizers per hectare of land for individual $\mathrm{i}$ in village j, $p_{ij}$ is the total wheat production of individual $\mathrm{i}$ in village j, $d_{ij}$ is a district dummy taking the value 1 for Balrampur and 0 for Faizabad and $X_{ij}$ denotes a range of individual level control variables (including literacy, sex of the HH head), household level variables (including per capita expenditure, assets, and household size), agricultural variables (including land area, irrigated area, wheat area and livestock ownership). The coefficients of interest are $\beta_1$-$\beta_4$ indicate the effect of receiving Nutrient Expert (NE), or Soil Testing (ST) recommendations as well as NE with fertilizer procurement (NEF) and soil testing with fertilizer procurement (STF) on expenditure.

[11] The government of India demonetised the high value currency notes – of INR 500 and INR 1000 denomination – constituting nearly 86 percent of all currency in circulation. These ceased to be legal tender from the midnight of 8th of November 2016 without prior notice.

[12] Source: Agricultural growth aftermath demonetization

*Table 6: Impact on fertilizer expenditure per farmer*

| | Expenditure on Fertilizers (per ha) | Expenditure on Fertilizers (per ha) | Expenditure on Fertilizers (per ha) |
|---|---|---|---|
| | (1) | (2) | (3) |
| *Nutrient Expert* | *-50.074* | *-43.264* | *-44.708* |
| *(sd)* | *(174.943)* | *(105.688)* | *(85.983)* |
| *p-value* | *0.777* | *0.686* | *0.608* |
| *Nutrient Expert and Fertilizer Procurement* | *-36.095* | *-43.042* | *-49.576* |
| *(sd)* | *(160.499)* | *(90.155)* | *(70.648)* |
| *p-value* | *0.824* | *0.638* | *0.490* |
| *Soil testing* | *20.745* | *20.982* | *32.037* |
| *(sd)* | *(150.004)* | *(130.999)* | *(100.342)* |
| *p-value* | *0.891* | *0.874* | *0.752* |
| *Soil testing and Fertilizer Procurement* | *102.470* | *82.657* | *100.282* |
| *(sd)* | *(160.838)* | *(145.121)* | *(115.077)* |
| *p-value* | *0.530* | *0.574* | *0.393* |
| *District FE* | | *-329.513**** | *-316.073**** |
| *(sd)* | | *(82.136)* | *(66.009)* |
| *Constant* | *779.664**** | *1,303.828**** | *1,352.682**** |
| *(sd)* | *(112.226)* | *(205.623)* | *(181.058)* |
| Observations | *404* | *404* | *404* |
| R-squared | *0.013* | *0.095* | *0.218* |
| Controls | No | Demographic# | Agricultural† |

Notes: Standard errors adjusted for clustering at village level are in parentheses; *** p<0.01, ** p<0.05, * p<0.1, P-values are below the standard errors. #Controls for various demographic characteristics (household size, household head gender. Household head literacy, household monthly per capita expenditure and household total asset value) are included. †Additional controls for agricultural characteristic such as irrigated land area, area under wheat cultivation, total value of livestock

After controlling for the yield per hectare, demographic and other agricultural variables, we see in column 3 of Table 6 that the fertilizer expenditure drops for both the nutrient expert treatments, which is consistent with the fall in usage of soil macro and micro nutrients as given in Table 5. However, we don't see the same happening for the soil testing with fertilizer availability treatment, for which the usage of both macro and micro nutrients also drops. We believe the expenditure on fertilizers increased for this group despite the drop in nutrient usage because of reduced application of cheaper fertilizers and increased application of some of the more expensive fertilizers. On average, this treatment group reduced the application of urea which costs INR 8 but increased the application of NPK fertilizers which cost approximately INR 20. The results for soil testing treatment are consistent with the increased usage of nutrients. However, given the small sample, none of the results we see are statistically significant.

## Conclusion

Most farmers in India tend to rely on blanket fertilizer recommendations which fail to account for the current soil fertility status as well as the nutrient demands of the cropping system. Moreover, the emphasis on nitrogen based fertilizers also implies that the supply chains for other nutrients have not been well established. As a result, even if farmers had the knowledge allowing them to adopt more effective fertilizer application practices, appropriate and timely supply of fertilizer may still remain a major constraint. We used a Randomized Control Trial to test the impact of providing farmers with individual level fertilizer recommendation and supply of fertilizers on the farmer practice as well as total expenditure on fertilizers.

Our baseline results are consistent with those of previous studies which find that the farmers rely heavily on Nitrogen based fertilizers. Both the soil testing and nutrient expert's recommendation is to reduce the application of nitrogen and increase that of potassium. In addition, farmers under consume soil micro-nutrients such as zinc and sulphur. The small sample size with a single round of data collection, as well as the demonetisation policy implemented at the onset of the agricultural season which led to severe cash shortage in the rural economy and an aggregated drop in fertiliser usage across all study groups, do not allow us to capture the true impact of the recommendations on farmer practice. The next step would be to conduct a longer-term project over multiple seasons so as to control for such macro-economic shocks and be able to compare before and after conditions of the different study groups.

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## Appendix A

*Table 7: Balance tests*

| | Total number of Household Members | Gender of Household head | Household head is literate | Household per capita monthly expenditure (INR) | Total area under cultivation (ha) | Total area under irrigation (ha) | Total area under wheat cultivation (ha) | Total value of livestock owned (INR) | Total value of all assets owned (INR) |
|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| *Nutrient Expert* | *0.08* | *0.01* | *0.03* | *-102.00* | *0.33* | *0.03* | *-0.64* | *1,451.21* | *-10,948.19* |
| *(sd)* | *(0.431)* | *(0.090)* | *(0.102)* | *(185.728)* | *(0.973)* | *(0.771)* | *(0.696)* | *(5,793.822)* | *(28,250.943)* |
| *p-value* | *0.855* | *0.952* | *0.780* | *0.588* | *0.734* | *0.971* | *0.366* | *0.804* | *0.702* |
| *NE and procurement* | *-0.33* | *0.07* | *-0.08* | *-156.40* | *-1.73* | *-1.23* | *-0.33* | *990.07* | *-47,076.84*** |
| *(sd)* | *(0.437)* | *(0.074)* | *(0.088)* | *(121.611)* | *(1.185)* | *(1.007)* | *(0.856)* | *(6,794.952)* | *(20,751.947)* |
| *p-value* | *0.450* | *0.366* | *0.380* | *0.211* | *0.157* | *0.233* | *0.704* | *0.885* | *0.033* |
| Soil testing | *-0.37* | *0.10* | *-0.07* | *-3.47* | *-0.47* | *0.12* | *0.21* | *2,995.21* | *-791.69* |
| *(sd)* | *(0.439)* | *(0.076)* | *(0.112)* | *(172.068)* | *(1.637)* | *(1.521)* | *(1.595)* | *(7,254.710)* | *(25,937.811)* |
| *p-value* | *0.396* | *0.219* | *0.517* | *0.984* | *0.775* | *0.940* | *0.895* | *0.684* | *0.976* |
| ST and procurement | *-1.13*** | *0.18*** | *0.16* | *74.98* | *-0.44* | *-0.14* | *-0.06* | *-3,478.54* | *-22,739.51* |
| *(sd)* | *(0.439)* | *(0.070)* | *(0.097)* | *(108.133)* | *(2.491)* | *(2.320)* | *(1.070)* | *(5,793.514)* | *(28,205.586)* |
| *p-value* | *0.011* | *0.016* | *0.118* | *0.495* | *0.862* | *0.952* | *0.958* | *0.554* | *0.428* |
| Constant | *6.37**** | *0.80**** | *0.45**** | *851.30**** | *6.34**** | *5.60**** | *2.99**** | *24,555.64**** | *65,522.84**** |
| | *(0.251)* | *(0.069)* | *(0.086)* | *(102.223)* | *(0.876)* | *(0.703)* | *(0.512)* | *(4,606.069)* | *(20,567.299)* |
| Observations | *423* | *423* | *423* | *423* | *423* | *423* | *423* | *423* | *423* |
| R-squared | *0.019* | *0.037* | *0.025* | *0.005* | *0.008* | *0.004* | *0.003* | *0.006* | *0.014* |

Notes: Standard errors adjusted for clustering at village level are in parentheses; *** p<0.01, ** p<0.05, * p<0.1, P-values are below the standard errors