University of Passau
Chair of Development Economics

A large-scale pilot experiment on low-cost soil-test kits to enhance sustainable farming among small holders in Indonesia

Final Report

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Zusammenfassung

Bisher werden weltweit nur ein Bruchteil der landwirtschaftlichen Flächen nachhaltig und unter Berücksichtigung der langfristigen Bodengesundheit bewirtschaftet. Deshalb bedarf es neben einem gesteigerten Umweltbewusstsein auch des Einsatzes moderner Technologien. Die Technologien müssen so angepasst sein, dass sie auch in Entwicklungs- und Schwellenländern zum Einsatz kommen können. Eine in diesem Sinne vielversprechende Technologie sind einfache und kostengünstige Bodentests, die geeignet sind, auf der einen Seite den Einsatz von Düngemitteln zu optimieren und auf der anderen Seite die Qualität der Böden und des Grundwassers zu verbessern.

Dieses Projekt führte eine groß angelegte Pilotstudie in Indonesien durch, um die Wirksamkeit von Schulungen zum nachhaltigen Nährstoffmanagement in Kombination mit individuellen Bodentests zu bewerten. Das Projekt untersuchte zudem die Bereitschaft der kleinbäuerlichen Betriebe, zu den Kosten der Bodentests beizutragen. Um robuste, kausale Evidenz zu liefern, kombinierten wir ein groß angelegtes Feldexperiment mit einer umfangreichen quantitativen Datenerhebung. Insgesamt wurden 1.104 Haushalte befragt, jeweils einmal 2022 und einmal 2023. Davon wurden 736 zufällig ausgewählte Haushalte eingeladen an einer Schulung zu nachhaltigem Nährstoffmanagement teilzunehmen. Diese Schulungen beinhalteten auch die Bodentests. Zudem führten wir führten ein Zahlungsbereitschaftsexperiment mit 600 Teilnehmenden durch.

Die Ergebnisse des Feldexperiments zeigen, dass Schulungen zu nachhaltigem Nährstoffmanagement und individuelle Bodentests kleinbäuerliche Betriebe unterstützen können, ihre Böden nachhaltiger zu bewirtschaften. Die Schulung hat die Anwendung von synthetischem Stickstoffdünger durch die kleinbäuerlichen Betriebe signifikant reduziert und den Einsatz von landwirtschaftlichem Kalk erhöht. Dieser Effekt wurde durch die Bodentests verstärkt, die den Teilnehmenden individuelle Informationen über ihre Bodenbedingungen lieferten. Zudem steigerte die Schulung die Nutzung von Blattfarbtafeln; ein Hilfsmittel, um den Stickstoffgehalt von Reispflanzen einfach visuell zu prüfen. Während nur wenige Kleinbauern und Kleinbäuerinnen die Bodentests nach der Schulung eigenständig durchführten, experimentierten viele mit den in der Schulung vorgestellten Blattfarbtafeln.

Unser Zahlungsbereitschaftsexperiment zeigt, dass kleinbäuerliche Betriebe bereit sind, zu den Kosten für Bodentests beizutragen. Dennoch reicht die Zahlungsbereitschaft nicht aus, um die vollen Kosten der Tests zu decken. Subventionen können durch die potenziellen Umweltvorteile gerechtfertigt werden, die sich aus der Vermeidung von Überdüngung und besserem Bodenmanagement ergeben. Die Bereitstellung könnte in bestehende landwirtschaftliche Informations- und Beratungsdienste integriert werden. Wir haben zwei Methoden getestet, wie Bodentests eingeführt werden können: als Dienstleistung für Einzelpersonen und über die Bereitstellung von Bodentest Kits und entsprechendes Training für größere Gruppen. Bei niedrigen Subventionen ist die Bereitstellung als individuelle Dienstleistung am effektivsten. Bei höheren Subventionen ist die Bereitstellung kompletter Bodentest Kits und Schulungen effektiver. Die Bereitstellung in einer Gruppe könnte die Wahrscheinlichkeit erhöhen, dass Kleinbauern und Kleinbäuerinnen die Bodentests in ihre Gruppenaktivitäten integrieren und die Akzeptanz nachhaltig erhöhen.

Dieses Projekt liefert verlässliche, kausale Ergebnisse mit hoher Relevanz für landwirtschaftliche Ministerien und andere Stakeholder, die daran interessiert sind, die Bodengesundheit zu verbessern und kleinbäuerliche Betriebe auf ihrem Weg zu nachhaltigeren Anbaumethoden zu unterstützen. Die Ergebnisse sind nicht nur für Indonesien, sondern auch für ähnliche Kontexte relevant.

Executive Summary

Only a fraction of agricultural land worldwide is currently managed sustainably with consideration for long-term soil health. Therefore, in addition to increased environmental awareness, the use of modern technologies is necessary. These technologies must be adapted so that they can also be implemented in developing and emerging countries. One promising technology in this regard are simple and cost-effective soil tests, which can optimize fertilizer use on the one hand and improve soil and groundwater quality on the other.

This project conducted a large-scale pilot study in Indonesia to evaluate the effectiveness of training on sustainable nutrient management in combination with individual soil tests. The project also smallholder farmers' willingness to contribute to the costs of the soil tests. To provide robust, causal evidence, we conducted a large-scale field experiment combined with extensive quantitative data collection. A total of 1,104 households were surveyed. Of these, 736 households were randomly selected to participate in training on sustainable nutrient management. This training included soil tests. We further conducted a willingness-to-pay experiment with 600 participants.

The results of the field experiment show that training on sustainable nutrient management and individual soil tests can support smallholder farms in managing their soils more sustainably. Training significantly reduced the use of synthetic nitrogen fertilizer by smallholder farmers and increased their use of agricultural lime. This effect was enhanced by personalized soil tests, which provided training participants with information about their soil conditions. Additionally, the training increased the use of leaf color charts, a simple tool to visually check the nitrogen demand of rice plants. While only a few smallholders conducted soil tests independently after the training, many experimented with the leaf color charts, which were introduced during the training.

The willingness-to-pay experiment shows that smallholder farmers are willing to contribute to the costs soil tests. However, their willingness to pay does not cover the full costs of the tests. Subsidies can be justified by the potential environmental benefits that could result from avoiding over-fertilization and better soil management. Soil test provision could be integrated into existing agricultural information and advisory services. We tested two methods of introducing soil tests: as a service for individuals and combined with training in a group setting. At low subsidy levels, providing the service individually is most effective. At higher subsidy levels, providing complete test kits and training is more effective. Provision in a group setting could increase the likelihood that farmer groups integrate soil tests into their group activities and thus increase acceptance.

This project provides reliable, causal evidence with high relevance for agricultural ministries and other stakeholders interested in improving soil health and supporting smallholder farmers on their path towards more sustainable farming. The results are relevant not only for Indonesia but also for similar contexts.

Danksagung

Das Projekt wurde durch die Unterstützung der Deutschen Bundesstiftung Umwelt (DBU) ermöglicht. Für das uns entgegengebrachte Vertrauen und die stets hervorragende und angenehme Zusammenarbeit und Betreuung möchten wir uns ganz herzlich bedanken. Daüberhinaus möchten wir uns bei den Kolleginnen und Kollegen der Universität Gadjah Mada (UGM), dem Indonesian Soil Research Institute (ISRI) und dem „Selbstständigen Landwirtschafts- und Ländlichen Ausbildungszentrum“ (Pusat Pelatihan Pertanian dan Pedesaan Swadaya, P4S) für die ausgezeichnete und konstruktive Zusammenarbeit bedanken. Ein besonderer Dank gilt auch den vielen Bauern und Bäuerinnen sowie den landwirtschaftlichen Dorfverbänden in Indonesien, die an unserer Studie teilgenommen und sich die Zeit genommen haben, unsere Fragebögen zu beantworten.

Acknowledgements

This project was funded by the German Federal Environmental Foundation (DBU). We would like to express our gratitude for the trust placed in us and the excellent and pleasant collaboration and support. Additionally, we thank our partners at Gadjah Mada University (UGM), Indonesian Soil Research Institute (ISRI), and “Self-Sufficient Agriculture and Rural Training Center” (Pusat Pelatihan Pertanian dan Pedesaan Swadaya, P4S) for the excellent and constructive collaboration. We are also especially grateful to the many farmers and farmer groups in Indonesia who participated in our study and took the time to answer our questionnaires.

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1. Introduction

Humanity is confronted with unprecedented challenges due to climate change, increasing demand for food, and growing scarcity of resources. Achieving a more sustainable agricultural system is crucial for overcoming these challenges. Agriculture plays a dual role, it is both impacted by and contributing to environmental problems. Globally, except for Sub-Saharan Africa, agricultural development has heavily relied on the increased use of chemical inputs. The intensive use of chemical inputs has contributed to substantial degradation of soils, biodiversity loss, groundwater contamination, and health risks (Hazell, 2009; IAASTD, 2009; IFAD, 2013). The Food and Agricultural Organization (FAO, 2018) estimates that around one-third of global soils is already moderately to severely degraded, with projections suggesting the majority could be degraded by 2050 (FAO & ITPS, 2015; Scholes et al., 2018). Soil degradation has the potential to exacerbate poverty, food insecurity and malnutrition in the future.

Sustainable soil nutrient management addresses these challenges. Soil testing is a key technology that can assist farmers in adjusting their fertilizer application to meet plant needs, thereby preventing over- or under-application. Increasing soil testing among smallholder farmers in the context of fertilizer overapplication could offer a double benefit: environmental sustainability through improved soil and water quality, alongside long-term increases in farmers' profits. However, agricultural technologies must be adapted to be applicable in low- and middle-income countries, where agriculture is dominated by smallholder farmers who often have limited financial resources, low formal education, and little exposure to modern technologies. While basic soil testing technologies exist, they are not yet widely utilized by smallholders in low- and middle-income countries. Traditional soil nutrient assessment in these countries often relies on expensive and time-consuming laboratory tests, conducted far from the farm (Golicz, Hallett, Sakrabani, & Pan, 2020).

Studies specifically addressing the potential of personalized soil information for smallholders in developing countries are scarce, and their results are mixed. While leaf color charts (LCCs), a simple tool for assessing Nitrogen availability, positively impacted nutrient management in Bangladesh (Islam & Beg, 2020), more comprehensive information in the form of "Soil Health Cards" had no effect on farmers' fertilizer decisions in India (Fishman, Gars, Kishore, Rothler, & Ward, 2019). Furthermore, individualized soil nutrient information had little effect on farmers' fertilizer input in Bangladesh (Beg, Islam, & Rahman, 2024), and only impacted farmers' fertilizer behavior in Tanzania when combined with subsidies (Harou et al., 2022).

This project conducted a large-scale pilot test in Indonesia to evaluate the effectiveness of training on sustainable nutrient management combined with individualized soil test information. The project further investigated farmers' willingness to contribute to the costs of soil testing, a policy relevant issue considering the resource constraints of most extension systems. In contrast to many previous studies, this project explored the potential of soil tests which smallholder farmers can implement themselves directly in the field after receiving instructions. This approach is particularly relevant in Indonesia, where laboratory tests are far too expensive for most farmers. This project aimed to provide policy makers with high-quality, context-relevant information to facilitate evidence-based decision-making. Indonesia serves as a particularly relevant case study. Indonesian farmers have widely adopted "Green Revolution" type technologies and while this has contributed to rapid productivity increases, their intensive use has come at a significant environmental cost (IAASTD, 2009; IFAD, 2013; Lai, 2017).

2. Project aim

This project investigated the potential of training farmers on soil nutrient management and offering them simple, rapid soil tests to assess their own soil. We implemented a large-scale field experiment with 1,104 farmers (across 69 villages) to provide robust, causal evidence, explicitly considering socio-economic and institutional factors to ensure the sustainability of the measures.

Recognizing resource limitations in extension services, the project also explored farmers' willingness to pay (WTP) for these rapid tests. While the Indonesian extension system faces resource constraints, there is also an urgent need to disseminate knowledge and technologies to promote sustainable farming. This raises the question of how soil tests could be distributed to farmers in a way that ensures adoption and is at least partially cost-covering. In our WTP experiment, we compared two dissemination methods: (1) extension workers conducting tests with recommendations as a service, and (2) farmer groups receiving training and entire soil test kits for self-testing (around 50 tests).

Specifically, this project aimed to address the following main research questions:

- **Does training on soil health management increase farmers' knowledge of optimal agricultural input use and lead to changes in their actual input practices?**
- **Can soil tests increase the impact of such training and facilitate a transition towards more sustainable agricultural practices among smallholder farmers?**
- **How much are smallholder farmers willing to pay for soil tests? Are subsidies a useful instrument and how should soil tests be disseminated?**

3. Project context

a. Overview: Agricultural sector

The agricultural sector in Indonesia is dominated by small-scale farms, employing around half of the rural labor force (BPS, 2018). On the island of Java, where this project took place, farms are the smallest in Indonesia, averaging less than 0.5 hectares per household and often focusing on subsistence farming (BPS, 2014; OECD, 2012). Java is the leading rice-producing area in Indonesia, and more than half of the agricultural households in Java plant rice at least once a year (BPS, 2014). Rice farming continues to carry great economic and political significance in Indonesia. Over the past decades, the production was intensified to increase production and achieve food self-sufficiency (Kawagoe, 2004; Mariyono, 2014). Yet, this agricultural intensification has come with environmental costs (Simatupang & Timmer, 2008). It is estimated that 107 million hectares of land in Indonesia are currently affected by acidification, caused, among other things, by decades of over-fertilization with Nitrogen fertilizers, mainly Urea (Nyi et al., 2017). The intensive and often unbalanced use of chemical fertilizers has also greatly reduced the organic matter content in agricultural soils (Turmuktini, Simarmata, Joy, & Resmini, 2012).

b. Context: Extension system

Indonesia operates a decentralized extension system. This approach leads to variation in practices across regions. In many regions, it operates as a multi-stakeholder network involving government agencies (extension workers), NGOs, universities, and farmer groups. Farmer groups are associations of farmers at the local level with an elected farmer group head and regular meetings. Not all registered groups are active. Extension workers directly advise farmers and groups on topics such as fertilizer and pest management. Staff shortages are one of the main challenges the system is currently facing. During one of our workshops, an extension worker in Yogyakarta explained that in their area there are only 80 extension workers where ideally should be 160.

To increase the transferability of our project results and their relevance to local policy makers, we aimed to align our training with the style of the existing system. Part of our trainers were already involved in the extension system outside of this project.

c. Context: Local context and farmer characteristics

This project was set in the Special Region of Yogyakarta, Indonesia. It was conducted in 69 villages across three districts: Sleman, Bantul and Kulon Progo (see Figure 1).

The focus was on smallholder rice farming. While farmers in Java generally tend to be older, this holds in particular for rice farmers. Among the 1104 respondents in our sample at baseline, the average age is about 51 years. More than 96% of the farmers in our sample have completed at least elementary school and more than half have completed senior high school.

Households in our sample cultivate on average around 2,100 m2 of land. Thus, cultivated land size is small, even compared to the average in Java. Many respondents cultivate multiple plots, with the average plot size being around 940 m2. Less than half of the rice plots cultivated by the household are also owned by the households. One of the sample selection criteria was that the respondent cultivates rice. Most respondents in our sample cultivate rice on flooded fields (wet rice) rather than dry rice. A large share of the harvest was self-consumed by the household. A considerable share also went to the landowner for plots that were cultivated under a sharecropping arrangement. As can be seen from Figure **2**, a significant share of farmers applied more Nitrogen to their fields than the ministry's recommendation of 138 kg/ha.

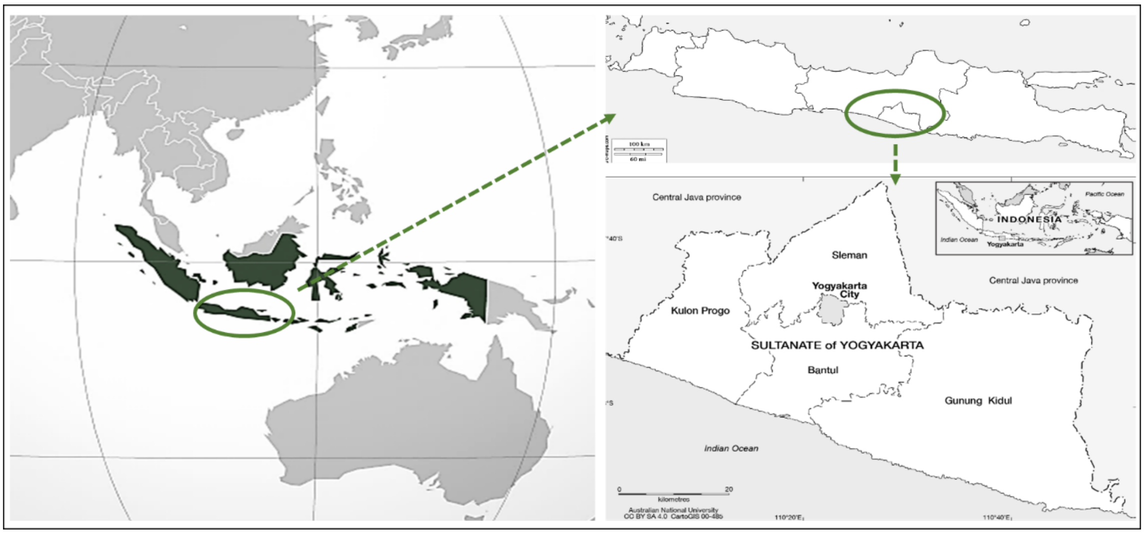
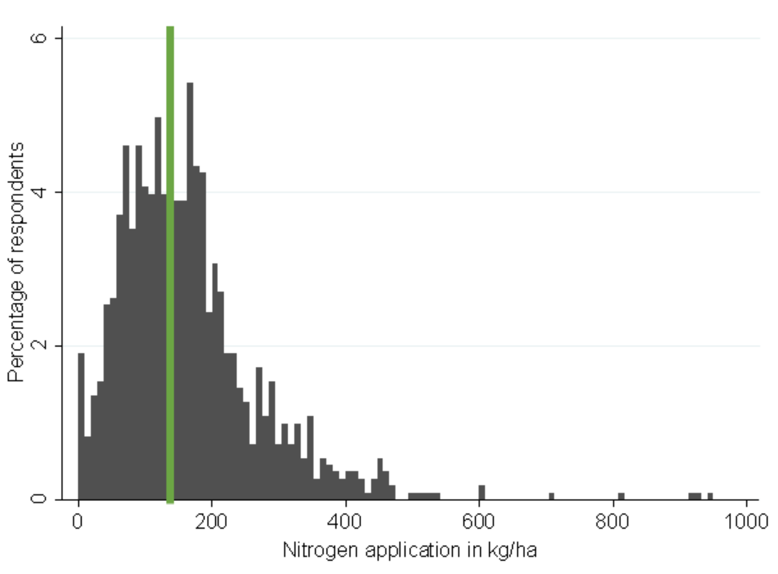


***Figure 1**: Project location*



Note: The green line indicates ministry recommended Nitrogen application

***Figure 2**: Nitrogen application of farmers prior to training*

Before the training sessions were held in our project, less than one-third of our respondents had ever heard of soil tests and only 12% of all respondents had ever tested their soil. In most cases, these soil tests referred to pH tests, thus tests that are far less comprehensive than the PUTS soil test. Another useful yet convenient and relatively economical agricultural technology that indicates Nitrogen levels, leaf color charts (LCCs), had also only been used by 4% of our respondents before the training.

Nearly 90% of the respondents or one of their household members belong to a farmer group. The majority of these farmer groups are still active and also conduct regular meetings. Interestingly, less than half of our respondents have had any contact with agricultural extension workers in the last two years.

d. Context: Soil tests

The soil tests used for this project are low-cost, rapid wet-chemistry soil tests that can be used directly in the field. The tests are marketed as kits under name "Perangkat Alat Uji Tanah Sawah" Paddy Soil Test Kit (PUTS). The soil test kit was introduced in 2012 by the Indonesia Soil Research Institute (ISRI)[1]. ISRI is part of the Indonesian Ministry of Agriculture.

The PUTS kit measures Nitrogen (N), Phosphor (P), Potassium (K), and pH levels. It is accompanied by a recommendation book for fertilizer use based on the soil assessment results. For N, P and K, the tests provide the qualitative information low, middle or high. For the pH level, the categories are very acid (pH <4), acid (pH 4-5), neutral (pH 5-6), slightly alkaline (pH 7-8), and alkaline (pH >8).

The kit comprises of test tubes and liquid to conduct around 50 soil tests and comes with a bag. It is a manual, wet-chemistry test kit that has been extensively tested and validated by ISRI. Results are available within 30 minutes and the analysis can be done directly in the field or at farmers' homes – sending soil samples to a lab is not necessary. This substantially reduces the cost and effort that farmers would otherwise have to invest to get their soil samples tested. One PUTS soil test kit costs IDR 1.8 million (around € 104), thus one soil test comes at a cost of around € 2. Since the kit has been developed and promoted by the Ministry of Agriculture it benefits from high local acceptance. ISRI disseminates the kits to extension offices. However, up to now, uptake remains very limited, with most farmers lacking exposure to soil testing. In the following, we illustrate the steps we undertook to conduct soil tests using the PUTS (based on the instructions by ISRI) in our training sessions.

<u>Step 1: Collecting a soil sample</u>

Farmers were instructed to obtain five soil samples from each plot using a hoe, avoiding corner areas as they may not represent the entire plot. Farmers were instructed to select five locations in their plot that are diagonally connected (see Figure 3 and Figure 4). Collecting several samples and then mixing them ensures a better representation of the overall soil characteristics of the plot.

<u>Step 2: Testing the soil sample</u>

Following the soil sample collection, trainers guided farmers on how to implement the soil tests. Trainers explained each soil test parameter step-by-step during the training sessions. Farmers tested their own soil samples with trainers' support. While some respondents faced challenges due to poor eyesight or age-related-trembling, overall farmers enjoyed conducting the tests themselves and were eager to participate. Figure 5 illustrates the steps of the soil test using the example of Nitrogen.

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[1] Now called Indonesian Soil and Fertilizer Standardization Institute (BPSI Tanah dan Pupuk). In our report we refer to the organization as "ISRI".

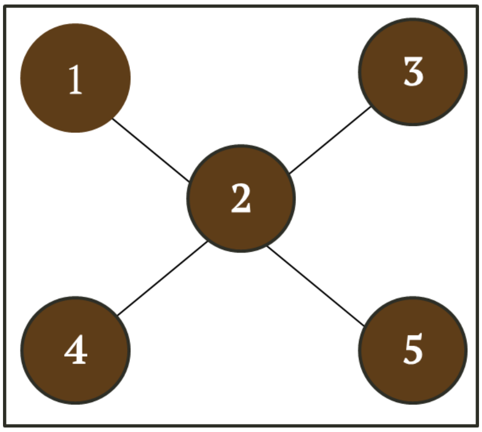


***Figure 3**: Instruction how to choose locations for soil samples*

***Figure 4**: Trainer collecting a soil sample using a hoe*

Step 3: Fertilizer recommendations

Based on the test results, farmers obtained fertilizer recommendations using the accompanying booklet. Farmers sometimes struggled because they had to re-calculate the fertilizer recommendations given by the booklet in tons/ha to their own plot size, e.g. 3,200 m2. In our training, the trainers helped the farmers with translating the test results into fertilizer recommendations and instructed them how to make the calculation.

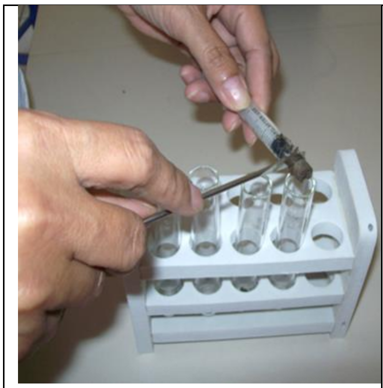
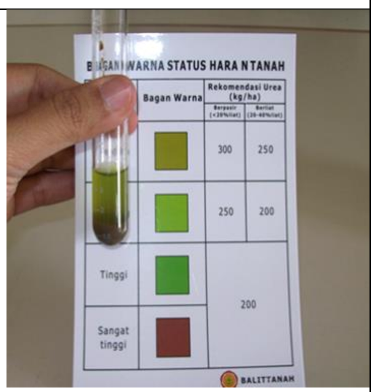
 1. Take 0.5 spoonful of test soil and put it in a test tube	 2. Add 2 ml N-1, stir until homogeneous	 3. Add 2 ml N-2, shake until smooth
 4. Add 3 drops of N-3, shake until smooth	 5. Add 5-10 grains of N-4, shake until smooth	 6. Wait 10 minutes and compare the color with the color chart

***Figure 5**: Steps to test Nitrogen using the PUTS*

e. Context: Leaf Color Charts (LCCs)

The leaf color chart (LCC) is a simple tool to assess the Nitrogen needs of rice crops. The LCC features four green strips, ranging from light yellow-green to dark green. Farmers are instructed to select several leaves from their rice crops and compare them with the colors printed on the LCC. The leaf color is closely related to the Nitrogen status of rice crops. Choosing the color that most closely resembles their leaf, farmers can then obtain recommendations on plants' Nitrogen needs on the backside of the leaf color chart. Greener leaves indicate lower additional Nitrogen requirements. Monitoring Nitrogen needs closely helps to prevent overfertilization. The LCC promotes efficient fertilizer use, optimizing plant health and crop yield.

***Figure 6**: Applying the LCC*

f. Context: Lentera Desa

Lentera Desa is an online education platform for agriculture. It is operated by the University Gadjah Mada (UGM), our main local partner in this project. The platform targets extension workers and farmers, offering structured online courses at low or no cost. Online courses comprise several short videos on specific topics, for example on soil health or how to build a shallot agribusiness. The videos, which usually have a duration of 2 to 15 minutes, are produced by UGM. In addition to the courses, the platform offers other features, such as a discussion forum. Users can login using their mobile phone or other devices suitable to access the internet.

The platform was initiated independent of our project and before the start of our fieldwork. However, the platform had only few users and lacked insights into users' needs and engagement with the platform. Together with our partners from UGM, we opted to offer farmers a blended learning experience, combining face-to-face training with free access to an online course. Hence, jointly with UGM and the trainers who also provided our face-to-face training, we created a course on soil health management and uploaded it on the Lentera Desa platform.

Integrating the platform into our project had several benefits. First, blending online and face-to-face learning can help to reach more farmers. It thus offers great potential for ministries and extension office with resource constraints. Currently, extension offices in Indonesia are just at the beginning of integrating online resources. Our project serves as a lab for this approach. Based on the insights from this project, UGM's faculty of agriculture, specifically the Department for Extension and Communication, can advise extension offices. Second, our project facilitated the platforms' large-scale rollout to 600 farmers, offering insights into usage patterns and areas for improvement. Thereby the project provided valuable opportunities to better understand farmers' needs and enhance service delivery. Third, UGM's long-term plans to enhance and operate the platform align with our project goals for sustainable impacts. The platform has the potential to enhance farming practices and mitigate environmental harm as well as to foster new business opportunities, ultimately benefiting smallholder farmers' welfare. Building on the insights of this project, UGM has already developed several other courses that are now offered on the platform. Figure 7 showcases the platform and some of the courses on offer.

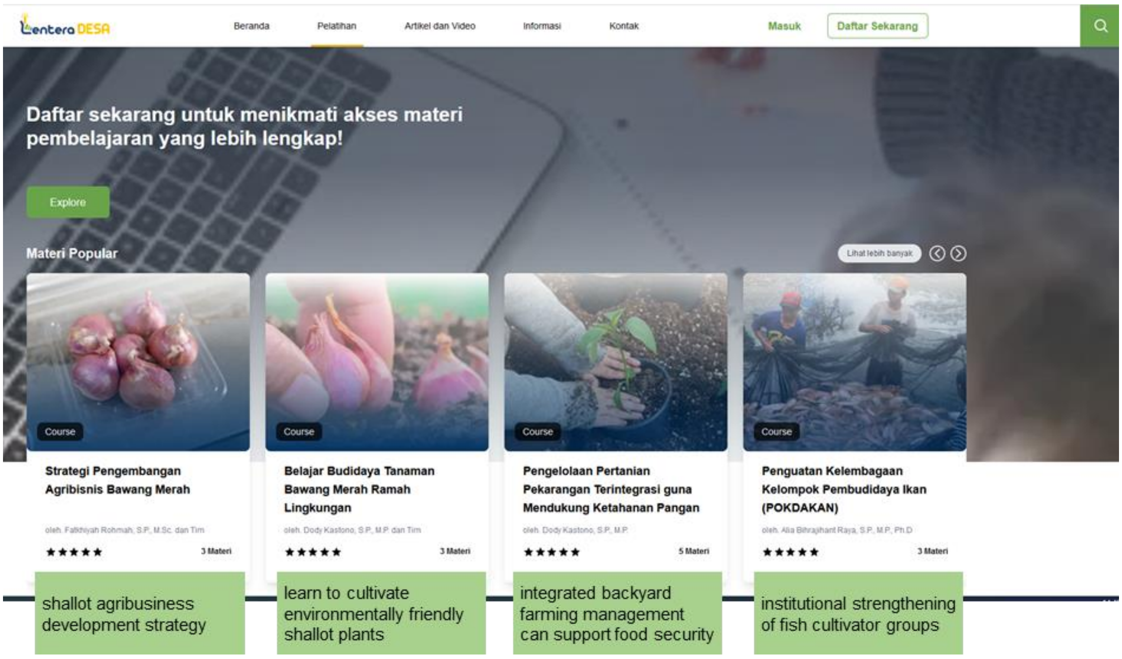


Figure 7: *Lentera Desa platform (screenshot)*

4. Sub-project 1: Impact of training and soil testing

This sub-project assessed the impact of soil health management training and individualized soil nutrient information on farmers' chemical fertilizer application behavior, use of organic inputs and knowledge. The project employed a randomized controlled trial (RCT) to compare the effectiveness of two training formats: a one-day soil health management training and a two-day training, which included soil testing using the PUTS kit. Both training formats are also compared to a benchmark scenario where farmers received no training.

The evaluation was based on two waves of panel data and aimed to answer the following questions:

- **Do small-scale rice farmers change their soil fertility management behavior in response to training?**
- **Does training on and access to soil testing increase the effect of training?**
- **Does training increase farmers' knowledge regarding soil nutrient management?**

In the subsequent sections, we discuss the methods and data employed, provide insights into the training design, and present the results.

a. Methods: Randomized controlled trial

This project used a randomized controlled trial (RCT) to establish a direct cause-and-effect relationship between the training and its impact. Simply comparing adopters of soil management practices with non-adopters can be misleading as these groups may differ in many other respects, i.e. education, which would then be confused with adoption. Likewise, comparing the same farmers before and after training can be misleading if other factors, such as subsidies, change simultaneously. Like in a medical trial, random assignment ensures that treatment and control groups are statistically comparable pre-training, allowing for a causal link between training and outcomes.

Randomization was conducted at the village level, i.e. all respondents from one village were assigned to the same group. We randomized respondents into three groups. Treatment group 1 was offered a one-day training, similar in structure and length to a typical training from extension officers. The training focused on soil health management. In addition, farmers received access to the digital platform Lentera Desa with educational farming videos. Treatment group 2 received the same one-day training as treatment group 1, access to Lentera Desa and an additional day of training focusing on soil testing and result interpretation. The control group received no training. Figure 8 displays the research design. This research design allows us to evaluate the benefits of different extension intensities (in comparison with the costs).

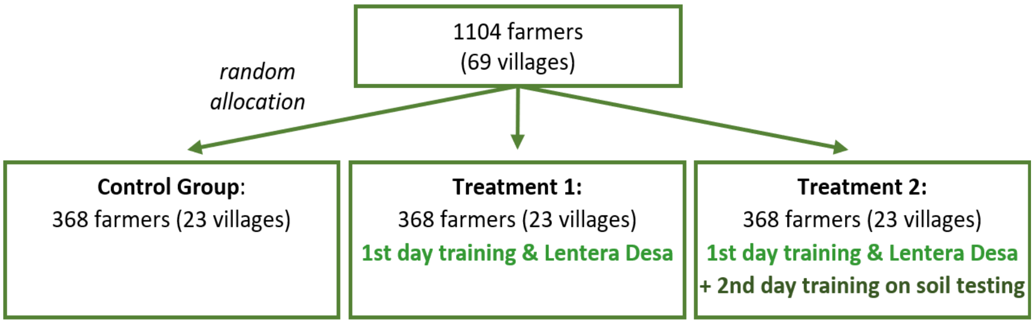


Figure 8: *Experiment set up*

b. Methods: Data collection and timeline

The experiment was conducted in 69 villages across three districts of Yogyakarta province: Sleman, Bantul and Kulon Progo. Pre- and post-training data were collected in August 2022 and June 2023. Respondents were sampled at the farmer group level. In total, 1,104 farmers were interviewed, i.e. 16 from each sampled village. Figure 9 provides a time line of the activities.

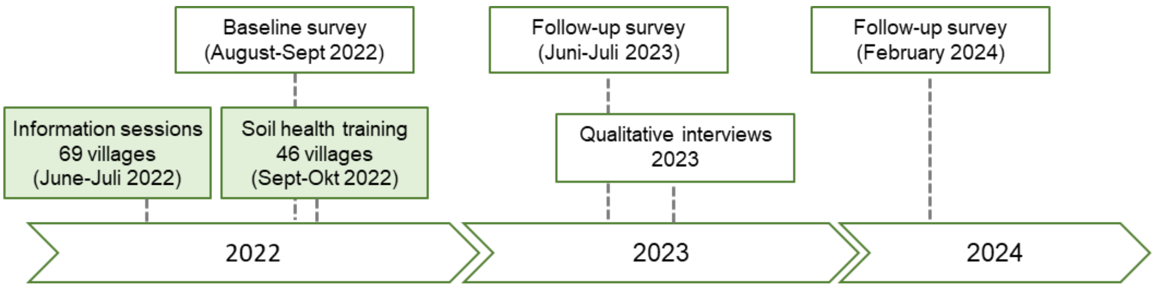


Figure 9*: Time line of project activities*

Villages were randomly selected among all villages in Yogyakarta, excluding those previously included in another project by the team. Before the baseline survey, farmers in the selected villages were invited to an information session focusing on digital farming resources. These sessions served multiple purposes: to provide relevant information to farmers, to pre-screen respondents based on their interest in participating in activities, and to compile a list of potential respondents. Potential respondents had to cultivate rice, be under 60 and have access to a smartphone (either through an own phone or through a family member). In each village, we randomly selected 16 respondents from the list of potential respondents based on the attendee list.

Data collection was carried out by a team of 10 enumerators during each wave, utilizing tablets and the software SurveyCTO for face-to-face interviews. Team members from Passau (Nathalie Luck and Udit Sawhney) and from UGM jointly provided supervision.

In addition to the quantitative data, we also collected qualitative data in both years to further explain the mechanisms and channels of behavioral change.

Prior to the fieldwork, we obtained ethical clearance from *the Committee for Ethics in Researc*h at the University of Passau. In addition, the project team obtained ethical clearance by the National Research and Innovation Agency (BRIN) in Indonesia. The same holds for sub-project 2.

c. Training intervention

The training sessions were participatory and involved classroom sessions on soil nutrient principles, discussions on problems associated with chemical-fertilizer-intensive farming and practical exercises on the production of organic inputs. All invited farmers were given access to the online extension platform Lentera Desa. In the 2-day training, farmers were additionally taught how to use the PUTS soil test kit using a soil sample from their plots. After the training, the groups in the 2-day training received a PUTS kit for their independent use post-training. The trainings were held in farmers' villages. The participation rate was high; on average 13.8 out of the 16 invited farmers per village participated.

The training curriculum was collaboratively developed by a team of trainers consisting of alumni from UGM's soil science and extension department, as well as practitioners from P4S. P4S are self-managed farmers' training centers in Indonesia. The P4S branch involved in our project specializes in organic agriculture. Training material provided by ISRI served as the basis for the training part on the PUTS soil test kit and trainers from P4S participated in a training-of-the-trainers session conducted by ISRI on the utilization of the PUTS.

Each training session was led by a duo comprising one member from UGM and one member from P4S. This pairing ensured a blend of practical field experience and scientific knowledge in every training session. To ensure the effectiveness of the training, several pilot sessions were conducted beforehand to adequately prepare all trainers and fine-tune the training materials.

The training timeline was as follows:

Day 1

- Introduction to soil health & nutrients
- Introduction to LEISA (Low external input sustainable agriculture)
- Interactive games in groups (e.g. crossword puzzles)

- Practical exercise to produce own input
- Practical exercise on how to use the leaf color chart
- Lentera Desa (digital platform): videos
- Soil sampling for soil tests – group 2

Day 2

- Soil testing using PUTS: Farmers analyze their own soil sample
- Fertilizer recommendations based on LEISA principles
- Lentera Desa (digital platform): videos & calculator

Figure 10: *Trainer solving puzzle with respondents*

Figure 11: *Trainer demonstrating organic input production*

d. Results

Our findings reveal that the training significantly reduced farmers' application of chemical Nitrogen fertilizer and increased farmers' use of agricultural lime. The impact was larger among the participants who were offered the 2-day training, which incorporated soil testing, allowing farmers to receive individualized information about their soil conditions. Results further indicate that farmers value information about simple farming tools like the LCCs. However, they are still hesitant to use more complex tools such as soil tests by themselves after the training. To ensure sustained utilization of such tools, farmers may benefit from extended training sessions or seasonal support from extension workers when farmers implement the soil tests. Although the training led to increased utilization of LCCs and agricultural lime while decreasing reliance on chemical fertilizers, its influence on the timing of fertilizer application, farmers' knowledge about soil nutrients, and their adoption of organic inputs was limited. It is worth noting that farmers exhibited relatively high scores in some of these aspects, e.g. the correct timing of fertilizer application, even before the training. In the following, we provide a more detailed description of the results.

Findings: Using organic inputs, lime and LCC

Organic inputs: Overall, the training could enhance the use of some organic inputs but not all. The considered inputs include fermented manure, liquid organic fertilizer, green manure, rice residues and MOL/ PGPR.

Lime: Trainers explained the importance of an optimal Ph level and that lime can be added to increase the Ph level. Farmers in the 2-day training additionally obtained results on the Ph level of their soil sample. We observe that the training increased the share of farmers who applied lime. The increase is larger for farmers receiving the 2-day training.

Leaf Color Chart (LCC): All training participants received an LCC (a simple tool indicating rice plants' Nitrogen status). Among farmers in the 2-day training, 18.4 percent used it, compared to only 1.2 percent in the control group.

Figure 12 compares treatment group 2 (2-day training), treatment group 1 (1-day training) and the control group with respect to respondents' use of agricultural lime and the LCC in 2023. Because the respondents were randomly allocated to the treatment groups and hence were comparable prior to the training, differences can be attributed to the training.

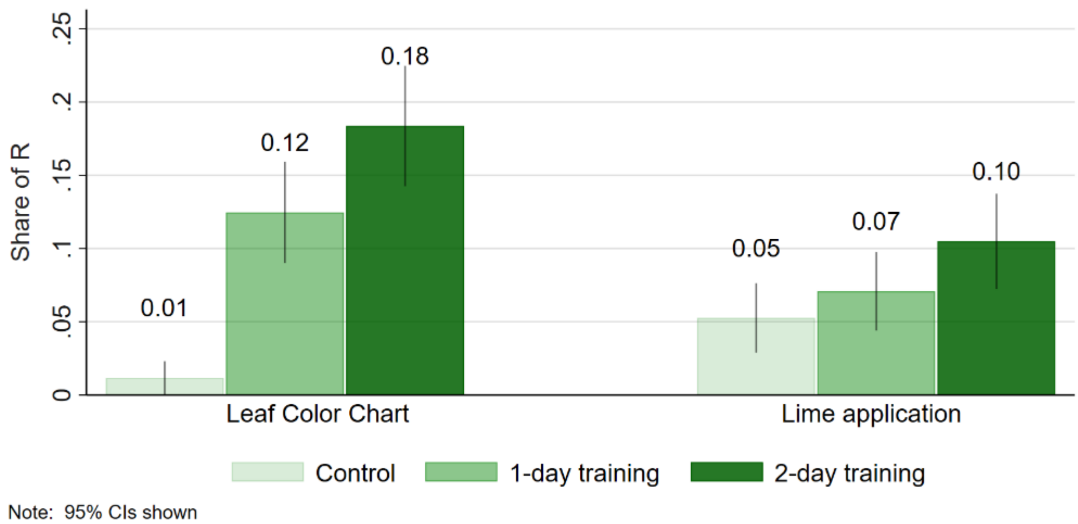


***Figure 12**: Training impact on use of LCC and lime*

Findings: Application of chemical inputs

The results show that training seems to be effective in addressing the overapplication of Nitrogen-rich fertilizers. Comparing the treatment groups with the control group shows that farmers who received a 2-day training applied on average **132 kg/ha** of Nitrogen, compared to **143** kg/ha in the 1-day training group and **159 kg/ha** in the control group. This finding is also in line with our finding that training increased the use of the LCC which helps farmers to adjust their Nitrogen application to the needs of the plants.

By contrast, the training had no impact on the application quantities of Phosphorus (P) and Potassium (K). Yet, the overapplication of these two nutrients through chemical fertilizer is also much lower in our sample.

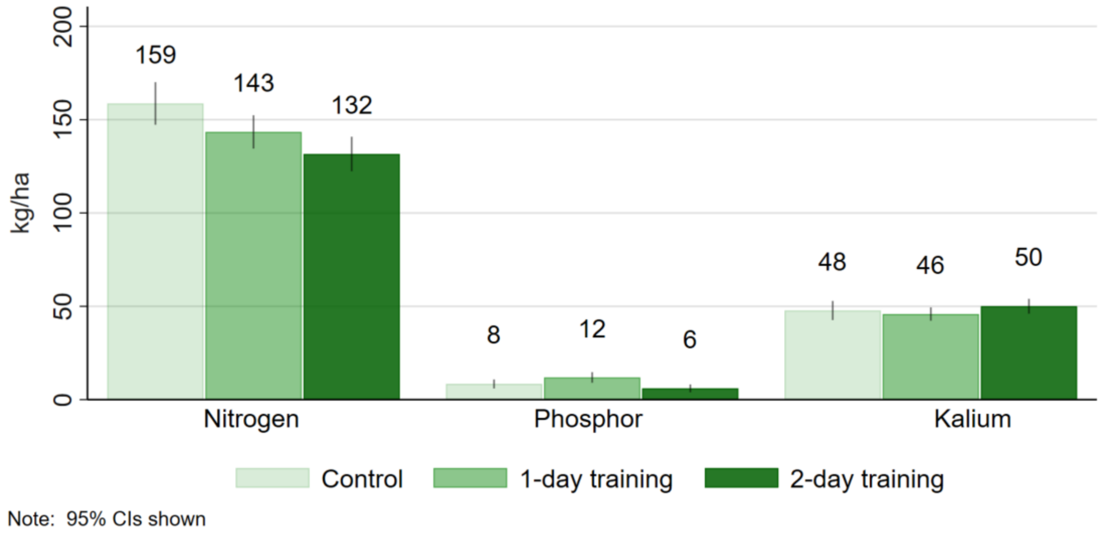


***Figure 13**: Training impact on chemical fertilizer application*

Findings: Adoption and knowledge score

A higher adoption score (max. 4) signals that the farmers' application pattern is more in line with the training recommendations (early application of Phosphorus, split Nitrogen application, early application of Potassium, and no late application of Nitrogen). Trainers further explained the role of different nutrients (mainly N, P, and K) in maintaining healthy crops. A higher knowledge score indicates that farmers answered more nutrient questions correctly. The score ranges from 0 (lowest) to 6 (highest). We do not see any clear impact of the training on the adoption score or the knowledge score.

Findings: PUTS use after training

One year after the training, only few farmers who were invited to the 2-day training had used the PUTS independently. This is in line with the qualitative data we collected in the form of semi-structured interviews. Farmers reported that they had forgotten how to use the soil test kits and do not feel confident using them without expert supervision, despite also having access to video instructions through the Lentera Desa website. Some farmers also reported that they feel hesitant to collect the soil test kit from another farmer's home.

During the qualitative interviews, respondents also expressed their appreciation for the training as it provides them with new knowledge about farming practices and tools, e.g. using leaf color charts. They also reported finding it easier to identify the characteristics of healthy soil.

In 2023, 1.5 years after the training, we conducted a shorter 3rd survey wave. This yielded insightful data on farmers' perspectives. Asked why they had not yet used the PUTS soil test kit independently after the training, some farmers explained that they found it difficult to implement it without a trainer, others reported that they were waiting for a joint test session in their farmer group. Regarding their test results from the training, farmers most frequently remembered the pH level of their plot. This is in line with our finding that the application of lime, which is used to manage the pH level, went up in treatment group 2 which received soil testing.

5. Sub-project 2: Farmers' willingness to pay

This sub-project investigated farmers' willingness-to-pay (WTP) for rapid paddy soil tests using an incentive-compatible approach. This implies that the experiment incorporates actual purchase decisions and thus reduces the risk of a social desirability bias that might otherwise inflate the stated willingness-to-pay. To explore how soil tests could be distributed to farmers in a way that ensures adoption and is at least partially cost-covering, we compared two approaches that government extension offices could employ: offering soil tests as a service along with fertilizer recommendations, and (2) providing farmer groups with the PUTS soil test kit along with training on its usage.

In the following sections, we outline the setup and auction mechanism used to assess farmers' WTP, provide an overview of the collected data, and present our findings.

a. Auction mechanism

To measure the WTP for soil tests, we used the Becker-DeGroot-Marschak auction mechanism (BDM). BDM is widely used in the literature and has the advantage of being incentive-compatible. Following the auction, those respondents who made offers exceeding the strike price purchased the product.

The principle of BDM is to offer a respondent a product and to ask for a price bid. This bid is then compared to a randomly drawn price – the strike price. If the price bid is equal to or higher than the drawn price, the respondent buys the product for the drawn price. If the bid is lower, the respondent cannot buy the product. Because the auction involves a real purchase, the assumption is that the BDM auction reveals respondents' true willingness to pay (WTP). A bid too low means missing out, while a bid too high means overpaying. The product and exact procedure to measure the WTP differs between the two experimental arms.

Service arm: product = 1 individualized soil test including fertilizer recommendation by an expert

Before the bidding process, our enumerators explained the bidding process. Then all participants made their bid, privately and one after the other. They were asked how many tests they want to buy at this price if they were successful. After all participants made their bid, a price was randomly drawn. Successful participants made a down payment and a date for the soil testing service was fixed.

Figure 14 illustrates this process. In this bidding scenario, all respondents were asked to submit bids for the service of receiving soil test results for one soil sample. For example, Person 1 bid IDR 11,000, Person 2 bid IDR 10,500, and Person 3 bid IDR 9,000. The fourth person, not interested in the soil test service, submitted a bid of 0. In the actual bidding process, all bids are made in private and not shared with anybody outside the research team. After all bids were collected, a price of IDR 10,000 was randomly drawn. Consequently, only Person 1 and Person 2 were eligible to purchase the soil test service at the price of IDR 10,000.

***Figure 14**: Example WTP Service*

Club good arm: product = PUTS kit with 50 soil tests and a group training session on how to use the kit

The bid by each participant represents a contribution to the entire kit, not an individual soil test. Again, the enumerators explained the bidding process. It was also explained that the two lowest non-zero bids would be doubled (subsidy). Each participant was asked how many soil tests he or she would like to perform in case the group is successful. After all participants had made their bid, a price was randomly drawn. If the sum of all bids plus the subsidy were above the price drawn, the group bought the test kit at the drawn price. Each participant paid a share of the total price (minus the subsidy) equivalent to his or her bid relative to the total bid. The group made a down payment and the date for the PUTS delivery and training was fixed.

Figure 15 illustrates the bidding process in the group setting. First, respondents were asked to indicate the amount that they are willing to contribute towards buying the soil test kit as a group. In Village 1, the total of all bids amounts to IDR 80,000. The two lowest non-zero bids (IDR 10,000 + IDR 20,000) were added as a subsidy, resulting in a total bid of IDR 110,000. The randomly drawn price in this example is IDR 150,000. This exceeds the total bid of Village 1, thus the village cannot purchase the kit. In village 2, the total of all bids amounts to IDR 120,000. Adding the two lowest non-zero bids as subsidy results in a total bid of IDR 160,000, exceeding the randomly drawn price of IDR 150,000. Thus, village 2 wins and can purchase the kit paying IDR 120,000.

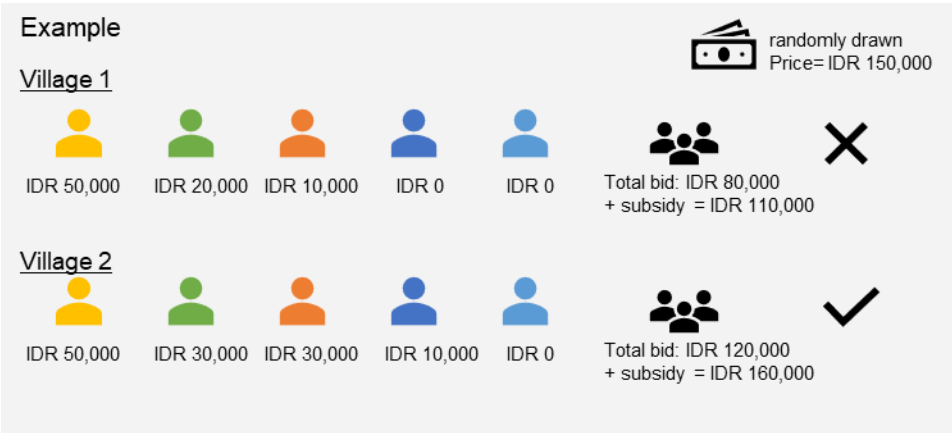


***Figure 15**: Example WTP Club Good*

b. Data and set-up

The WTP experiment was implemented in 45 villages in the province of Yogyakarta. In each village, we invited farmers to an information session on soil testing. Between 7 and 25 farmers participated per village. In total, we could enroll 603 participants, 295 in the 24 villages that were assigned to the service arm and 308 in the 21 villages that were assigned to the club good arm. The WTP experiment was conducted in June and July 2023. In February 2024, we conducted a short follow-up survey.

During the information session, a facilitator first explained the concept of the PUTS soil test kit. The facilitators illustrated the mechanism of the PUTS with at least one nutrient and further explained the advantages of the PUTS and soil testing in general. All facilitators previously supported the project as trainers and were thus experienced in conducting and explaining the PUTS. Following the introduction of the PUTS, enumerators proceeded to outline the bidding process. During each information session, the enumerators ran a sample bidding exercise using either a pair of sandals in the service treatment groups or a blood-pressure measurement device in the club good treatment groups. We chose the blood-pressure measurement device as it can be shared across people but has a limited number of tests that can be done with the included material, mirroring the characteristics of the PUTS. After the bidding demonstration, enumerators took additional steps to ensure participants' comprehension of the process. This included clarifying the suitability of the PUTS for various crops, emphasizing the confidentiality of price bids, and reaffirming that bidding represented a commitment to pay in the event of success. Subsequently, enumerators conducted individual interviews with each participant, recording their price bids and conducting a brief survey.

c. Results

Results from our experimental study show that smallholder farmers in Indonesia are willing to pay for/contribute to the cost of rapid soil tests. This finding holds particular relevance given the resource constraints confronting Indonesia's extension system. The results suggest that the extension system may not have to cover the full costs of soil testing. Moreover, there is potential for farmers' WTP to increase over time, especially as they experience the benefits that the PUTS can offer. However, farmers' WTP does not cover the full costs of the tests. To address this shortfall, subsidies may be justified by the potential environmental benefits that could result from the prevention of fertilizer overuse and better soil management.

Our project further illustrated two approaches how the PUTS provision could be integrated into the existing extension system, given that farmers were willing to pay in both scenarios. Extension workers could provide soil tests as a service on an annual basis or conduct training sessions to teach farmers how to conduct the tests themselves. However, additional data collected in 2023 and qualitative insights suggest that after just one training session, some farmers may still feel insecure or lack motivation to use the PUTS again. In a setting similar to the club good setting, it may be necessary for extension workers to revisit the groups to initiate soil testing and help if farmers encounter any challenges. In the following section, we provide more details on the results.

Farmers' WTP

The average WTP was IDR 15,600 (0.99 USD) in the service arm and IDR 24,200 (USD 1.54) in the club good arm (see Table 1). Hence, people were willing to pay in total more for soil tests in the club good setting. Yet, in the club good arm, participants made bids for contributions towards the entire soil test kit containing 50 soil tests, and hence the total WTP must be adjusted for the number of desired plots to be tested. If expressed on a per-test basis, the WTP was very similar in both treatment arms and a little bit lower in the club good arm (15.6 vs. 14.4.).

The range between the minimum and maximum was also comparable in both settings, but in the club good setting the share of zero bids was higher by 5.7 percentage points. We asked participants who provided zero bids for the reason. Perceived lack of usefulness, land rental arrangements and affordability are by far the dominant reasons. Among those who made a positive bid, the number of desired tests was higher in the club good arm than in the service arm (2.1 vs. 1.7). This might partly be related to the fact that participants know that the kit offers 50 tests and the group bidding for it was, on average, much smaller.

Since we drew prices well below actual costs, 52.5% of all bids in the service good arm and 61.9% of all bids in the club good arm were successful.

***Table 1**: Outcome of BDM auction*

	Service	Club Good
Individual level		
WTP (total contribution) (in 1,000 IDR)	15.6	24.2
Desired # of tests per participant (if non-zero bid)	1.7	2.1
WTP per soil tets (in 1,000 IDR)	15.6	14.4
Village (Dusun) level		
Group size	12.3	14.7
Spread of WTP per test within group (in 1,000 IDR)	56.5	57.2
Share of zero bids by group	0.254	0.311
Outcome of BDM auction		
Successful (share individuals / share groups)	0.525	0.619
Average bid among those successful (indiv. / group)	26.95	437.46
Participants	295	306
Village groups (Dusuns)	24	21

Demand curves

Figure 16 relates the price and uptake for both experimental arms. The curves for both settings largely overlap. At the actual cost of IDR 36,000 per test (price of a test without any service) uptake would be about 20%.

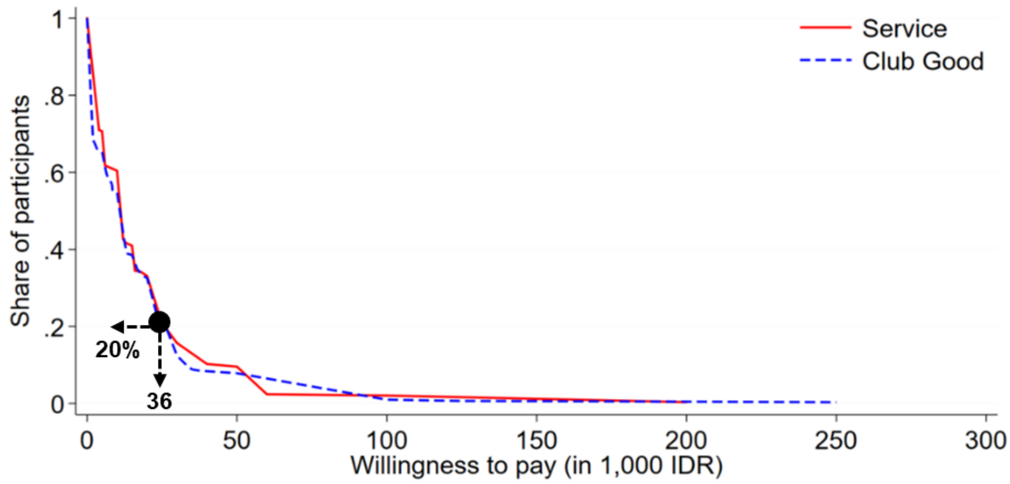


***Figure 16**: Demand curve*

Further data analysis

Age is not significantly related to the bid amounts but bids increase with education. Participants with junior secondary schooling bid, on average, about IDR 5,500 more than those with no or primary schooling. This may of course also capture a wealth effect.

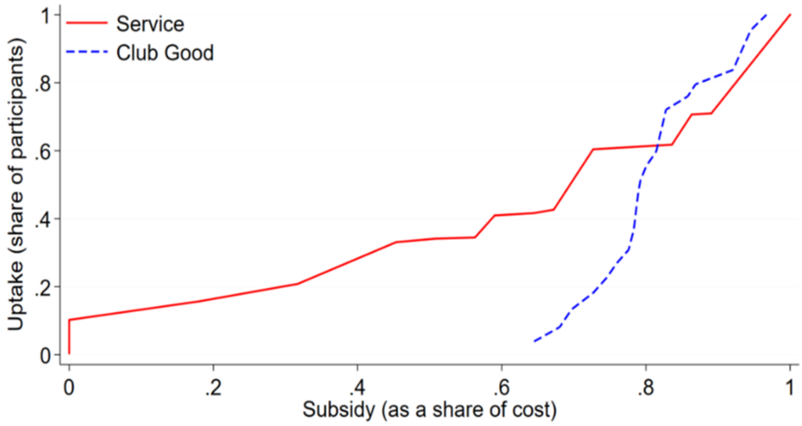
Bids also decrease by IDR 870 with each additional group member, possibly because farmers anticipated learning from the tests of others. However, we find that the effect is smaller in the club good arm. This suggests that free-riding on the contributions of others is not the key driver of the group size effect.

We find that the bid per test declines by IDR 4,000 with each additional desired test. This may indicate that after the first test, farmers attribute a lower value to additional tests, probably assuming that a test on one plot may also have valuable information for other (close by) plots.

Finally, we explore whether WTP varies with land ownership status. We find that the WTP declines with the share of the land under sharecropping that the farmer wants to test (vs. owned/land under fixed-rent).

Scope for subsidies to foster soil test uptake

Figure 17 shows the take-up as a function of the share of the total cost that is subsidized for both experimental arms. For lower subsidies, the provision of the soil test as an individual service is the most effective. Uptake among groups is zero unless at least 60% of the costs are subsidized. But for subsidies above 75%, i.e. a farmers' contribution of 25 % or less, uptake is higher in the group setting. For an 80% subsidy, the uptake is about 60% in the service arm and 70% in the club good arm. For a 90% subsidy, the difference increases to almost 20 percentage points.



Notes: Costs include only the costs of the soil tests without the service and training, i.e. IDR 36,600 in the service arm and IDR 1,830,000 in the club good arm. In the club good arm, uptake is weighted by group size, i.e. both lines show uptake at the individual level.

***Figure 17**: Uptake at different subsidy levels*

Summary of key findings

Our experimental study shows that small scale farmers in Indonesia are willing to contribute to the cost of rapid low-cost soil tests. Yet, the WTP does not cover the cost of the tests. Subsidies can be justified by the potential environmental benefits that could result from the prevention of fertilizer overuse and better soil management. The provision could be integrated into existing extension services. For low subsidies the provision as an individual service is the most effective. For higher subsidies the provision of entire test kits and training is more effective to increase uptake. The provision in a group setting might increase the probability that farmer associations integrate soil testing in their group activities.

6. Dissemination and public outreach

a. Workshops

The project prioritized public outreach, dialogue, and dissemination as integral components of its mission. We conducted three workshops within this project to foster engagement with policymakers and relevant stakeholders. The first workshop was held in 2022 before the fieldwork started and two workshops were held in 2024 to discuss and disseminate the results. Additionally, the project was presented and discussed at two academic workshops: one in Passau in 2022 and another in Yogyakarta in 2024. The workshops served as platforms for exchanging insights, sharing results, and fostering collaboration within the academic and policy communities. We also presented our research at workshops and conference organized by other institutions including the RWI in Essen, the TU Munich and the GIGA in Hamburg. In the following section we provide details on our workshops in the order they were held.

2022: Pre-fieldwork workshop

The first project workshop, jointly organized by UGM and the Passau team, took place on the 13th of July 2022 in Yogyakarta, Indonesia. The workshop aimed to introduce the project to local ministries and the UGM community, foster the discourse between different stakeholders in the Indonesian extension service sector, and lay the groundwork for future engagement with stakeholders. Around fifty participants from academia, ministries as well as farmers attended our workshop and engaged in a lively discussion on soil health and digital extension. After introducing the planned research activities, the research team handed over to speakers from UGM and ISRI. Dr. Ladiyani Retno Widowati from the Indonesian Soil Research Institute (ISRI) gave the keynote speech. In the second, interactive part of the workshop, participants formed small groups to discuss the role of academics, farmers, extension workers and the government in accelerating the adoption of innovations in soil health management.

2022: Passau workshop

We also organized a two-day workshop on 29-30 September 2022 at the University of Passau to which we invited three involved researchers from Indonesia - from IPB, the University of Atma Yaya Yogyakarta and UGM - and colleagues from German Universities (Bonn, Göttingen and Hannover), all experts on sustainable farming. The workshop served to discuss interventions and instruments to enhance sustainable farming practices with a specific focus on Indonesia. The workshop also featured a public lecture on sustainable palm oil production by Prof. Matin Qaim, director of ZEF Bonn and Professor at the University of Bonn. The event was funded by the Passau International Centre for Advanced Interdisciplinary Studies (PICAIS) and was advertised with the logos of the DBU and DFG (which funds a related project at the Chair).

2024: Academic workshop (5th of March)

We shared and discussed the findings of this project at a DFG-funded academic workshop in Yogyakarta, Indonesia, on the 5th of March 2024. The workshop focused on Sustainable Agriculture, Digital Extension, and Soil Testing. It discussed recent research on how to support smallholders in their transition towards more sustainable agricultural practices, the potential of soil testing, and new developments in agricultural extension, including digital extension. Presentations covered recent academic research on organic farming, soil testing, sustainable palm oil, digital extension, and the challenges of Indonesian rice farmers. Academics from several different Indonesian universities participated in the workshop, totalling around 30 participants.

2024: Local policy workshop

A workshop for local policy makers, jointly organized with UGM, took place on the 6th of March 2024 in Yogyakarta. This workshop was partly funded by this project and partly by a DFG project by the same project team. The results from the two projects complement each other and are relevant for the same policy makers. The workshop was held bilingual with simultaneous translations into English and Indonesian.

Both, the Passau and the UGM research team presented results from the project. The presentations from Passau focused on the causal impact of soil management training and the added benefit of soil tests as well as on farmers' willingness to pay/contribute to the costs of soil tests. The UGM team shared results on the opportunities and hurdles farmers face when using the PUTS independently and on the insights that were gained from the integration of the Lentera Desa platform into the training. Positioning the workshop and the project results as a collaborative effort between the Passau and the UGM team was important to dispel any notion of a "foreign" solution being imposed on Indonesian challenges. Furthermore, it strengthened the position of our colleagues at UGM as future points of reference for these topics among local policy makers.

The policy workshop was attended by a diverse group of participants:

- Extension workers from three districts in Yogyakarta: Sleman, Bantul, and Kulon Progo
- The Head of the Regional Planning and Development Agency (BAPPEDA) of the Special Region of Yogyakarta
- The Head of the Agricultural Training Center of Central Java Province, a neighbouring province of Yogyakarta
- The Head of Agricultural Extension and Infrastructure Division, Department of Agriculture and Food of Kulon Progo Regency in Yogyakarta
- Staff from the Food Crop Division and the Coordinator Extension Officer of the Department of Food and Fisheries, Tasikmalaya District in West Java
- Representatives of the P4S group which also participated as trainers in our project
- Research team members from UGM and Passau

At the workshop, we not only shared the results of our project but also discussed with the participants what learnings can be taken for the local extension system. Policy makers and extension workers shared the challenges they are currently facing and how these relate to the project results. Participants further shared their experiences with the PUTS in the extension system and the challenges they face when introducing new agricultural technologies to an aging farming population. In the discussion, the participants showed great interest in the fact that our project's trainers were predominantly young farmers and young alumni from UGM's extension and soil department, yet were well-received by the mostly elderly training participants. Some workshop participants who had not yet used the PUTS also reported that the workshop sparked their interest to integrate the PUTS into their own activities (e.g. the representative from a training centre in Central Java).

2024: National and international policy workshop

The workshop for policy makers at the national and international level took place on the 7th of March in Bogor, Indonesia. As all other workshops in Indonesia, it was jointly organized with UGM. The topic and presentations were similar to the local policy workshop detailed above.

The policy workshop in Bogor was attended by participants from the following national and international agencies:

- ISRI, the agency that developed the PUTS (the head Dr. Ladiyani Retno Widowati and several colleagues participated)
- BPPSDMP, an Indonesian agency under the Ministry of Agriculture which is responsible for agricultural extension and human resource development
- BBPP Lembang, a large agricultural training centre in West Java which is under the jurisdiction of the Ministry of Agriculture

- Center of Food Crop Research which is part of the National Research and Innovation Agency (BRIN) in Indonesia
- GIZ, Indonesia office
- Food and Agriculture Organization (FAO), Indonesia office
- Center for International Forestry Research (CIFOR), an international non-profit scientific research organization

Project results were discussed intensively. The discussion delved, for example, into farmers' willingness to pay versus what the Ministry assumes they can afford, considering high lab test costs and comparably lower PUTS usage costs. In the discussion we highlighted that farmers of course differ in their preferences and also that for most, the PUTS is a new product. Subsidies can help to introduce soil testing to farmers, and once farmers can observe the benefits of soil testing, their willingness to pay for soil tests will tend to increase.

b. Publications

As part of our project, we have produced a series of policy briefs in both English and Indonesian to disseminate our findings among local Indonesian policymakers and international organizations such as the GIZ and FAO. These policy briefs aim to inform policy decisions to support sustainable agricultural practices.

We are currently finalizing papers to be submitted to peer-reviewed international journals. There will be two key papers corresponding to the two main sub-parts of the project. The first paper will focus on the impact of training and soil tests on farmers' adoption of sustainable soil management practices. The second paper will explore farmers' willingness to pay for soil testing services. Additionally, the data collected in this project contributes to several other academic papers currently being written by the project team and the partners from Indonesia. These include a paper on the role of norms around leaf greenness in influencing farmers' fertilizer behavior, a paper on the role of blended learning in sustainable farming training, and farmers' decision-making about using the PUTS following training. The academic papers complement the policy briefs and are made available to policy makers and other stakeholders as in-depth background material.

Furthermore, several student theses were written as part of this project. These include a number of bachelor theses, mostly focused on farmers' experiences with blended learning and the PUTS, conducted by students from UGM. Additionally, a Master's thesis by a student from the University of Passau examined the role of norms and group behavior regarding farmers' decisions about increasing organic fertilizer use and reducing chemical pesticide use. Another Master's thesis by a student from UGM explored farmers' uptake of the education platform Lentera Desa and its relation to farmer characteristics and knowledge.

These publications and academic contributions highlight the extensive research and collaborative efforts undertaken in this project.

7. Partners and capacity building

a. University Gadjah Mada (UGM)

The University Gadjah Mada (UGM) was our main academic partner in Indonesia. UGM is one of the largest and most renowned universities in Indonesia and is located in our study region Yogyakarta. At UGM, we collaborated in particular with Dr. Alia Bihrajihant Raya, who is the Chair of the Agricultural Extension and Communication Study Program at the Faculty of Agriculture. Dr. Alia Bihrajihant Raya is an expert on agricultural extension, and very well connected to the implementing agencies of the local agricultural ministry. This has been a great asset to the project, especially in terms of continuity once the funded project period ends.

Dr. Alia Bihrajihant Raya and her team developed a high level of ownership in this project. They are well equipped and enthusiastic to further assist local extension offices with respect to the introduction of the PUTS, soil health management training and blended extension. Within the scope of our project, the UGM team developed policy relevant lines of research. The team used the data collected in this project and jointly with the Passau team conducted a series of Focus Group Discussions (FGDs) to triangulate these findings with qualitative data. These FGDs were conducted with farmers, extension workers and government officials.

The collaboration with UGM was instrumental for both the success of our project and its sustainability beyond the funding period. UGM supported the project with the implementation on the ground and also benefited from significant capacity building. The project facilitated local knowledge and expertise on the PUTS itself and strategies on how to introduce it to smallholder farmers. This knowledge was created through joint research, interlinking the project with teaching at the Bachelor and Master level and by involving alumni as trainers, some of them on their path to becoming extension workers. Additionally, the project enabled UGM to develop expertise in designing and executing large-scale field experiments for agricultural impact assessment.

Below we summarize the research sub-projects conducted by UGM.

Soil test innovation: Decision-making among smallholder farmers

This study evaluates farmers' readiness to adopt the PUTS by considering farmer characteristics, the training impact, and human capital. It is based on an additional survey conducted by UGM with 170 respondents from our project who received access to the PUTS through the training. Farmers felt that the training material on soil health was appropriate to farmers' needs and they appreciated the PUTS technology presented. The study finds that training and extension are important to disseminate the PUTS. Extension should be carried out in stages with assistance from agricultural extension workers.

The challenges of blended learning-based extension

Blended learning combines the advantages of face-to-face meetings with the benefits of web-based learning. This study finds that farmers face difficulties in using internet-based media and digital devices. Up to now, farmers rarely utilize online media as information source, despite the abundance of agricultural information available online. Examining the adoption of the Lentera Desa platform revealed that many farmers forgot relatively rapidly how to access the platform. Thus, farmers may require repeated instructions and practice sessions after a first introduction to online resources.

What determines farmers' use of digital extension tools?

This study explores the utilization of online agricultural information by smallholder farmers using the example of the Lentera Desa platform. It addresses three research questions. First, following the face-to-face training, did farmers use the Lentera Desa platform? What was the extent of their use? Second, does the length of the face-to-face training (one or two days) impact farmers' use of the platform? Third, which farmer characteristics influence the use of the platform? The study employs the full dataset from the large-scale project survey and combines it with qualitative data collected in the field. It finds that most farmers spent only a few minutes on the platform, indicating the need for short videos with the most important information presented in the first minute. Education and previous experience using a smartphone to search for agricultural information are positively correlated with the use of the platform. Farmers' age is negatively correlated with the use of the platform.

b. Indonesian Soil Research Institute (ISRI)

The Indonesian Soil Research Institute (ISRI) developed the soil test kit PUTS. The agency is a sub-unit of the Ministry of Agriculture and is headed by Dr. Ladiyani Retno Widowati who was our direct point of contact. Dr. Ladiyani Retno Widowati and her team participated in our workshops, implemented a "training of the trainers" session and provided advice during the design of the training material (which was partly based on ISRI's material). Many of the research questions explored in this project are relevant directly to ISRI, which constantly strives to increase the uptake of soil testing in Indonesia.

8. Sustainability of this project

a. Continuation and perspectives

Capacity building among local partners was a key feature of our project in order to create a strong foundation for sustainable impact beyond the funding period. The continuous engagement with local policymakers facilitated evidence-based discussions. Policymakers aiming to promote sustainable farming have a toolbox of technologies and extension activities to choose from. This project offered them causal evidence on a key technology. While the implementation of the project results is of course not guaranteed, this project met the local demand for information with scientific evidence.

The dissemination of the project results offered local and national ministries causal evidence on the impact of soil health management training, the PUTS and farmers' willingness to contribute to the costs of the PUTS. We are committed to supporting the Ministry of Agriculture at both provincial and national levels in integrating project results into future programs and policies. UGM's well-established communication channels with regional and national authorities will play a key role.

The expansion and further development of the Lentera Desa platform based on our project results is another example of the sustainability of this project beyond its funding period. New courses on sustainable farming, for example on sustainable shallot farming, have already been added to the platform and the platform is further evolving to better address the needs of farmers and extension workers.

b. Environmental impact

In a context where chemical fertilizer overuse is prevalent, soil testing can help to decrease its use, thus making a significant contribution towards improving soil quality and protecting groundwater and biodiversity. Our research results show that soil testing can counteract the overuse of chemical fertilizers. Furthermore, our findings offer policy makers insights into scaling up the dissemination of the PUTS soil test kit. Firstly, farmers' willingness to contribute to the cost of soil tests is crucial in a resource-constrained extension system. Secondly, our evidence supports the effectiveness of both dissemination approaches: providing soil tests as a service or as a training with subsequent testing by the farmers themselves.

While the project primarily aimed to produce reliable, causal evidence for policymakers and enhance local capacities, it also yielded significant direct impacts. We conducted 46 training sessions, teaching hundreds of farmers about balanced chemical fertilizer use and the self-production of organic fertilizers. A total of 368 farmers were invited to the 2-day training, which also included soil testing and the discussion of soil test recommendations. On average, farmers invited to the training sessions decreased seasonal Nitrogen application by 16-20 kg per hectare in their rice plots, reflecting only the first-year reduction. Farmers reported that they adjust urea application gradually, continually assessing plant responses. This suggests potentially even stronger effects in the future. Reducing Nitrogen application from chemical fertilizers decreases greenhouse gas emissions and contributes positively to climate protection. Additionally, about 230 farmers received soil test results through the Willingness-to-pay study.

9. Conclusion

This project is the first of its kind due to its innovative approach and scale. It is the first large-scale pilot study to investigate the potential of simple, low-cost soil tests that can be implemented by farmers themselves in the field, i.e. without sending soil samples to the lab. The latter being time-consuming and costly. Unlike previous studies, our project provides causal evidence of the efficacy of these soil tests and examines the additional impact of integrating them into agricultural extension training. Furthermore, to address the important question of uptake, we assessed farmers' willingness to pay for soil tests. To this end, we pilot-tested two different distribution scenarios: In the first scenario farmers had to decide on the purchase of the service getting their plot tested. In the second scenario, farmer groups had to contribute jointly to entire soil test kits and training to undertake the tests themselves. This approach enabled us to formulate policy-relevant recommendations based on cost-effectiveness considerations regarding subsidies to enhance the uptake of soil tests.

The key findings of the project are that training on sustainable farming practices reduced synthetic nitrogen, increased agricultural lime application, and the use of the Leaf Color Chart. We found that providing farmers with individualized soil tests amplified the training's impact. Farmers are willing to contribute to the cost of soil tests. However, to cover the full costs, subsidies are necessary. For low subsidies, uptake is higher if soil tests are disseminated as individual services. For larger subsidies, uptake can be maximized by equipping farmer groups with soil test kits and training. The latter may make the adoption also more sustainable as it allows farmer groups to integrate soil tests into their daily practice.

Moving forward, the project team, in collaboration with our colleagues from UGM, continues to support policymakers in scaling up the project results to programs and interventions implemented by local ministries and their executive agencies. Our ongoing partnership with UGM includes joint publications, capacity building, and knowledge exchange.

In summary, this project has provided valuable insights and empirical evidence on the potential of low-cost soil tests. It has also established the foundation and the necessary empirical evidence to design programs and interventions to promote sustainable soil management.

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