IWMI RESEARCH REPORT

130

Economic Gains of Improving Soil Fertility and Water Holding Capacity with Clay Application:

The Impact of Soil Remediation Research in Northeast Thailand

Rathinasamy Maria Saleth, Arlene Inocencio, Andrew Noble and Sawaeng Ruaysoongnern

International Water Management Institute

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Cover photograph shows farmers and researchers discussing the impact of clay application to sandy soils on the growth of forage sorghum in Northeast Thailand. Sorghum in the background has received bentonite clay whilst that in the foreground has not (*Photo credit:* Andrew Noble).

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Project

The initial project that introduced the clay-based technology to Northeast Thailand was associated with the project initiated by IWMI on Sandy Soils Remediation in Northeast Thailand.

Partners

Partners that contributed to the project included Khon Kaen University, Thailand, the Land Development Department of the Royal Thai Government and local farmer wisdom networks.

Khon Kaen University, Thailand

Donors

This project was funded from the core funds of IWMI during 2002-2006, which consisted of contributions from the following countries and organizations:

Australia
Belgium
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Summary

Using data from a survey of 250 farmers and applying different impact assessment methods, this paper provides an ex-post impact assessment of the Soil Remediation Research Project undertaken by IWMI in Northeast Thailand during 2002-2005. This project demonstrated and promoted the application of clay technology as a quick and cost-effective means of improving the fertility and water holding capacity of sandy soils.

With the empirically estimated average impacts of this technology, and the clay using area observed in the sample (176 hectares [ha]) and that estimated for the region (5,600 ha), the overall impact and economic viability of this project are evaluated during 2002-2008 for both the sample and also at regional level. Recognizing the roles of partners and others, the share of benefits attributed to IWMI are only 50 and 10% for the sample and regional level evaluations, respectively.

From an exclusive IWMI perspective, the project has a net present value (NPV) of US$0.41 million involving an internal rate of return (IRR) of 36% and a benefit-cost ratio (BCR) of 2.44 in the context of the sample. But, in the larger context of the region, it has a NPV of US$21 million involving an IRR of 267% and a BCR of 75.

Since impacts cover only direct income benefits, and since their evaluation involves conservative assumptions on benefit calculation and attribution, these estimates represent only the lower bounds of the true size of the project's impact. Despite an apparent soil focus, the evaluated impacts also equally capture the effect on yields of an improved soil water holding capacity.

Economic Gains of Improving Soil Fertility and Water Holding Capacity with Clay Application: The Impact of Soil Remediation Research in Northeast Thailand

Rathinasamy Maria Saleth, Arlene Inocencio, Andrew Noble and Sawaeng Ruaysoongnern

Introduction

The organic and multifarious relationships between soil and water, especially in the context of agriculture, are well known both from a scientific and popular perspective. One of these relationships involves the ability of the soil to hold water and use the stored moisture to retain and supply the nutrients for plant growth. This ability, which is crucial for water use efficiency and land productivity, is not uniform across soils. The sandy soils that are observed in many parts of the world have a very low capacity to store and exchange water and nutrients and, hence, have a very low inherent productivity. Since most areas with such soils remain the main source of food and livelihood for millions of poor farmers, this soil-related problem has many socioeconomic implications, including the inability of farmers to apply and benefit from modern farm inputs. The issue gets even more complicated in areas relying exclusively on rainfed cultivation, where soil moisture and water holding capacity remain the dividing line between food security and poverty. This is precisely the situation in Northeast Thailand, where sandy soils—with a low capacity to hold water and nutrient but a high susceptibility to erosion and salinity—remain a main constraint for water use and crop yield.

The problems caused by poor soils are usually addressed with a number of agronomic and farm management interventions that include zero tillage, mulching, and the application of manure and compost. While these options do improve the long-term soil health and yield, they may not normally have an immediate effect on farm income. As a result, they are not that appealing to poor rural groups with smaller farms, where quick and tangible results are required for the adoption of any new management strategy. One option that is traditionally used in Northeast Thailand is the application of soils from termite mounds. Although this has immediate effects on yield, the cost and supply issues associated with this practice make it infeasible as a long-term strategy for poor farmers. Taking these conditions as an entry point, IWMI, along with its national and international partners, has attempted to develop, demonstrate and promote an alternative option under its Soil Remediation Research Project (SRRP) implemented in Northeast Thailand during 2002-2005. This option involves the application of locally available, and relatively cheaper, bentonites, or in a simple and popular term, clay materials[1], as a quick and low-cost means for improving the fertility and water holding capacity of sandy soils.[2]

[1] In this paper, the terms ‘bentonite’ and ‘clay’ are used interchangeably.

[2] This is based on the fact that much lower quantities of clay (up to 50 tonnes/ha [t/ha]) are required to achieve a similar effect that is obtained through the application of up to 7,200 t/ha of termite mound material.

This paper attempts to provide an *ex-post* assessment of the field level impact and economic viability of the SRRP using the empirically derived estimates of the average income impacts that the application of bentonite or clay technology has generated among farm communities in Northeast Thailand. These impact estimates for the sample area are based on household survey data collected from a sample of 250 farmers, representing three farming systems, i.e., vegetable farms, organic rice farms and integrated farms.[3] The estimates for the region (Northeast Thailand) are based on a mix of secondary data, opinion of experts, and information from farmers. The impacts are evaluated only in terms of the net income associated with the application of clay technology and the evaluation does not cover other direct and second-round benefits related to food security, resource conservation, farm diversification and livestock development. Finally, given the specific nature of the soil problem and the predominance of rainfed farming in the region, the impact, as assessed here, also captures the effects on yield and crop pattern of the improved soil water holding and nutrient capacity as achieved through clay application.

The paper is organized as follows. The section, *Soil Remediation Research: Background and Context*, sets the background and context by providing relevant details on the project and the region used as a basis for the research, including some evidence of the initial impact from field trials. The section, *Impact Pathway: Analytics and Actors*, provides an analytical presentation of the impact pathways of the project to clarify the relative roles of key stakeholders and factors that affect the development, promotion and application of clay technology. The section, *Methodological Framework*, specifies four different impact assessment methods, including their basic logic and statistical basis. The section, *Empirical Approach and Data*, describes the empirical context and data, including the definition of variables and clarification of assumptions. The section, *Costs and Benefits of Clay Application*, provides a descriptive analysis of the distinct pattern of input use, costs and returns observed between clay users and others in the context of different samples and farming systems. The section, *Estimation of the Impact of Clay Technology*, presents the estimates of the average and total impacts on clay users as obtained under different methods and in the context of different farming systems, and also explains why most of these impacts can be directly attributed to clay technology. In the section, *Research Impact and Attribution*, the overall impact and economic viability of the SRRP is evaluated both for the project as a whole and also from the perspective of IWMI, in particular. The final section, *Concluding Remarks*, concludes with a recap of the paper with a summation of the results obtained and some remarks on the research and policy implications.

Soil Remediation Research: Background and Context

At the outset, a brief review of the background and context of the SRRP is useful to set the stage for the impact assessment exercise. As noted already, the project was undertaken in Northeast Thailand, where over 80% of the population is involved in farming. This region has a total area of 18.9 million hectares (Mha) and an agricultural area of 8.2 Mha, representing one-third and two-fifths, respectively, of the corresponding national figures NSO (2003); LDD (2004). Northeast Thailand accounts for 69%

[3] The 'integrated farming system' is a new approach that was introduced in Thailand by state policies. It is based on a variety of crops (as well as poultry and animals) intended to meet all home food needs, recycle farm by-products, reduce chemical use and improve biodiversity.

of the total national area under rice cultivation, 30% under field crops and 20% under vegetables and horticultural crops (NSO 2003). Despite its dominant share of the cultivated area, the region has low productivity levels in most crops. For instance, the data on regional trends in rice yields per hectare for the period 1980-2006 show that the Northeast remains consistently low. Due to low farm productivity and inadequate non-farm options, income per capita for the region is less than 40% of the national average and the incidence of poverty is as high as 37% (Matsuo 2002).

The low agricultural productivity can be largely attributed to the sandy nature of soils[4] that dominate the landscape of Northeast Thailand. It is estimated that 80% of the agricultural area in this region is based on the light-textured sandy soils with very low organic matter and clay content (Ragland and Boonpuckdee 1987; Yuvaniyama 2001; LDD 2004). From an agronomic and production perspective, these soils have low fertility,[5] poor water holding capacity, and limited cation exchange capacity (CEC), i.e., the ability to buffer and release nutrients.[6] Despite being confined to a six-month rainy season, the annual rainfall (800 to 1,400 millimeters [mm]) could be enough to support an efficient farming system, provided that the soils can hold water and maintain moisture over the cropping seasons. Unfortunately, the sandy soils fail to play this vital function, exacerbating seasonal drought and periodic crop water stress (Panichapong 1988; Suzuki et al. 2007). This soil problem also acts against the use of modern farm inputs.

The traditional approach adopted by farmers to improve the soils involves the application of cattle manure, composts derived from farm and household wastes and leaf litter, and soils from termite mounds. Although these amendments are useful and indeed demonstrate the role of traditional knowledge in developing and implementing soil remediation strategies, they do face serious supply and sustainability issues. For instance, these amendments are neither sufficient to provide adequate levels of nutrients nor do they have a lasting effect on soil fertility due to the rapid mineralization process under the prevailing climatic conditions. Since routine additions of these amendments are necessary, there will also be supply issues.[7] The approach based on conservation tillage and mulching of crop residues, though useful to enhancing the accumulation of organic matter in soils, will be less appealing to small farmers partly because the required level of yield benefits may not accrue for several years, and because the associated changes required in current production systems are not easy. An alternative approach involves the application of clay materials of various forms. Although farmers have traditionally recognized the value of clay materials in restoring the fertility and water holding capacity of sandy soils, this approach has not been widely used. The use of clay materials such as the bentonites[8] and termite mound material represents a definite improvement over the current practices, because these materials, when added, can raise the capacity of the soils to hold water and nutrients

[4] From a geological perspective, the sandy soils found in Northeast Thailand are the results of deposited wind blown sands from China (Yoothong et al. 1997).

[5] A key property that determines soil fertility is the amount of negative charge that is resident on the surfaces of the microscopic particles in the soils. This negative charge is able to attract positively charged cations that are so vital for plant growth, such as calcium, magnesium, potassium and nitrate, retain them against leaching forces, and make them available for uptake by plant roots. This negative charge is measured in terms of centimoles per kilogram (cmol/kg) of soil. Since this negative charge is directly related to the level of organic matter (humus) and clay content of soils, soil fertility is usually associated with these soil components (see Noble et al. 2000, 2001). The same soil components are also responsible for determining soil water holding capacity.

[6] The sandy soils with a clay content of just 2.50-6.60% only have a CEC in the range of 0.31–1.40 cmol/kg compared to Vertisols which have a CEC above 12 cmol/kg. This shows the limitations in the ability of sandy soils to retain and supply nutrients in an exchangeable form (see Noble and Suzuki 2005).

[7] For instance, in the case of soils from termite mounds, which are commercially excavated from a large number of termite mounds, farmers used to apply up to 7,200 t/ha to small plots where intensive vegetable production is undertaken (Noble et al. 2004).

[8] Bentonites are naturally occurring 2:1 layer silicate clays that have a high permanent negative charge due to isomorphous substitution that occurred during their formation. As a result, these materials have a high CEC, which is often dominated by essential cations such as calcium and magnesium. For more details, see Noble et al. (2001).

and reduce potential water and nutrient losses through leaching (Noble et al. 2001). Also, from a supply perspective, these materials are relatively abundant within the northeast region and within Thailand.[9]

Taking these conditions as the entry point, the SRRP was undertaken by IWMI during the period 2002-2005 in collaboration with the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Land Development Department (LDD) of the Royal Thai Government, and the Khon Kaen University (KKU) based in Northeast Thailand. There are other formal and informal collaborators, who have also facilitated the research planning and implementation in different ways. They include the farmer networks in the project region, industries and private groups involved in the supply and distribution of clay. The research was supported by the Australian Centre for International Agricultural Research (ACIAR), IWMI's core funds, and also some limited funds from KKU and LDD. The main objective of the project was to rejuvenate sandy soils with the application of locally-sourced clay materials either alone or with traditional soil amendments such as manure, compost and leaf litter. The focus of the research was on the effects of clay application on the short-term and long-term fertility and water holding capacity of sandy soils.

Initial studies, which were conducted during 2002-2003, were focused on the application of the clay technology in the experimental plots selected from the region. The results from these studies have established that the application of locally-sourced bentonite had dramatic effects on the yield of forage sorghum grown under rainfed conditions. Measuring yield in terms of cumulative dry matter production over a two-year period, the yield ranged from 0.22 t/ha under control treatment to 23 t/ha under the treatment involving an application of 50 t/ha of bentonite, and 36 t/ha under the treatment involving a combination of 50 t/ha of bentonite and 10 t/ha of leaf litter. The two photographs in Figure 1(a) and 1(b) show these differential impacts, where it can also be noted that the crop failed completely in the control plot (Figure 1(b)) during the second year, when there was a drought. The results clearly supported the fact that the application of clay technology has increased not only the fertility but also the water holding capacity of soils and, thereby, reduced the potential risk of crop failure due to water stress in the early stages of growth (Suzuki et al. 2007).

During 2003-2005, IWMI in collaboration with the Khon Kaen University has promoted the use of naturally occurring and locally-sourced bentonite clays within farmer networks in the region. As these networks have been moving towards organic farming systems in view of the increasing domestic and international demand for organic rice and vegetables, the clay technology was a natural fit to such farming systems. Trials were carried out on rice crops in farmers' plots and farmer field schools with the active involvement of the members of participating farmer networks. In these trials, farmers themselves have evaluated how the application of clay technology has increased productivity. The two photographs in Figure 1(c) and 1(d) contrast the differential performance of rice plots with and without clay application. Table 1 presents the results based on the data collected from the trials of clay application in the rice fields of participating farmers and members of farmer networks.

[9] Usually, the termite soils are locally sourced from mounds ubiquitously found in the northeast region. But, with the over-exploitation and exhaustion of their proximate sources, new supplies are to be sourced further and further away from the field, causing both supply constraints and also higher supply and transport costs. Clay materials, in contrast, are relatively abundant and cheaper with closer supply sources in the region. Their supply networks are also well-developed with many private suppliers.

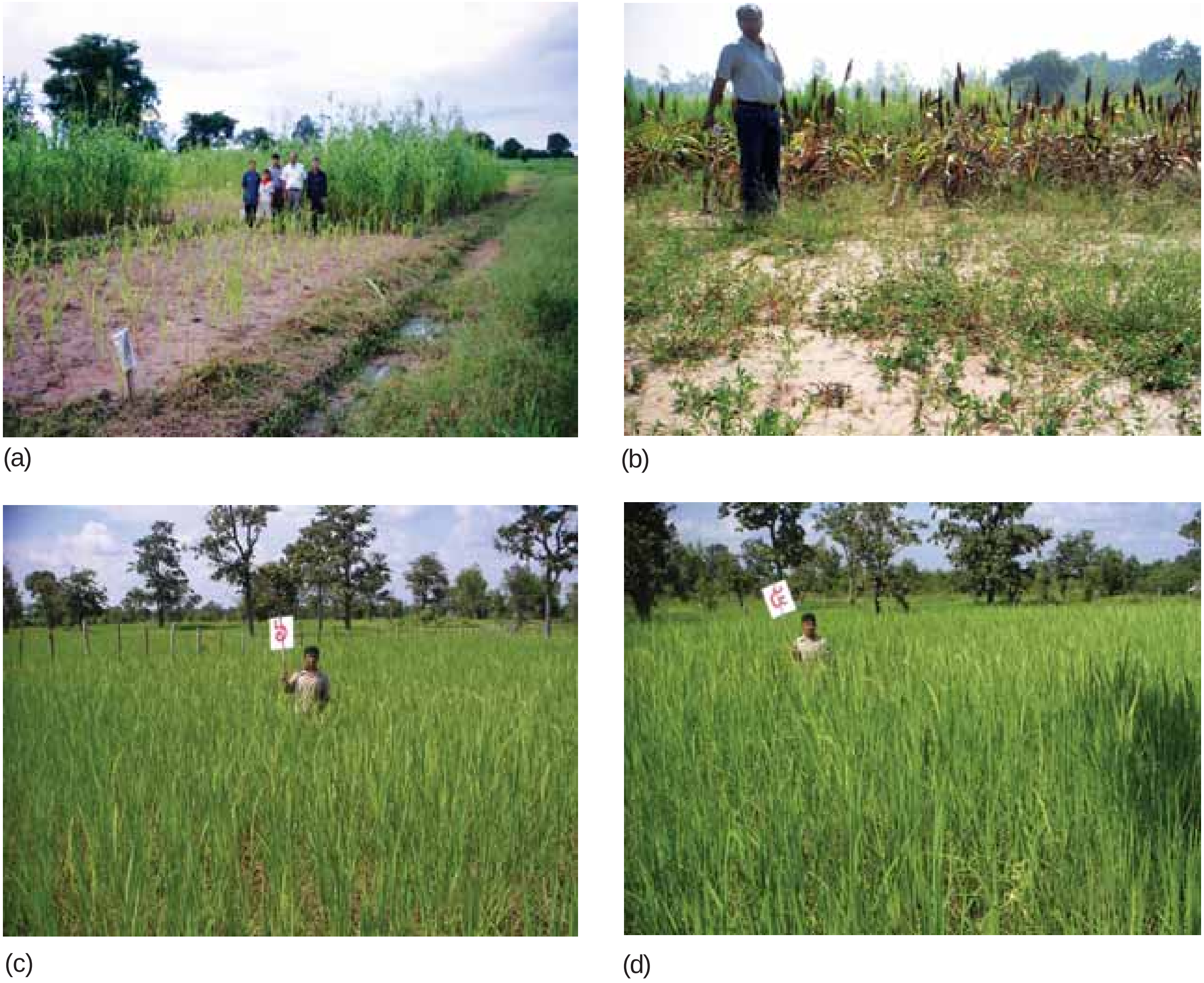

FIGURE 1. Impact of clay application on the growth of forage sorghum and rice crops, Northeast Thailand, 2002-2005. (a) The growth of forage sorghum receiving bentonite (background) to that receiving normal farmer inputs (foreground); (b) the effect of applying bentonite to light sandy soils is clearly evident during a dry year: a plot not receiving bentonite, where the crop has failed (foreground); a plot receiving bentonite (background); (c) a farmer's rice field without applying bentonite; and (d) the same farmer in an adjacent field where he has applied bentonite.

Since rice farmers traditionally apply compost to their fields, the treatments considered in Table 1 were: compost without clay application and compost with clay application. As can be seen from the additional yield gains, clay application did enhance yield considerably across farms. But, there were significant variations in the yield response to clay quantity. Since all trial farms are rainfed and, hence, rely on the moisture retained by soils from the rainfall, the variations in yield response can, in part, be attributed to other farm-specific variations, including initial soil variability and other inputs. Although such variations suggest the need for controlling other factors while evaluating the effects of clay application, the impressive role of clay application in raising yield levels is rather clear from the results presented in Table 1.

TABLE 1. Results from the farm and field school trials of clay application and rice yields in Northeast Thailand, 2003-2005.

No.	Participating farmer's name	Clay application rate	Rice yield without clay application	Rice yield with clay application	Increase in yield
		(t/ha)	(t/ha)	(t/ha)	(%)
1	Mr. Sen Sookprasert	1.252	1.002	2.003	100
2	Mr. Chai Kaewnonghee	1.252	1.502	3.005	100
3	Mr. Yod Ketsipong	0.626	2.003	2.598	30
4	Mr. Noojee Yodnamkam	1.252	2.504	4.006	60
5	Mr. Suthinan Network	5.008	3.456	4.758	38
6	Don Hee Farmer Field School	1.565	2.116	2.711	28
7	Ban Yae Farmer Field School	1.252	1.202	2.229	85
8	Non Haad Farmer Field School	3.130	0.682	1.102	61
9	Kudstian Farmer Field School - Plot 1	1.252	3.005	5.609	87
10	Kudstian Farmer Field School - Plot 2	1.252	1.540	1.665	8
11	Laohansai Farmer Field School - Plot 1	10.016	0.977	2.003	105
12	Laohansai Farmer Field School - Plot 2	10.016	1.515	1.847	22
13	Srikaew Farmer Field School	2.504	0.801	1.509	88
14	Kudchiangmee Farmer Field School	1.252	1.189	2.003	68
15	Nonpakha Farmer Field School	1.565	1.033	1.671	62

Source: Noble and Suzuki (2005)

While clay technology was originally demonstrated on organic rice farms, it is now used in non-organic rice farms and even more so in vegetable farms, especially those in peri-urban areas. Figure 2 shows the growth performance of a leafy vegetable crop in experimental plots (Figure 2(a) and 2(b)) and the same in an irrigated peri-urban farm with a sprinkler system (Figure 2(c) and 2(d)). Irrespective of the farming system, clay use has generated immediate yield benefits even while leading to the long-term health of land resources. Since it is also scale neutral and 'pay-as-you-go' technology, farmers can apply it on a smaller area initially but with the income from productivity gains, it can be expanded to cover their entire farms over time. For the soil features and erosion conditions found in Northeast Thailand, the fertility effects of clay application is estimated to last up to 10 years, if not more. With improved land productivity, there are also a number of secondary effects, including an improved prospect for farm management and income enhancing options such as crop rotation, livestock development, and farm diversification. As such, clay technology can enhance both farm income and also the use efficiency and productivity of land and water resources.


(a) (b) (c) (d)

FIGURE 2. Impact of clay application on the growth of irrigated vegetable crops, Northeast Thailand, 2003-2005. (a) A second crop of vegetables grown using traditional methods; (b) an adjacent second crop of vegetables grown using the traditional method as well as applying bentonite; (c) an irrigated vegetable farmer's plot receiving clay-based materials; and (d) the pumping station used in the sprinkler irrigation of vegetables.

Impact Pathway: Analytics and Actors

The roles of actors and factors involved in the development, promotion, application and impact of clay technology can be captured as shown in Figure 3. Although Figure 3 is self-explanatory, there are a few key points that need to be stated more explicitly, especially for adding context and clarification on the relative role of actors and factors involved in the process of technology development and its final impact.

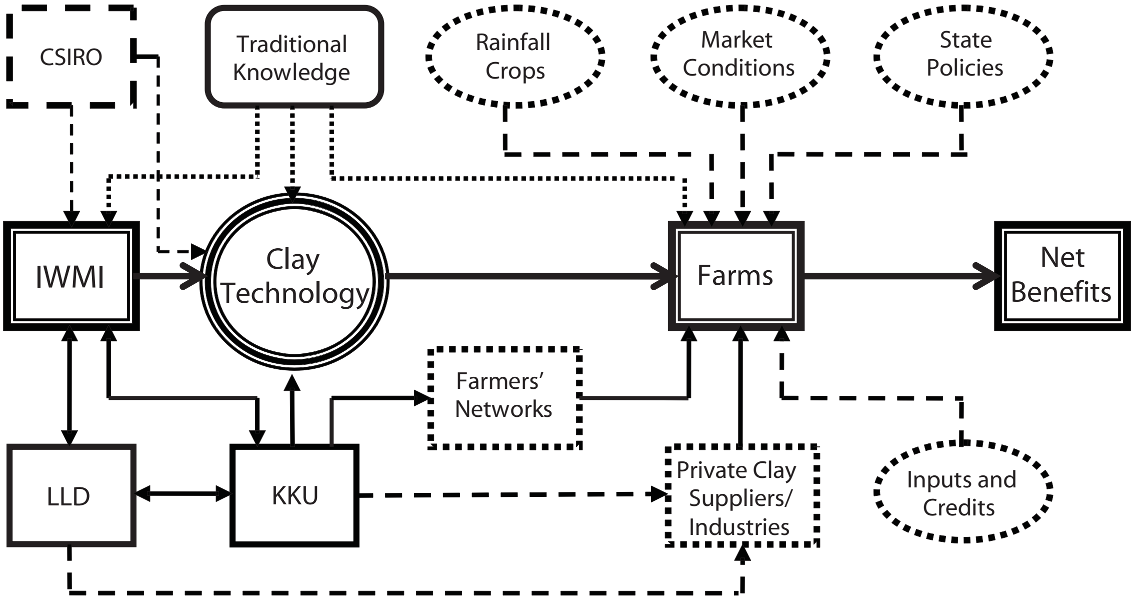

FIGURE 3. Impact pathway of clay technology: Roles of partners, players and factors.

First, Figure 3 sets the analytical framework for understanding the impact pathway—starting from the research activity to its outcome and, finally, to its impact—as well as the intervening roles of different actors and factors on this pathway.

Second, the pathway highlights the organizations that contributed to the research on soil remediation. The development and application of the technology in Northeast Thailand can be largely attributed to IWMI and its national partners, i.e., KKU and LDD, including the farmer networks and private industries, especially given their role in facilitating the development and promoting the application of the technology. However, the role of CSIRO in the initial stages of soil remediation research and that of traditional knowledge, are equally important and, therefore, cannot be underestimated.

Third, the focus of the evaluation is largely confined to yield gains and does not capture either the secondary economic effects or the direct environmental benefits.

Finally, while farmer networks and private clay suppliers play key roles, neither these roles nor those of the exogenous factors (rainfall, crops, market, input supply, and national farm and trade policies) are explicitly evaluated.

The points noted above are important in setting the analytical scope of impact assessment and also in sorting out the issue of impact attribution among the key partners and players. Being a joint effort between IWMI and its collaborators, the impact of the project cannot be entirely attributed to one or the other. This issue gets more complicated when we consider the roles of exogenous factors that affect the nature and magnitude of the impact. Clearly, we need to make some assumptions both in delineating the effects of these factors and also for apportioning the benefits among the organizations. Since the effects of the exogenous factors are the same for both clay users and non-users, it is possible to assume these factors to have a neutral effect. This assumption is tenable among farmers with similar crops, input use, and other socioeconomic features, but not so among farmers with heterogeneous conditions, where the technology will have different effects on inputs and outputs. As discussed in the next section, such differential effects of clay technology can be handled with impact assessment methods that can control for variations in farm feature and input usage. On the issue of benefit attribution among partners, there is a need for making some arbitrary assumptions though there are some objective criteria that also have to be taken into consideration.[10]

Methodological Framework

The statistical and econometric methodologies for assessing the impacts of technologies and policy interventions, both in experimental and non-experimental contexts, are well established (e.g., Rubin 1974; Rosenbaum and Rubin 1983; Cobb-Clark and Crossley 2003; Abadie et al. 2004). The practical challenges and potential extensions for these methods in dealing with the socioeconomic impacts are also well known from available literature (e.g., Baker 2000; Ravallion 2001; Bourguignon and Pereira da Silva 2003, Coryn and Scriven 2008). For the impact assessment of clay technology, we use the 'Potential Outcome Framework' proposed by Rubin (1974) and rely on the common empirical approaches suggested by Cobb-Clark and Crossley (2003) and Abadie et al. (2004). For specifying the methodology, let us define the following notations:

N is the number of farms with i = 1, 2, ... N,

T_i ε {0, 1} is a binary treatment with 1 for treated and 0 for untreated,

Yi(1) is the outcome for farm i with treatment,

Yi(0) is the outcome for farm i without treatment,

X_i is a (k×1) vector of covariates affecting outcome along with the treatment, and

E is the operand for expectation.

The treatment, in our case, is the clay application, the outcome is the net farm income, and the covariates are the variables capturing the socioeconomic characteristics and input usage (other than clay) of the sample farms. Given the vector of these variables, the net income of farm i will vary depending on the application of clay. That is,

$$Yi = Yi(Ti|Xi) = \begin{cases} Yi(1|Xi) \text{ if } Ti = 1 \\ Yi(0|Xi) \text{ if } Ti = 0 \end{cases} \quad (1)$$

With the *outcomes* Yi(1|Xi) and Yi(0|Xi), the *impact*, i.e., the additional net income, as a result of clay application can be calculated as:

$$\Delta Yi = [Yi(1|Xi) - Yi(0|Xi)] \quad (2)$$

While equation (2) shows the additional benefit of clay application for an individual farm, the average additional benefits for all sample farms, regardless of the adoption of treatment, will be:

$$\sum_{i}^{N} [\Delta Yi](1/N) = \sum_{i}^{N} [Yi(1|Xi) - Yi(0|Xi)](1/N) \quad (3)$$

In terms of the impact assessment terminology, the average additional benefit given by equation (3) is known as the average treatment effect (ATE). Since we are interested in evaluating the impacts on farms that have applied the clay

[10] Davis et al. (2008: 70-71) suggest that the relative shares either in implementation responsibility or in total costs can be used to attribute the share of benefits among partners. Favoring the cost share criterion, they also discuss its application in different scenarios defined by how indispensable the project is for the intended impact. However, in practice, one cannot ignore the inevitability of subjective factors, both when real costs and non-monetary costs are involved, and separability of responsibility and defining the impact by actors is difficult. As a result, arbitrary, but less controversial and conservative, approaches are often being used to attribute the relative share of benefits among partners.

technology, what is more pertinent for our purpose is actually the average additional benefit for all farms with the treatment, i.e., the average treatment effect on the treated (ATT).[11] The ATT for the sample and the population can be obtained from equations (4) and (5), respectively (see Cobb-Clark and Crossley 2003; Abadie et al. 2004):

$$\sum_{i}^{N} [\Delta Yi(1/Ti),\ Ti=1] = \sum_{i}^{N} \{Yi[(1|Xi),\ Ti=1] - Yi[(0|Xi),\ Ti=1]\}(1/Ti) \tag{4}$$

$$E\ [(\Delta Yi),\ Ti=1] = E\{Yi[(1|Xi),\ Ti=1] - Yi[(0|Xi),\ Ti=1]\} \tag{5}$$

In equations (4) and (5), the additional benefit or the impact is calculated by comparing the outcome with treatment against the outcome without treatment. In this case, the outcome without treatment provides the counterfactual needed to establish the impact of treatment. While it is theoretically straightforward, there is a major practical problem, especially in non-experimental contexts. That is, although we observe Xi, Ti, and Yi for all i, we never observe Yi(0) and Yi(1) for the same individual. This problem of missing data or, more appropriately, the lack of counterfactual is, therefore, the major challenge in estimating the ATT in equations (4) and (5).[12]

The missing data and the lack of counterfactual is obviously a serious problem, but it is not altogether insurmountable. There are different approaches for overcoming this problem under different assumptions and econometric procedures (Rosenbaum and Rubin 1983; Cobb-Clark and Crossley 2003; Abadie et al. 2004). For instance, if the impact of clay is assumed to be homogenous, i.e., farms, regardless of their differential characteristics and input usage, are assumed to respond similarly to treatment. Under this assumption, we will have: Yi[(0|Xi), Ti=1] = Yi[(0|Xi), Ti=0]. In this case, it is possible to approximate the missing data and, hence, establish the counterfactual, in terms of the data for farms without clay application. This is the basis for estimating the impact of treatment using the 'with-without' approach, where the average outcome of clay users are compared with that of non-clay users to establish the ATT.[13] That is:

$$\Delta Yi = \sum_{i}^{N} \{[(Yi)(Ti)][(1/Ti)]\} - \sum_{i}^{N} \{[Yi(1-Ti)][1/(1-Ti)]\} = Y1 - Y0 \tag{6}$$

The assumption of homogeneity is obviously not sustainable in practice and this is especially so in the context of clay application, where the impact will vary considerably across farms with differential use of other inputs. As a result, there will be a bias in the estimation of ATT and such bias directly varies with the extent of heterogeneity. Fortunately, there are well-established statistical and econometric procedures that could allow the estimation of ATT with minimization and correction for heterogeneity bias in impact. Two of these approaches, which will be used in this paper, rely on the regression and matching methods. Both of these approaches have the same basic logic for bias correction, i.e., the use of the covariates Xi, but they differ in the way these covariates are used. The regression approach can be explained with the linear model of the form:

$$Yi = \alpha + \beta\ (Ti) + \varepsilon i \tag{7}$$

Note that equation (7) is just a simple rearrangement of equation (2), after substituting Yi for Yi(1), α for Yi(0), and β for ΔYi.

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[11] As we replace 0 with 1 for Ti in equation (4), we can also obtain the average treatment effect on control (ATC). In fact, the ATE, which is the treatment effect regardless of the adoption of treatment, can be calculated as the average of ATT and ATC, after some adjustments to the number of treated and control cases.

[12] This will not be a problem in experimental contexts, where pre- and post-treatment data can be obtained under controlled conditions. This is also the case, to some extent, in non-experimental contexts with base data and where the intervening effects of exogenous factors can be accounted for.

[13] Note that under the assumption of homogeneity, ATT=ATE (see Cobb-Clark and Crossley 2003).

This equation can be estimated using the Ordinary Least Squares (OLS) regression of Yi on Ti. The estimated coefficient will also be unbiased when $E(\varepsilon i)=0$, which implies the homogeneity assumption. Since it is difficult to sustain this assumption, there will be a bias similar to that under the 'with-without' approach as formalized in equation (6). However, this bias can be econometrically corrected by capturing the variation in the untreated outcomes across individuals in terms of their covariates (Cobb-Clark and Crossley 2003). This can be done by just adding Xi into equation (7).[14] That is:

$$Yi = \alpha + \beta\ (Ti) + \delta\ (Xi) + \varepsilon i \qquad (8)$$

Equation [8] allows for heterogeneity in impact and could be estimated by a simple linear regression. Such estimation will give an unbiased estimate of β , which is actually the ATT that we need for assessing the total impact on the treated.[15]

The matching approach also relies on the covariates to generate the counterfactual necessary for an unbiased estimate of ATT.[16] But, unlike the regression approach, the matching approach makes the estimation process explicit and also allows the researcher to control the weighting of estimated treatment effects across different individuals. The basic logic of this approach is based on the simple idea that the best estimate for the unobserved counterfactual untreated outcome for an individual in the treatment group is related to the outcome of one or more individuals in the control group with similar characteristics in terms of the observed covariates Xi. Specifically, the matching procedure uses the values of Xi to select one or more observations (Yi(0), Ti=0) with similar characteristics (Xi) from the control group to generate an estimate of the expected counterfactual (E [Yi(0)], Ti=1). The observed outcome values are, then, compared with the estimated counterfactual to estimate the impacts ($\Delta Yi=Yi(1) - E[Yi(0)]$). By aggregating these impacts for the treated groups, we can estimate the ATT as follows:

$$\sum_{i}^{N} \{[Yi(1) - E\ (Y(0))](Ti)\}\{1/Ti\} =$$

$$\sum_{i}^{N} [\Delta Yi](1/Ti) \qquad (9)$$

Equation (9) provides the basic logic for estimating the impact under the matching approach. Although there are different procedures, which are being used to perform matching,[17] all of them allow for heterogeneity and also have provisions for adjusting the number of matches, weighting matrix, and bias correction (see Cobb-Clark and Crossley 2003; Abadie et al. 2004). As a result, the matching approach is more realistic and also robust for application under the normally obtained conditions of heterogeneity or differential treatment response both among and between the treated and control groups.

In this paper, for evaluating the average impact of clay on the treated, we will be using all four approaches described above, i.e., (a) the statistical approach or the 'with-without' approach in equation (6); (b) the regression approach with homogeneity restriction as captured in equation (7); (c) the regression approach that allows for heterogeneity as stated in equation (8); and (d) the matching

[14] It is assumed here that the vector Xi captures most, if not all, sources of heterogeneity that are relevant for the present evaluation context. This assumption implies that all relevant sources of heterogeneity are observable through Xi.

[15] The main point to note here is that the homogenous treatment effect (â) is identified with a conditional mean independence assumption. This implies that the potential untreated outcomes do not vary systematically between treated and untreated groups once we control for differences in Xi. As a result, the distribution of untreated outcomes is independent of Ti but conditional on Xi. For details, see Cobb-Clark and Crossley (2003).

[16] The matching approach, like the regression approach, also relies on the conditional independence assumption. For this assumption to hold in the context of the matching approach, a common support condition is also needed (Rosenbaum and Rubin 1983). This condition requires $0 < P(Xi) < 1$, where P(Xi) is the probability of treatment given the observable characteristics Xi. When P(Xi) is equal to 1 or 0, we will not have any observations on [Yi(0), Ti=1] or [Yi(1), Ti=0] for some values of Xi. By avoiding these possibilities, the common support condition ensures the existence of one or more matches for each observation from the opposite group.

[17] The matching methods differ mainly in terms of the way the matching is performed. For instance, the neighborhood matching pairs matches the outcome value of each observation with that of one or more observations in the opposite treatment group using the values of Xi (see Abadie et al. 2004). But, in propensity score matching, the matching is performed using the propensity score: P(x) = Probability (Ti=1, Xi=x), which can be estimated with a logit regression (see Rosenbaum and Rubin 1983).

approach in equation (9).[18] For the matching approach, we will rely on the nearest neighborhood procedure, though other procedures can also be equally applicable. As noted in the previous section, the regression approach that allows for heterogeneous effects, has an important role in accounting for farm-specific variations in input use and other socioeconomic characteristics and, thereby, neutralizing their roles from the impact. The matching approach also performs the same role, though implicitly in the sense that the estimates of the untreated outcomes of the treated cases are based on the average outcomes of the untreated cases with similar or closer values for input use and farm characteristics. But, under the regression approach, we can explicitly get an estimate of the average or expected individual effects of these farm-specific covariates.

Empirical Approach and Data

For collecting the necessary data for the empirical assessment of the impact of clay technology, a sample survey was conducted in Northeast Thailand during October 2007-March 2008. The sample covered 250 farms representing typical clay users and non-users in the three main farming systems in the region, i.e., vegetable farms, organic rice farms, and integrated farms, where clay technology fitted well both economically and ecologically. The sample was selected mostly on a random basis, except in the case of clay users in organic rice farms, where purposive selection was used to tap the support of the active farmer's networks for the survey. Table 2 shows the composition and area coverage of the sample. As can be seen, the sample covered 119 vegetable farms (59 with clay use and 60 without), 64 organic rice farms (30 with clay use and 34 without), and 67 integrated farms (36 with clay use and 31 without). Although the total farm area owned/operated by all farmers in the sample was 563 ha, the survey covered only 319 ha.[19] The distribution of these areas by clay use and farming system are shown in Table 2. Although the total number of farms with clay use and that without clay use are the same at 125, the total farm area of the treated and control groups are, however, different, i.e., 176 ha for clay users but 144 ha for non-clay users.

Having selected the sample, a questionnaire specifically designed for the present purpose and context was used to collect all the relevant farm-level socioeconomic, agronomic, input, and yield data. This survey instrument is provided in Annex A. Although the survey covered different crops (especially in the case of vegetable farms), it covered only a single cropping season. All the data were collected in the local area unit of *rai* and local currency unit of Baht, but the data were converted into hectares (6.26 *rai* per hectare) and United States dollars (33.6 Bahts per US$), respectively. Since many farms are small and also vary in size, all the inputs, costs, and outputs were standardized to one hectare to ensure comparability. Similarly, given the variations in crops, both within and across farms, the average price and value of output are used rather than the price or yield levels of individual crops. From the detailed data collected from all sample farms, the following key variables are used in the analysis of results in the ensuing sections:

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[18] Since the four methods involve different assumptions and estimation procedures, the ATT estimates obtained under these methods can be compared to evaluate their robustness and consistency.

[19] The reasons as to why the area covered in the survey is lower than the total owned/operated area are: (a) part of the area under the sample farms is under current or permanent fallow; and (b) not all the area under cultivation is being treated with the clay technology.

RESPGEN	=	Respondent's gender (0 = male; 1 = female);
RESPEDU	=	Respondent's education (in years);
RESPVIS	=	Number of times the respondent visits nearby cities per year;
FAMSIZE	=	Family size;
FAMASET	=	Total value of all farm assets other than land (in '000 US$);
LANDTOT	=	Total land area cultivated (both owned and rented) (in hectares);
LANDSUR	=	Total land area surveyed for data collection (in hectares);
SOILQLT	=	Soil quality (1 = poor; 2 = average; 3 = good; 4 = excellent);
WATSOUR	=	Source of irrigation water (1 = completely rainfed; 2 = common ponds; 3 = private ponds/wells);
CLAYUSE	=	Clay application (0 = no; 1 = yes);
CLAYQTY	=	Quantity of clay applied (in t/ha);
CLAYCST	=	Cost of clay, including transport costs (in US$/t);
MANUQTY	=	Quantity of manure/compost applied (in t/ha);
MANUCST	=	Cost or value of manure/compost (in US$/t);
FERTQTY	=	Quantity of chemical fertilizer applied (in kg/ha);
FERTCST	=	Cost of chemical fertilizer (in US$/kg);
LUSETOT	=	Total labor units used (in '000 man-days);
LUSEHIR	=	Proportion of hired labor units (%);
LUSERAT	=	Average wage rate (in US$/day);
PRODPRC	=	Average price of crop output (in US$/kg);
PRODVAL	=	Total value of crop output (in '000 US$/ha);
GROSREV	=	Gross revenue (in '000 US$/ha);
TOTCOST	=	Total costs (in '000 US$/ha);
NRETPHA	=	Net return per hectare (in '000 US$/ha);
NRETPTC	=	Net return per unit of clay applied (in '000 US$/tonne);

TABLE 2. Sample composition and area coverage.

Clay application	Particulars	Units	Farm categories			Total
			Vegetable farms	Rice farms	Integrated farms	
Yes	Number of farms	(number)	59	30	36	125
	Total farm area	(ha)	139	51	110	300
	Farm area for data collection	(ha)	25	50	101	176
No	Number of farms	(number)	60	34	31	125
	Total farm area	(ha)	62	129	71	262
	Farm area for data collection	(ha)	34	76	34	144
Total	Number of farms	(number)	119	64	67	250
	Total farm area	(ha)	201	180	181	563
	Farm area for data collection	(ha)	59	126	135	319

Most of the variables defined above are straightforward, but some of them do require some clarifications. For instance, RESPVIS captures the extent to which the respondent is engaged in part-time or periodic work in urban areas. LUSETOT includes both the use of own and hired labor. For the purpose of simplification, in the case of all labor-related variables, i.e., LUSETOT, LUSEHIR, and LUSERAT, no distinction was made against gender, although separate data are available from our survey. GROSREV includes the total value of outputs (PRODVAL) plus the value of farm by-products, most of which are used either as livestock feed or for making compost. Notably, TOTCOST, one of the key variables in net benefit calculation and, hence, impact analysis, summarizes a number of cost-side variables, both the ones listed above as well as those not listed here essentially to save acronyms. Essentially, it covers the full costs of all inputs, land, land preparation, seed, clay, fertilizer, and manure/compost.[20] The calculation of TOTCOST also involves some assumptions on the temporal influence of clay inputs and related costs. These assumptions are necessary because the effects of some of the inputs transcend across seasons. In the case of these inputs, there is a need to calculate the shares of these costs that can be specifically attributable to the season for which income and cost are assessed.

Accounting for the costs of seasonal inputs such as seed and fertilizer is simple compared to accounting for inputs having implications beyond a season such as rent, land preparations, manure/compost application, and, more importantly, clay use. The rental cost of land is accounted for all farms with rented land in terms of actual rent paid. But, for farms with owned land, the rental cost is calculated using the prevailing average rent in the region, i.e., about US$1,600 (10,000 Baht)/year. This land cost is, then, apportioned to a season by dividing it by the number of crop seasons assumed for the three farming systems, i.e., four for vegetable farms and two each for organic rice and integrated farms. Since the effects of manure/compost are gradual and expected to last only up to a year, their costs are divided by the relevant number of seasons. Unlike manure/compost, the effects of clay are not only immediate but also expected to last up to 10 years. But, for calculating the seasonal costs of clay, we only assumed a three-year period for the impact to occur. With this three-year period and the crop seasons assumed for different farming systems, the clay costs reported in the survey were adjusted to obtain the costs that can be attributable to a season.

Costs and Benefits of Clay Application

The effects of clay application on plant growth and land productivity are shown in figures 1 and 2 and also in Table 1. As argued earlier, clay application has a positive impact on growth and yield mainly because it improves the nutrition and water holding capacity of the treated soils. Even though these are essentially agronomic effects, they also induce some major changes in the economic dimensions of farm production, especially in terms of changing the level and composition of different farm inputs and also improving the market responsiveness of the production system. Indeed, it is the variations

[20] It is important to recognize that unlike the costs related to fertilizer and manure/compost, those related to rent, land preparation, and seed are likely to be, more or less, the same among clay users and others for a given crop. In this sense, although one can argue for the exclusion of the latter set of costs, it is safe to include them to account for possible variations across crops and farming systems.

in the quantity and composition of these yield-increasing inputs that explain the differential productivity and cost-return calculus of the farms treated with clay and the control farms without clay application. This is obvious even with a simple comparison of descriptive statistics for key input and output variables between the two groups presented in Table 3.

TABLE 3. Input, cost, output and income details across sample groups.

Variables	Acronym	Units	All samples (250)		Clay users (125)		Non-users (125)	
			Mean	***Standard Deviation***	***Mean***	***Standard Deviation***	***Mean***	***Standard Deviation***
Land Area	LANDTOT	(ha)	2.25	2.00	2.41	1.75	2.10	2.22
Land Area Surveyed	LANDSUR	(ha)	1.28	1.34	1.41	1.55	1.15	1.09
Clay Quantity	CLAYQTY	(t/ha)	88.34	166.51	176.68	199.86	0.00	0.00
Clay Cost	CLAYCST	(US$/t)	1.95	3.77	3.90	4.57	0.00	0.00
Manure Quantity	MANUQTY	(ton/ha)	2.89	8.83	1.13	2.28	4.65	12.05
Manure Cost	MANUCST	(US$/ton)	12.21	13.74	7.93	12.22	16.50	13.88
Fertilizer Quantity	FERTQTY	(kg/ha)	322.24	523.96	483.12	684.19	161.36	176.00
Fertilizer Cost	FERTCST	(US$/kg)	0.38	0.32	0.41	0.40	0.36	0.19
Labor Units Used	LUSETOT	(‘000)	1.58	1.45	1.81	1.74	1.35	1.05
Labor Units Hired	LUSEHIR	(%)	26.34	25.98	31.28	28.66	21.40	22.02
Average Wage Rate	LUSERAT	(US$/day)	3.74	2.39	2.96	2.44	4.52	2.07
Average Output Price	PRODPRC	(US$/kg)	0.37	0.27	0.40	0.33	0.34	0.18
Total Output Value	PRODVAL	(‘000 US$/ha)	3.06	4.93	4.10	5.72	2.03	3.72
Gross Revenue	GROSREV	(‘000 US$/ha)	3.07	4.93	4.10	5.72	2.04	3.72
Total Costs	TOTCOST	(‘000 US$/ha)	0.81	0.63	0.99	0.76	0.63	0.41
Net Return	NRETPHA	(‘000 US$/ha)	2.26	4.57	3.11	5.25	1.41	3.59
Return/Clay Unit	NRETPTC	(‘000 US$/ton)	0.013	0.028	0.026	0.035	-	-

As can be seen from Table 3, clay is not applied to the entire farm, but only to a portion of the farm. On average, clay users apply 177 t/ha, though there are considerable variations across farms, which are mainly due to issues related to soil quality, costs and crop pattern. Table 3 is also helpful in seeing the distinct pattern in input use between the treated and control farms. To begin with, farms using clay apply more fertilizer whereas those that do not use clay apply more manure/ compost. On average and on a per hectare basis, clay users apply almost three times more fertilizer than non-clay users, but the latter group apply manure/compost more than twice as much compared to the former group. Considering the prices of these two inputs, clay users tend to apply high-value fertilizers whereas non-clay users tend to apply high-value and good quality manure. In terms of labor use, farms with clay application use 30% more labor than those without clay application. Although both groups rely mostly on their own labor, clay users hire 40% more labor than non-clay users.

Besides its role in changing the nature and composition of farm inputs, clay application also seems to influence the output price received by the farmers. The fact that the average output price for clay users is 18% higher than that for non-clay users suggests that either clay users go for high-value crops (as in vegetable farms) or they get a higher price due to better quality output (as in organic rice and integrated farms). In view of the higher level of input use, the production costs are obviously higher. However, due to the higher level and quality of yield, they are able to meet these costs and still get much higher net returns compared to farms not using clay. For instance, the average cost per hectare of clay-using farms is

57% higher than that of non-users, but per hectare gross revenue of the former group is twice as high. As a result, clay-using farms have a net return that is more than twice the net revenue of their counterparts. As we compare the net return values of the treated and control groups, clay application leads to a net benefit of about 120%.

The general pattern in input use and net return between the treated and control groups, which is observed in Table 3, is also largely valid between the two groups in each of the three farming systems. However, there are notable differences, exceptions, and caveats (see Annex B, Table B1). Most of the clay application is confined to vegetable farms. Clay users in vegetable farms apply, on average, 333 t/ha, which is close to eight times more than that applied in organic rice farms (47 t/ha) and over 11 times more than that applied in integrated farms (29 t/ha). This is partly due to a relatively lower clay cost (US$1.36/t for vegetable farmers as compared to US$11.82/t for rice farmers and US$1.47/t for the integrated farms) and partly due to high profitability (US$5,880/ha for vegetable farms as compared to US$620-650/ha for other farms). These same reasons also explain why clay users in vegetable farms apply most of the chemical fertilizers observed among all clay users. For instance, among clay users, fertilizer is applied at the rate of 780 kg/ha in vegetable farms compared to the application of only 121 kg/ha in rice farms and 298 kg/ha in integrated farms.

The difference in manure application between the treated and control farms is only noticeable in the context of vegetable farms. But, in the case of the other two farming systems, there is not much difference in the manure application between clay users and others. In terms of labor use, clay application involves a higher use of both total and hired labor in the case of vegetable and rice farms. In contrast, in the case of integrated farms, clay application actually reduces the total labor used by 16% and hired labor used by 10%, possibly due to a change in crop composition among clay using farms. Although clay application leads to a substantially higher net return in the case of all farming systems, as one can expect, most of the benefits are accrued by vegetable farms. For instance, the average net return for the treated farms is more than twice that for the control farms in vegetable cultivation, but it is only about 80% more than the control farms in the case of both rice and integrated farming systems.

Estimation of the Impact of Clay Technology

The results in Table 3 (and also in Annex B, Table B1) clearly show the effects of clay technology on input use and outcome, both from an overall context and also from a farm system-specific context. Now, we can provide a more formal estimate of the impact, that is, the differences in net return per hectare between the treated and control units, particularly from the perspective of the treated group. In other words, what we are interested in here is an estimate of the ATT, i.e., the average treatment effect on the treated. Like the outcomes, the estimated impact under these methods will also be on a per hectare basis. To obtain this estimate, all the four approaches were used, i.e., statistical or 'with-without' method, regression method-1 (without covariates Xi), regression method-2 (with covariates Xi), and the matching method based on the nearest neighborhood procedure. These approaches are described in the section, *Methodological Framework*, and are formally defined in equations (6) to (9).

Obviously, estimation of the ATT under the statistical approach is simple and straightforward because it is essentially the difference between the mean net returns per hectare of the treated and control farms and it can be directly derived from

Table 3 (and from Annex B, Table B1). Estimating the ATT using the other methods requires econometric approaches. SHAZAM (version 10) was used for the regression methods and the econometric and data management package of STATA (version 10) was used for the matching method. The 12 covariates used in the context of regression method-2 and the matching method are: RESPGEN, RESPEDU, RESPVIS, FAMSIZE, FAMASET, LANDTOT, SOILQLT, WATSOUR, FERTQTY, MANUQTY, LUSETOT and LUSEHIR.[21] In the case of all the four methods, the estimate of ATT was obtained both for the overall sample as well as for the three farm system-specific samples. While the method-specific detailed results are provided in Annex B (Tables B2-B4), Table 4 gives the ATT estimates and other details needed for calculating the total impact on the treated groups under the four methods in the context of the different samples.

TABLE 4. Clay technology impact: Estimates under different approaches.

Particulars		Units	All farms	Vegetable farms	Rice farms	Integrated farms
Total area with clay application		(ha)	175.81	25.45	49.84	100.53
Total quantity of clay applied		('000 tons)	53.13	46.18	2.41	3.19
Average net benefits of clay application (ATT)	Statistical method	('000 US$/ha)	1.70	3.33	0.28	0.29
	Regression-1 method	('000 US$/ha)	1.55	3.33	0.28	0.25
	Regression-2 method	('000 US$/ha)	1.48	2.96	0.33	0.23
	Matching method	('000 US$/ha)	1.83	3.95	0.33	0.43
Total net benefits of clay application for the treated	Statistical method	('000 US$)	299.55	84.70	13.73	29.22
	Regression-1 method	('000 US$)	273.36	84.70	13.73	25.06
	Regression-2 method	('000 US$)	260.56	75.30	16.61	22.75
	Matching method	('000 US$)	321.46	100.54	16.69	43.24

As shown in Table 4, the impact of clay application per hectare, as evaluated in terms of the value of ATT, varies considerably across the four methods as well as in the context of the sample or estimation. In general, regardless of the farming system, the ATT estimates under the matching method are higher than those obtained from the other three methods. Notably, the ATT estimates under the Regression method-1 are either the same or very close to the estimates obtained with the statistical method in the case of all three farming systems. As can be expected in the light of the results in Table 3 (and Annex B, Table B1), irrespective of the method used, the impact of clay application per hectare in vegetable cultivation is many times higher than that in the other two farming systems. Between the rice farms and integrated farms with the lower ATT values, the impact is only marginally different. As a result, the issue of whether rice farms have a better impact than integrated farms or vice versa, depends entirely on the method being used. For instance, the ATT value for rice farms is almost the same as that of integrated farms under the statistical method, but it is higher under regression methods and lower under the matching method.

Taking the estimates of ATT of all the methods into consideration, the impact varies from US$1,550/ha to US$1,830/ha in the context of all the samples. For vegetable farms, the average net

[21] The reason for the choice of these variables for the matching method is obvious because they can capture the farm and farmer-specific attributes that are likely to influence not only participation in, but also the impact of, clay application. While these variables cover most of the major attributes, there can be other un-observed variables such as pre-exposure, length of experience with the technology, and credit and other institutional support. Although the matching method excludes these variables, it is still possible to expect that the variables selected and included here can cover the major part of the heterogeneity.

benefit is in the range of US$2,960 to US$3,950, but in the case of rice farms, the average net benefit is significantly lower and ranges from US$280 to US$330/ha. The latter is also the case with the integrated farms, where the average net benefit is in the range of US$230 to US$430/ha. Since the ATT values capture the average impact per hectare for the treated groups, the total impact for the treated groups as a whole can be calculated by multiplying these ATT values under different methods with the total treated area in the context of the different samples. These total impact values are also presented in Table 4. These values, like the ATT values, also vary across the different methods and samples.

For clay users in the context of all the samples, the estimates of the total impact are in the range of US$260,560 to US$321,460. The range for clay users under vegetable cultivation is US$75,300 to US$100,540. But, for clay users in rice farms, the total impact is far less, hovering in the narrow range of US$13,730 to US$16,690. Although the total impact for the integrated farms is also far lower than that for vegetable farms, as compared to the total impact on rice farms, it is substantially higher in the range of US$22,750 to US$43,240. This is mainly due to the larger area of clay application (101 ha) in integrated farms as compared to that in rice farms (50 ha) within our sample. In the case of vegetable farms with far higher ATT values, on the other hand, the total impact is several times higher despite the far lower area (25 ha) of clay use as per our sample.

While estimating the ATT and total impact values, we have implicitly assumed that the entire impact is attributable to clay application. What about the roles of other yield-increasing inputs such as fertilizer, manure and labor? As discussed in the section, *Methodological Framework*, both the regression-2 and matching methods do take into account the effects of these inputs as part of the larger set of covariates involved in their estimation. It is necessary to note that it is the clay application that leads to the additional use of these inputs (compared with non-treatment) and not vice versa. We have seen this, to some extent, while discussing the results in Table 3 (and also in Annex B, Table B1). But, with a simple correlation analysis, we can see the exact nature and direction of the relationships that clay use has with other input and outcome variables is still better. The correlation results, presented in Table 5, show a strong positive correlation between clay application and the use of both fertilizer and labor. There is also a positive correlation between fertilizer and total labor use. Thus, clay application leads to higher fertilizer and labor use (both directly and also indirectly via fertilizer use). The same point can also be extended to the cost side as well because the application of most of the additional inputs is caused by clay application itself. Thus, from the perspective of both input use and cost, one can attribute most of, if not all, the additional benefits to clay application.

TABLE 5. Correlation among input and outcome variables for clay users.

Variables	*CLAY QTY*	*FERT QTY*	*MANU QTY*	*LUSE TOT*	*LUSE HIR*	*PROD PRC*	*TOT COST*	*NRETPHA*
CLAYQTY	1.000							
FERTQTY	**0.509**	1.000						
MANUQTY	0.121	-0.027	1.000					
LUSETOT	**0.684**	***0.472***	0.222	1.000				
LUSEHIR	-0.166	-0.009	***-0.353***	***-0.302***	1.000			
PRODPRC	0.052	0.073	-0.050	0.073	0.062	1.000		
TOTCOST	**0.722**	**0.734**	0.186	**0.927**	-0.240	0.075	1.000	
NRETPHA	***0.459***	***0.358***	0.122	**0.571**	-0.099	0.190	**0.611**	1.000

Besides the attribution issue, we also need to settle two other issues that are both related to the selection of appropriate total impact figures. First, under all the methods, the values of the total impact in all the samples are not the same as the sum of the total impacts obtained in all three farming systems. This is mainly attributed to the fact that in all the samples, the ATT values are used uniformly for all clay users without recognizing the differential outcomes of clay use across farming systems. To avoid this problem, first, we can use the sum of the total impact in each of the three farming systems. Second, we also need to make a choice from the total impact figures obtained under the four methods. Certainly, the impact figures obtained under regression-2 and the matching methods are more realistic and reliable mainly because they allow heterogeneous effects to be considered and also involve more formal and rigorous estimation procedures. Since there is no formal approach to choose between methods, the simple average of the total impact figures associated with these methods was used. On this basis, the total impact on all the treated groups under vegetable, rice and integrated farms are: US$87,921, US$16,650 and US$32,997, respectively. The total impact for all the treated groups in the overall sample is US$137,568.

Research Impact and Attribution

Given the impact figures that represent the farm-level impact of clay technology, it is relatively straightforward to evaluate the overall impact of the Soil Remediation Research Project (SRRP). This evaluation obviously involves the benefit and cost streams of the project over a period deemed appropriate for an *ex-post* evaluation. The evaluation period selected is 2002-2008 that covers both the project period (2002-2005) and the post-project period (2006-2008).[22] As established already, since the total impact can be attributed mainly to clay application, these impact values can also be taken as the direct benefits of the project for a given crop season in the context of our sample. Taking four crop seasons for vegetable farms and two seasons each for the other two farming systems and assuming that the impact continues, more or less, at the same level over crop seasons, the annual benefit streams of the project can be calculated for the post-project period.[23] Similarly, the cost streams for the project can be easily established based on the annual project expense figures available at IWMI' Budget Office. Since the rate of interest that IWMI funds usually receive is about 2.5%, both the benefit and cost streams can also be compounded for the appropriate period (i.e., eight years for costs and three years for benefits). The cost and benefit streams for the project are presented in Table 6.

[22] Clearly, the benefit flows from clay application occur far beyond 2008. One can consider a longer evaluation period to account for the future benefits that occur with no additional project costs. But, this exercise will make the evaluation *ex-ante* rather than *ex-post*.

[23] The crop seasons assumed are conservative especially for vegetable farms, which grow up to six crops per year. Unlike the rice farms, integrated farms with many crops also have more then two major cropping seasons. On the issue of benefits, although there were also some benefits during project period, there is no data to estimate them. Thus, we assume the benefit stream to start only after the project period.

TABLE 6. Cost and benefit streams for the SRRP, Northeast Thailand, 2002-2008.

Particulars	('000 US$)							
	Project period				Benefits period			Total
	2002	2003	2004	2005	2006	2007	2008	
IWMI's research costs for the SRRP	(35.00)	(34.37)	(66.88)	(136.08)	(3.40)	(3.32)	(3.23)	(282.28)
Net benefits for vegetable farms	-	-	-	-	351.68	360.47	369.48	1,081.64
Net benefits for rice farms	-	-	-	-	30.44	31.20	31.98	93.62
Net benefits for integrated farms	-	**-**	**-**	**-**	65.99	67.64	69.33	202.96
Total net benefits for the SRRP	(35.00)	(34.37)	(66.88)	(136.08)	444.71	456.00	467.56	1,095.93
Net benefits attributable only to IWMI (50%)	**(35.00)**	**(34.37)**	**(66.88)**	**(136.08)**	**220.65**	**226.34**	**232.16**	**406.83**

Notes:

a. Figures in brackets are costs and, hence, negative numbers. These costs only include IWMI's investment on the SRRP during the project period plus the cumulative interest costs (compounded at 2.5%) during both the project and benefits periods.

b. The benefit figures are the sum of the total impacts in all farm categories as obtained by the average values of the impacts estimated under the regression-2 and matching methods (see Table 4). These benefit figures are also compounded at 2.5% for the benefits period between 2006 and 2008.

c. The impact attributable to IWMI is based on the assumption of a 50% share in total net benefits. The remaining share can be attributable to the role of other partners and also to the effects of exogenous factors such as rainfall, input supply, markets and government policies.

As can be seen in Table 6, the total investment of IWMI on the SRRP, including the research costs and interests, is only US$0.28 million. This figure also represents the costs of developing and promoting the application of the clay technology. But, the total benefits generated by the research investment on clay technology amount to US$1.38 million during the evaluation period. Hence, the total net benefits of the SRRP are also substantial at about US$1.10 million. Although IWMI has played a central role in, and covered almost all the costs of, the project, all the benefits of the project cannot be entirely attributed to IWMI. It is also reasonable to recognize the role of other partners (CSIRO, LDD, KKU and farmers networks) and actors (suppliers of clay and other inputs and private industries). More importantly, there are also the effects of exogenous factors (rainfall, markets and government policies). In view of the practical difficulties associated with the exact quantification of the relative roles of IWMI vis-à-vis these partners, actors and factors, we adopted a simple but arbitrary approach of attributing 50% of the total benefits to IWMI and the remaining 50% to others. Under this approach, the total benefits attributable to IWMI are US$0.69 million. Given the project costs of US$0.28 million, the total net benefits attributable to IWMI is about US$0.41 million.

The net benefits—viewed from either an IWMI perspective—do suggest the considerable economic value of the research undertaken within the SRRP. To establish the economic viability of the project in more formal terms, we have calculated its NPV, IRR and BCR. Table 7 presents these three values of economic and financial viability under two conditions: (a) benefits calculated in terms of the clay area observed within our sample; and (b) benefits calculated in terms of the estimated area in the study region, i.e., Northeast Thailand, where clay has been used by farmers over the past few years. Obviously, the values calculated in the context of the sample are based on the cost and benefit streams presented in Table 6. But, the total benefits in the larger context of the region is based on the estimated clay using areas of 5,000 ha for vegetable farms, 100 ha for organic rice farms, and 500 ha for integrated farms. These areas are estimated using a mix of actual data on the area under different farming systems and the learned judgment of experts and farmers in the region on clay using areas across these systems.[24] While a 50% share of the benefits is attributed to IWMI in the context of the sample, only a token share of 10% is attributed to IWMI in the larger context of the region. A lower share is selected for the regional context because here the influence of IWMI and its direct project partners is less whereas that of other actors and factors is more.

Even restricting the focus only on the sample, the SRRP, taken as a whole, has a NPV of 1.10 million involving an IRR of approximately 69% and a BCR of 4.88. From the exclusive perspective of IWMI, the project also fairs well having a NPV of US$0.41 million and with an IRR of approximately 36% and a BCR of 2.44. But, if we consider the impact from a regional perspective, the NPV of the project, as a whole, increases to approximately US$213 million. Even in terms of the benefits attributable to IWMI alone, the NPV of the project during the evaluation period comes to approximately US$21 million with a very high IRR of approximately 267% and a BCR of approximately 75. Thus, notwithstanding the conservative assumptions on the number of crop seasons and clay areas used in the calculation of total benefits and regardless of whether the evaluation is performed in the context of the sample or on a regional level, IWMI's research undertaken through the SRRP has had a significant impact on land productivity and farm income of poor rural communities in the soil and water-wise most vulnerable region of Northeast Thailand.

TABLE 7. Economic viability of the SRRP, Northeast Thailand, 2002-2008.

	Based on observed clay area in the sample		Based on estimated clay area in the region	
Financial indicators	Total project contribution	Attributable to IWMI	Total project contribution	Attributable to IWMI
NPV (million US$)	1.10	0.41	213.44	21.09
IRR (%)	69.35	35.80	563.83	266.78
BCR	4.88	2.44	757.12	75.71

Note: The calculation of benefits for the regional context is based on estimated clay using areas of 5,000 ha for vegetable farms, 100 ha for organic rice farms and 500 ha for integrated farms. In this context, the share of benefits attributable to IWMI is only a token figure of 10%.

[24] Since clay use in organic rice farms and integrated farms are almost entirely due to the project and are also confined largely to a relatively smaller area, the estimated areas of clay use are, more or less, accurate. But, in the case of vegetable farms, it is somewhat complicated, partly because these farms are dispersed around urban centers and rural areas and also because published data from the civil society (CSO) provide area figures only for the joint category of 'vegetables, herbs, flowers and ornamental plants'. Given the total area of 53,000 ha under this category for the Northeast region, we first assumed half of this area to be under vegetable cultivation alone and based on the income from experts and farmers, 5,000 ha (or about 20% of the vegetable area) is taken as the area with clay application.

Concluding Remarks

In this paper, we have presented an economic assessment of the *ex-post* impact of the SRRP undertaken by IWMI in the northeast region of Thailand during 2002-2005 in collaboration with national and international partners as well as farmers. This assessment is based on the average impacts for the treated group (i.e., the average treatment effect on the treated [ATT]) empirically estimated under different impact assessment methods using socioeconomic and production data collected from a sample of 250 farmers from three farming systems, i.e., vegetable, organic rice, and integrated farms, in the project region. Given these average impact figures—evaluated on a per-hectare and per-season basis—and the clay using area observed, the total impacts of clay use was calculated for different methods and farming systems. For evaluation of the economic viability of the project, instead of using the total impact figures associated with any one method, we have used the average values of the total impact obtained under the two most realistic and reliable methods, i.e., the regression approach involving the covariates, and the matching approach involving the nearest neighborhood procedure. Given the central role of clay in affecting the use of other inputs, the total impacts were largely attributed to clay technology and, hence, to the project that led to its development.

Evaluation of the overall impact and economic viability of the project was undertaken for the period of 2002-2008, covering both the project period (2002-2005) and the benefits period (2006-2008). The evaluation is conducted both in the context of the sample, by taking the clay using area actually observed in our sample, and also in the context of the region as a whole, with the actual clay using areas in Northeast Thailand, and estimates were made with actual data and information from experts and farmers. In each context, the evaluation is performed both for the project as a whole and also from the specific perspective of IWMI. For the IWMI-specific evaluation, the share of benefits attributable to IWMI was assumed to be 50% in the context of the sample but reduced to only 10% in the context of the region. Taking an exclusive perspective of IWMI and considering the impacts as observed within the sample, the NPV of the SRRP is estimated to be about US$0.41 million involving an IRR of approximately 36% and a BCR of 2.44. But, as we take the impact in the larger context of the region, where clay technology has actually been used since the completion of this project, the NPV of the SRRP is as high as US$21 million with correspondingly higher figures of approximately 267% for IRR and approximately 75 for BCR.

Judging from any perspective and especially recognizing the conservative assumptions involved in the calculation and attribution of benefits, the economic impact and financial viability of the research investment that IWMI has made on the SRRP is truly remarkable. This is still more so given the fact that this assessment considered only the direct income benefits to clay users. Even though we have not evaluated them, the other direct as well as second-round individual and social impacts, particularly in terms of food security, diversification, livestock, environmental, and resource benefits associated with this project, should have been substantial. Therefore, obviously, the impact and economic viability values presented here are only the lower bound indicators for the true magnitude of the social, economic and environmental impacts of the SRRP. Although the SRRP and its impact assessment have only focused on a region, in view of their relevance to other parts of Asia and Africa with similar soil-related problems, they have research and policy implications far beyond Northeast Thailand. Finally, given the specific nature of the soil problem and the predominance of rainfed cultivation in the region, the impact, as assessed here, also captures the effects on yield and crop pattern of an improved soil water holding capacity achieved through the application of clay technology. In this sense, the impact assessment presented here can also be taken as an economic evaluation of the water harvesting and moisture conservation role of the clay technology that is developed under the SRRP.

Annex A

The Survey Instrument

INTERNATIONAL WATER MANAGEMENT INSTITUTE

Impact Assessment of Soil Remediation Research in Northeast Thailand

(October 2007-March 2008)

A. IDENTIFICATION DETAILS

1. Village/community Name --
2. Cultivation type --

   (Vegetables=1; Organic Rice=2; Integrated Farming=3)

3. Clay Use ***(Yes=1; No= 0***) -- ☐

B. SURVEY PARTICULARS *(To be filled after the completion of this schedule)*

1. Signature and name of investigator --
2. Date of survey --
3. Signature and name of field supervisor --

C. RESPONDENT'S PARTICULARS

1. Name of the respondent --
2. Gender ***(Male=1; Female=2***) -- ☐
3. Education level -- ☐

   (In number of years in school, use '0', if uneducated)

4. Frequency of visit to urban centers -- ☐

D. HOUSEHOLD PARTICULARS

1. Family size (numbers) -- ☐
2. Approximate total value of household assets (Bahts) --- ☐

   (Note: It includes all assets other than land such as houses, household items, equipment, vehicles, etc.)

3. Approximate income from all non-farm sources -- ☐

   (Note: It includes income from non-farm employment, money remitted and livestock)

4. Active members ***(excluding non-workers)*** -- ☐

   (a) Total (numbers) -- ☐

   (b) Males (numbers) -- ☐

E. LANDHOLDING DETAILS

1. Total cultivated area (*Rai*) -- ☐
2. Own land -- ☐

   (a) Area (*Rai*) -- ☐

   (b) Market value (Bahts) -- ☐

3. Number of farm fragments (plots) -- ☐

   ***Note*: In the case of CLAY USERS, take TWO PLOTS (one with clay application and the other without clay application) and for NON-CLAY USERS, take only ONE plot**.

4. For each plot, complete the following details:

Characteristics	Plot number	
	(a) (If Clay is used)	(b) (If Clay is not used)
(a) Area (*Rai*)		
(b) Ownership and use ***(Owned and used=1, Rented and used=2)***		
(c) Market value or rental value, if rented (Bahts)		
(d) Distance from home (in minutes)		
(e) Distance from the nearest farm road (in minutes)		
(f) Irrigation source ***(Rainfed=1, Common ponds=2, Farm ponds/wells=3)***		
(g) Soil fertility/quality ***(Poor=1, Average=2, Good=3, Excellent=4)***		
(h) If Clay is applied, note the percentage of area being applied (%) *(Note: If it is applied to a whole plot, put 100%, but if it is only to a part of the plot, put the relevant percentage*		

F. USAGE OF INPUTS AND COSTS, AND OUTPUT AND INCOME (OR VALUE)
(*Note*: *All details pertain to the last crop year)*

Items	Particulars	Plot number	
		(a) *(If Clay is used)*	(b) *(If Clay is not used)*
1	Area cultivated (*Rai*)		
2	Lease payment paid, if any (Bahts/year)		
3	Crop ***(Specify)***		
4	Variety of main crop ***(High-Yielding Varieties=1, Local=0)***		
5	Tillage ***(Tilled=1, Not tilled=0)***		
6	If tilled, tillage and other land preparation costs (Bahts)		
7	Seed quantity (kg)		
8	Seed cost (Bahts/kg)		
9	Clay applied (tonnes)		
10	Clay costs (Bahts/tonne)		
11	Farmyard manure applied (tonnes)		
12	Farmyard manure cost (Bahts/tonne)		
13	Compost or biomass applied (tonnes)		
14	Compost or biomass costs (Bahts/tonnes)		
15	Fertilizer used (kg)		
16	Fertilizer costs (Bahts/kg)		
17	Pesticide costs (Bahts)		
18	Source of irrigation ***(Rainfed=1, Common ponds=2, Farm ponds/wells=3)***		
19	Pump-set is installed ***(Yes=1, No=0)***		
20	Years since pump-set was installed		
21	Total investment in pump-set (Bahts)		
22	Electric/diesel costs (Bahts/crop year)		
23	Sprinkler/drip use ***(Yes=1, No=0)***		
24	Years since sprinkler/drip was installed		
25	Total investment in sprinkler/drip (Bahts)		

Items	Particulars	Plot number	
		(a) (If Clay is used)	(b) (If Clay is not used)
26	Total labor used (Days/crop year)		
27	Share of Female labor (%)		
28	Share of hired labor (%)		
29	Wage rate for men (Bahts/day)		
30	Wage rate for women (Bahts/day)		
31	Crop output (kg)		
32	Crop output sold (kg)		
33	Crop price (Bahts/kg)		
34	Crop residues or biomass (kg)		
35	If this biomass is used or sold, give its total value (Bahts)		

G. DETAILS OF CLAY USERS

1. How many years have you been using clay? -- ☐

2. Do you think Clay has helped to improve your yield? ***(Yes=1, No=0)*** -- ☐
(<u>Note</u>: Ask the farmer to take time to compare the present yield with clay use as reported in section F-26 with that used before clay use and, then, report the response)

3. If yes, roughly, how much more yield do you get now? (Kg/*Rai*) -- ☐

4. In your experience, clay is more effective when ***(Tick <u>only one</u> box)*** -- ☐

- (a) Used alone -- ☐
- (b) Used with farmyard manure -- ☐
- (c) Used with compost/biomass -- ☐
- (d) Used with chemical fertilizer -- ☐
- (e) Used with both farmyard manure and chemical fertilizer -- ☐

5. The main problems in getting and applying clay ***(Tick <u>one or more</u> boxes)***

- (a) Lack of adequate supply -- ☐
- (b) Supply is not available in time -- ☐
- (c) High and variable price -- ☐
- (d) Poor or variable quality of the material -- ☐
- (e) Problems in getting loans, etc. -- ☐
(e.g., soils from termite and other sources, manure, etc.)

H. DETAILS FOR NON-CLAY USERS

1. Reasons for not using clay ***(Tick <u>one or more</u> boxes)***

- (a) No knowledge of the technology -- ☐
- (b) Problems in getting timely supply -- ☐
- (c) Cost is higher than the benefits -- ☐
- (d) No need because the use of manure and biomass can be enough --- ☐
- (e) No need as the land quality is already good -- ☐

Annex B. Additional Tables

TABLE B1. Input, cost, output and income details across farming systems.

Variables	Acronym	Units	Clay use	Vegetable farms Mean	Vegetable farms Standard Deviation	Rice farms Mean	Rice farms Standard Deviation	Integrated farms Mean	Integrated farms Standard Deviation
Land Area	LANDTOT	(ha)	Yes	2.35	1.83	1.72	1.10	3.07	1.85
			No	1.04	0.86	3.81	2.73	2.28	2.25
Land Area	LANDTOT	(ha)	Yes	0.43	0.46	1.66	1.14	2.79	1.86
			No	0.56	0.40	2.22	1.07	1.10	1.15
Clay Quantity	CLAYQTY	(t/ha)	Yes	332.89	193.77	46.80	32.10	28.89	19.52
			No	-	-	-	-	-	-
Clay Cost	CLAYCST	(US$/t)	Yes	1.36	0.32	11.82	1.82	1.47	0.48
			No	-	-	-	-	-	-
Manure Quantity	MANUQTY	(t/ha)	Yes	1.24	2.10	1.14	3.15	0.94	1.69
			No	8.75	16.46	0.78	0.98	0.97	1.36
Manure Cost	MANUCST	(US$/t)	Yes	6.52	11.07	8.85	12.79	9.46	13.58
			No	21.03	14.00	8.44	9.07	16.56	14.34
Fertilizer Quantity	FERTQTY	(kg/ha)	Yes	779.49	892.05	121.33	101.63	298.89	189.94
			No	268.67	191.81	52.65	70.38	72.90	75.60
Fertilizer Cost	FERTCST	(US$/kg)	Yes	0.39	0.06	0.53	0.82	0.36	0.05
			No	0.48	0.08	0.19	0.17	0.29	0.20
Labor Units Used	LUSETOT	(‘000)	Yes	2.98	1.90	0.78	0.66	0.74	0.13
			No	2.01	1.07	0.59	0.65	0.88	0.34
Labor Units Hired	LUSEHIR	(%)	Yes	28.56	28.43	44.68	33.21	24.59	21.09
			No	22.36	19.70	20.10	17.44	20.97	30.04
Average Wage Rate	LUSERAT	(US$/day)	Yes	2.86	2.54	3.45	2.62	2.72	2.10
			No	5.89	0.66	3.65	1.99	2.81	2.19
Average Output Price	PRODPRC	(US$/kg)	Yes	0.54	0.44	0.29	0.09	0.27	0.05
			No	0.39	0.25	0.28	0.03	0.32	0.06
Total Output Value	PRODVAL	(‘000 US$/ha)	Yes	7.34	7.01	1.06	0.64	1.31	0.74
			No	3.47	4.96	0.65	0.76	0.75	0.55
Gross Revenue	GROSREV	(‘000 US$/ha)	Yes	7.34	7.01	1.06	0.65	1.32	0.74
			No	3.48	4.96	0.66	0.76	0.76	0.55
Total Costs	TOTCOST	(‘000 US$/ha)	Yes	1.46	0.84	0.44	0.20	0.67	0.27
			No	0.93	0.36	0.31	0.20	0.40	0.18

Variables	Acronym	Units	Clay use	Vegetable farms Mean	Vegetable farms Standard Deviation	Rice farms Mean	Rice farms Standard Deviation	Integrated farms Mean	Integrated farms Standard Deviation
Net Return	NRETPHA	('000 US$/ha)	Yes	5.88	6.62	0.62	0.56	0.65	0.63
			No	2.55	4.91	0.34	0.59	0.35	0.57
Return/Clay Unit	NRETPTC	('000 US$/t)	Yes	0.02	0.03	0.03	0.05	0.03	0.02
			No	-	-	-	-	-	-

Note: In the case of vegetable, rice, and integrated farms, the clay users are 59, 30, and 36%, respectively. The corresponding number for non-clay users is 60, 34, and 31%, respectively.

TABLE B2. Estimates of the impact of SRRP under the statistical method.

Particulars	Units	All farms	Vegetable farms	Rice farms	Integrated farms
Total area under clay application	(ha)	175.81	25.45	49.84	100.53
Net return for clay users	('000 US$/ha)	3.11	5.88	0.62	0.65
Net return for non-clay users	('000 US$/ha)	1.41	2.55	0.34	0.35
Net benefits of clay use	('000 US$/ha)	1.70	3.33	0.28	0.29

Note: The net benefit of clay use is the difference between the average net return of clay users and that of non-users (See Table 3). The total net benefits are the product of the net benefit of clay use and the total area of clay application.

TABLE B3. Estimates of the impact of SRRP under the matching method.

Context	Average treatment effect for	Cases	Estimated coefficients	T-ratio
All farms	Sample	250	**0.945**	2.820
	Treated	125	**1.828**	4.760
	Control	125	0.061	0.160
Vegetable farms	Sample	119	**3.138**	3.310
	Treated	59	**3.951**	4.400
	Control	60	**2.338**	2.020
Rice farms	Sample	64	**0.256**	2.830
	Treated	30	**0.335**	3.560
	Control	34	**0.186**	1.910
Integrated farms	Sample	67	***0.345***	1.360
	Treated	36	***0.430***	1.470
	Control	31	***0.247***	1.354

Notes:(a) The matching is based on the nearest neighborhood matching procedure and the variables used for matching included all the 12 covariates listed in Table B3.

(b) The **bold** values are significant at 10% or higher and the ***bold and italicized*** values are significant at 20% or higher.

TABLE B4. Estimates of the impact of SRRP under the regression methods.

Variables	All farms		Vegetable farms		Rice farms		Integrated farms	
	Estimated coefficients	T-ratio	Estimated coefficients	T-ratio	Estimated coefficients	T-ratio	Estimated coefficients	T-ratio
Regression Method-1 (without Xi)								
CLAYUSE	**1.555**	2.714	**3.328**	3.120	***0.275***	1.919	***0.249***	1.354
Constant	**1.448**	3.574	**2.551**	3.396	**0.343**	3.493	**0.523**	3.873
R-Square	0.029		0.077		0.056		0.027	
F-Value	**33.854**		**33.888**		**23.582**		**9.884**	
Regression Method-2 (with Xi)								
CLAYUSE	**1.482**	2.575	**2.959**	1.958	***0.333***	1.903	**0.226**	1.961
RESPGEN	***-0.865***	-1.641	***-1.641***	-1.486	-0.074	-0.550	-0.082	-0.344
RESPEDU	-0.110	-0.777	***-0.847***	-1.535	0.024	0.803	-0.053	-0.970
RESPVIS	0.282	1.236	0.481	0.947	-0.012	-0.234	0.042	0.351
FAMSIZE	0.049	0.320	0.089	0.229	***-0.061***	-1.496	0.015	0.303
FAMASET	0.015	0.387	0.017	0.181	-0.013	-1.235	0.007	0.403
LANDTOT	0.096	0.668	0.221	0.524	0.040	1.222	-0.065	-1.060
SOILQLT	0.463	1.119	***1.689***	1.649	0.029	0.313	***-0.293***	-1.593
WATSOUR	**1.129**	2.718	**2.480**	2.433	**-0.307**	-2.594	**0.429**	1.847
FERTQTY	**0.001**	2.576	***0.001***	1.349	0.000	-0.238	-0.001	-0.666
MANUQTY	***0.038***	1.280	0.043	0.922	0.022	0.628	0.019	0.291
LUSETOT	**0.959**	4.628	**0.959**	2.462	**0.442**	4.187	-0.234	-1.229
LUSEHIR	***0.015***	1.379	***0.052***	1.854	***-0.004***	-1.504	**-0.008**	-1.922
Constant	0.612	0.336	1.881	0.435	-0.331	-0.799	**3.042**	2.654
R-Square	0.290		0.239		0.547		0.173	
F-Value	**12.513**		**7.177**		**9.539**		**2.020**	

Notes:(a) The Xi represents the covariates, i.e., the socioeconomic characteristics and input usage of farms. These 12 variables are listed in the table.

(b) Under this approach, the coefficient for the 0-1 variables, CLAYUSE captures the average net benefits of clay application.

(c) The **bold** values are significant at 10% or higher and the ***bold and italicized*** values are significant at 20% or higher.

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