Food and Agriculture Organization of the United Nations

The challenge of making climate adaptation profitable for farmers: evidence from Sri Lanka's rice sector

FAO AGRICULTURAL DEVELOPMENT ECONOMICS WORKING PAPER 21-01

ISSN 2521-1838

February 2021

The challenge of making climate adaptation profitable for farmers: evidence from Sri Lanka’s rice sector

Sidath Bandara
Hector Kobbekaduwa Agrarian Research and Training Institute, Colombo, Sri Lanka

Ada Ignaciuk
Agrifood Economics Division, FAO

Shantha Hewage
Hector Kobbekaduwa Agrarian Research and Training Institute, Colombo, Sri Lanka

Jihae Kwon
Agrifood Economics Division, FAO

Thilani Munaweera
Hector Kobbekaduwa Agrarian Research and Training Institute, Colombo, Sri Lanka

Antonio Scognamillo
Agrifood Economics Division, FAO

Nicholas J. Sitko
Social Protection Division, FAO

Food and Agriculture Organization of the United Nations

Rome, 2021

Required citation:

Bandara, S., Ignaciuk, S., Hewage, A., Kwon, J., Munaweera, T., Scognamillo, A. & Sitko, N. 2021. *The challenge of making climate adaptation profitable for farmers: evidence from Sri Lanka's rice sector.* FAO Agricultural Development Economics Working Paper 21-01. Rome, FAO. https://doi.org/10.4060/cb3384en

ISSN 2664-5785 [Print]

ISSN 2521-1838 [Online]

ISBN 978-92-5-133974-9

Contents

Tables

Figures

Abstract

Increased incidences of drought and water scarcity due to climate change is an important challenge facing Sri Lanka's agricultural sector. Identifying farm practices that can reduce its adverse impacts on agricultural production and farmers' livelihoods is a key policy objective in Sri Lanka. This paper makes use of household survey data collected in Anurādhapura District to evaluate the impacts of 11 drought adaptation practices adopted by farmers in the district. The impacts of the practices are estimated simultaneously along two dimensions: 1) impact on sensitivity to water stress (measured in terms of the probability of experiencing crop loss due to wilting), and; 2) impact on household livelihood (measured in terms of total value of crops harvested and total gross household income). After accounting for a wide range of confounding factors, five practices are found to be associated with a reduced sensitivity to water stress. However, only two of these are simultaneously associated with a higher gross value of crops harvested, while none is associated with significant differences in household income relative to non-adopters. The reasons for this vary by practice, but are linked to opportunity costs of household labour and market weaknesses for crops other than rice. Making climate adaptation practices profitable is a key challenge faced by policy-makers and will require a holistic research and extension approach that is bundled with complementary support to market institutions, such as appropriate mechanization services, value chain support for other field crops, and input supply systems.

Keywords: climate adaptation, water, food security, quantitative.

JEL codes: Q18, Q13, Q15, N45, O2.

Acknowledgements

The data collection and analysis presented in this paper were financially supported by the German Federal Ministry of Food and Agriculture (BMEL) through the project “Building the Basis for implementing the Save & Grow approach - Regional strategies on sustainable and climate-resilient intensification of cropping systems” (Grant number: GCP/INT/259/GER).

The authors would like to thank Dharmassree Wijeratne, Sandra Corsi and MariaGiulia Crespi for their valuable input on the manuscript. The authors are also grateful to Daniela Verona for her editorial and layout support, as well as publishing coordination.

Corresponding author: Nicholas.Sitko@fao.org

1 Introduction

For the majority of farmers in Sri Lanka, rice is both the staple food and the main source of income. Climate change is likely to alter the timing and duration of seasonal precipitation in South Asia, and adversely affect water availability for rice cultivation (Burchfield and de la Poterie, 2018; Kim *et al*., 2013; Lobell *et al*., 2011). Without effective adaptation measures at the farm-level, reductions in water availability will have serious consequences for farmers' welfare and food security (United Nations Economic and Social Commission for Asia and the Pacific, 2010; Weerakoon *et al*., 2011). This is a particular concern in Sri Lanka's dry zone, which accounts for two-thirds of Sir Lanka's total land and over 70 percent of paddy production in the country (De Silva *et al*., 2007).

The adverse impact of low rainfall and low water availability was highlighted during the major drought event that effected multiple farming seasons in Sri Lanka between 2016 and 2017. Reduced rainfall in the primary season *(Maha*) of 2016 and the *Yala* of 2017 severely affected water availability for agricultural production. By the end of the *Yala* season in 2017 water levels in Sri Lanka's reservoirs were critically low. The World Food Programme (WFP) estimated as a result of the drought, reservoirs were on average at just 18 percent of their capacity and 45 percent of communities reported that their closest reservoirs were empty (WFP, 2017). This led to a significant drop in crop production and a rapid increase in food insecurity among rural households. In total, it was estimated that 900 000 households were negatively affected by the drought (WFP, 2017).

The *Overarching Agricultural Policy* in Sri Lanka recognizes the importance of adapting and building resilience to climate events such as droughts in order to achieve national development and food security objectives (Government of Sri Lanka, 2019). This includes a focus on promoting the adoption of suitable agricultural strategies and practices to help farmers adapt to reduced rainfall and water availability. However, empirical evidence on climate adaptation strategies in Sri Lanka's dry zone is limited. This paper, therefore, seeks to support the implementation of Sri Lanka's agricultural policy by providing evidence on the impacts of a range of drought adaptation practices utilized by rice producing households in the dry zone, and the socio-economic and institutional factors that influence their adoption.

In this paper we make use of a unique dataset of 1 100 rice producing households in Anurādhapura District, Sri Lanka to assess the impacts of six different climate adaptation practices, which are further disaggregated by the agricultural field types (upland and lowland) and agricultural seasons (*Maha* and *Yala* seasons) that they are implemented in (see Table 1), and the factors that influence their adoption. The survey reference period of 2017-18 coincided with an exceptionally dry period. As a result, we are able to measure the impacts of adopting these practices in terms of sensitivity to drought-induced water stress, which is a key objective of the paper, and their impacts on household welfare under adverse rainfall conditions, measured in terms of the total harvest value and household income. This multidimensional approach allows us to unpack important trade-offs and complementarities between the climate risk reduction and profit maximization objectives that farmers navigate when adopting a particular adaptation practice. Finally, we complement the analysis by examining empirically the socio-economic and institutional factors that are associated with the adoption of these practices.

The results show that while a number of the practices considered are effective at reducing sensitivity to water stress, this benefit rarely translates into improvements in agriculture profitability and household income.

The remainder of the article is organized as follows. In the next section, background information is provided on the study location and the practices under consideration. In Section 3, a description of the conceptual model used in the paper is presented, which is followed by a description of the empirical strategy. Section 4 provides information on the data set and key variables used in the analysis, and provides descriptive evidence from the sample population. Section 5 presents the findings from the empirical on the impacts of the practices, followed in Section 6 with an analysis of the adoption determinants of the practice. Finally, in the last section, concluding remarks and policy implications are discussed.

2 Background

2.1 Study location

Anurādhapura District is located in the North Central Province and dry zone region of Sri Lanka. It is home to one of Sri Lanka's ancient capitals and has been an important centre of rice cultivation for thousands of years. It remains one of the most important rice producing districts in Sri Lanka, accounting for the largest share of paddy area extent of any district in the country (over 11 percent of the country's total rice area extent) and the second most number of producers, after the Ampara District (Department of Census and Statistics, 2019).

In Sri Lanka, agricultural production occurs under three primary water access systems. The first are the major irrigation systems. Major irrigation systems are those having a command area of more than 80 ha and where water supply comes from a major tank, a river or a major stream diversion.[1] In total, there are nearly 400 000 hectares of land under major irrigation in Sri Lanka, which is equivalent to 44.8 percent of the total extent of paddy land in the country. Of this, 30 619 hectares of major irrigated land are found in the Anurādhapura District. Second, are the minor irrigation systems, which have a command area of less than 80 ha and water is supplied by small tanks or stream diversions. Minor irrigated paddy lands cover 237 000 hectares of land in Sri Lanka, or roughly 27 percent of all paddy land. The Anurādhapura District has a high concentration of minor irrigated paddy land, covering a total of 56 111 hectares of land. Many of these minor systems have experienced reductions in tank capacity due to silting and drying up during dry seasons. Water stress risks are, therefore, often higher in these systems than major irrigation systems. Finally, there are rain-fed production systems, which are highly dependent on precipitation levels for cultivation. In Sri Lanka, 256 000 hectares of paddy land are managed under rain-fed conditions. In the Anurādhapura District, 16 000 hectares of land are classified as rain-fed paddy land (Shand, 2002).

Farm land in Sri Lanka is also distinguished by field type i.e. if the field is an upland or a lowland area. In most cases, farmers operate both upland and lowland fields. Upland fields are typically rain-fed or irrigated with agro-wells, lift-irrigation systems, and surface tanks (*Pathas*). The risk of agronomic water stress is, therefore, higher in upland fields, and production is mostly focused on crops other than rice. Paddy production is mostly concentrated in irrigated lowland fields, where water stress risks are driven by aggregate rainfall levels and the conditions of reservoir and canal systems.

Finally, variability exists between the dominant farming seasons. In Sri Lanka, there are two farming seasons, which are driven by two distinct monsoon rainfall patterns. The main cultivation season is known as *Maha* and occurs during the "north-east" monsoon, which begins in October and ends in March. The secondary monsoon and production season, known as *Yala,* begins in April and lasts until September (Zubair, 2002). A high spatial variability is observed for the onset of both the *Maha* and *Yala* seasons throughout the dry zone. Many Agro Ecological Regions (AERs) in the Dry Zone (and some AERs in the Intermediate Zone) do not have a

[1] Administratively, major irrigation systems are maintained by either the Department of Irrigation or Mahaweli Authority of Sri Lanka. This study distinguishes the areas in which irrigation water for farm activities is provided by the *Mahaweli* Development Project from other major irrigation systems. This is because Mahaweli is the largest multipurpose national development programme in Sri Lanka, and a number of peculiarities motivate the choice.

distinct *Yala* season. The *Yala* rains in the Dry Zone are highly variable and the most probable length of the season may not exceed four weeks. Rice cultivation during the *Yala* season is, therefore, increasingly infeasible in most rain-fed and some irrigated systems. During the *Maha* season, there is typically enough rainwater for paddy cultivation. However, dry periods within the *Maha* season routinely pose challenges to rice production, particularly in rain-fed and minor irrigation systems (Chithranayana and Punyawardena, 2014).

As a result, appropriate adaptive practices and levels of sensitivity to water stress are likely to vary between upland and lowland fields as well as between seasons and irrigation systems. Accordingly, the subsequent analysis disaggregates adaptation practices and water stress impacts between upland and lowland fields, and estimates the impacts of these practices during the *Maha* and the *Yala* season separately, while controlling for the type of irrigation system at the field level.

2.2 Farming practices to reduce water stress sensitivity

In Sri Lankan rice systems, there are a variety of practices that are promoted to help reduce the sensitivity of production to water stress, and to foster improved household welfare. As highlighted above, when and where these practices can be usefully adopted is likely to vary, depending on field type (upland or lowland), and season (*Maha* or *Yala*). Importantly, these practices also vary in terms of the relative intensities of land, labour, capital and knowledge they require to implement, and the potential risks they may entail to household welfare. This includes, among others, risks associated with market uncertainty and delayed or uncertain impacts on production.

We focus on six unique practices, which are disaggregated into 11 field type and season specific practices in the analysis (Table 1). In particular, we examine the following practices: (1) the adoption of short duration rice seed varieties on lowlands during the *Maha* and *Yala* seasons; (2) planting other field crops (OFC) on lowland fields during the *Yala* season; (3) planting maize on uplands during the *Maha* season; (4) retaining trees on lowlands during *Yala* and on uplands during both the seasons; *(5)* using soil erosion barriers on uplands during both the *Maha* and *Yala* seasons; (6) residue retention on lowlands during both the seasons. These practices were selected based on two criteria. First, these practices are included in policy frameworks and extension guidelines in Sri Lanka to support climate adaptation in the agricultural sector. Second, the adoption rates of these practices by farmers are reasonably high, implying that they are appropriate for rice production systems in the region. As a result, important drought adaptation practices such as alternate wetting and drying have been excluded as they are adopted only by a very restricted number of farmers in the study area. In the following paragraphs, each of these practices are briefly discussed in order to provide a better understanding of their potential impacts on water stress sensitivity and household welfare, as well as key factors required for effective adoption.

Table 1. Practices considered in the analysis

SEASON	FIELD	FARM PRACTICES
Maha	**Lowland**	Short duration rice seeds
		Improved residue retention
	Upland	Cultivating maize
		Agroforestry trees
		Soil erosion barriers
Yala	**Lowland**	Other crops in the field (OFC)
		Short duration rice seeds
		Agroforestry trees
		Improved residue retention
	Upland	Soil erosion barriers
		Agroforestry trees

Source: Authors' own elaboration.

The adoption of short-duration rice varieties is being promoted in Sri Lanka as a strategy to manage reductions in precipitation and increases in evapotranspiration, which may become particularly acute in the months of January and February under future climate scenarios (De Silva *et al*., 2007). In the study area, short duration varieties are widely adopted on lowlands in minor irrigation systems during *Maha* and by households in the major *Maha*weli system during the *Yala* season.

The cultivation of OFCs is an important adaptation strategy for water scarcity in Sri Lanka (Handawela *et al*., 1995). This strategy is emphasized in the National Climate Change Adaptation Strategy, which calls for diversification away from rice towards less water-intensive OFCs as a means of reducing the adverse impact of declining agricultural water availability (Imbulana *et al*., 2006). This is particularly the case during the *Yala* season, when irrigation water is not adequate for cultivation of rice over the entire command area and farmers are compelled to cultivate OFCs with less water demands in paddy fields. It is also common in upland, rain-fed fields in both *Maha* and *Yala* seasons. The crops cultivated as OFCs include chili, maize, green gram, cowpea, and onions. Maize has been specifically identified as a growth sector by the government of Sri Lanka, due in part to rising demand for animal feed, which has increased Sri Lanka's import requirements. We, therefore, treat this crop separately in the analysis. Crop diversification in paddy land can be more labour intensive than standard rice production techniques, mostly due to increased weed management (Burchfield and de la Poterie, 2018). Markets for these crops are also more volatile than rice markets and inputs more limited (Burchfield and de la Poterie, 2018). This is expected to reduce the welfare benefits of the practice. Moreover, this is likely to concentrate adoption among households with greater access to household labour, as well as households able to manage the risk of crop diversification through access to alternative non-farm income sources.

Intensive agroforestry practices, such as planting wind breaks or integrating leguminous tree species into farm systems, are not common in dry land system (Mahendrarajah, 2003). This is particularly true in lowlands, where agroforestry can compete with paddy field operations on the thin bunds between fields. However, retaining trees on fields is a common passive agroforestry strategy used by farmers to reduce soil moisture loss in crop fields and protect against winds (Kumara *et al*., 2002). This can provide some benefits for the farmer and is adopted by a wide range of farm households. For this reason, our analysis focuses on the impacts of trees already established in farmers' fields.

Establishment of soil erosion barriers to reduce runoff velocity is likely to affect the farmers' sensitivity to water stress in countries like Sri Lanka where the soil erosion hazard is high. Soil erosion risk in Sri Lanka is not only due to the actual magnitude of the erosion, but more importantly due to that the soils are dominated by a thin layer of reddish brown earth that sit atop a layer of gravel (International Union for Conservation of Nature , 2016). As a result, even a small amount of erosion rapidly degrades the productivity of soil. In addition, many interrelated socio-economic factors such as fragmentation of lands due to increase in population, and encroachment into sensitive crown lands have also contributed to soil erosion (Nayakakorale, 1998). Establishment of soil erosion barriers in Sri Lanka can be observed only in uplands. Establishing soil erosion barriers, especially mechanical ones, is a labour-intensive practice, and is therefore expected to be more widespread among farmers with greater labour endowments or less opportunity for off-farm income activities. The government of Sri Lanka, over the last two decades, gives subsidies for farmers to establish multipurpose contour bunds in their own uplands, and recommending the cultivation of the bunds with some perennials like moringa, lemon, or pomegranate to preserve bunds while contributing to household income.

The retention of crop residues or use of mulch are practiced to reduce soil moisture evapotranspiration and to build up soil organic matter over time. Most rice producers in Sri Lanka practice some form of residue retention on their lowland fields. Mulching and residue retention generate the highest benefits during low rainfall conditions, and may have minimal direct impacts on yields under normal conditions. Residues on many Sri Lanka paddy fields are retained owing to combine harvesting, which leaves residues in the field. However, this practice can be improved by adding urea or water to hasten decomposition. Because basic residue retention is practiced on the vast majority of paddy fields, the analysis focuses specifically on "improved residue management strategies". Furthermore, as the effects of the practice on the soils are expected to accrue after multiple years of consecutive adoption, this analysis further restricts the pool of adopters to those that have retained residues in the field for five consecutive years.

3 Conceptual framework: linking water stress sensitivity, household welfare, and adaptation choices

Our conceptual framework seeks to account for the complex interplay between household-level socio-economic characteristics, the factor intensities and biophysical attributes of the farming practices, and heterogeneous production environments within which they are implemented (upland/lowland fields, *Maha/Yala* seasons, and irrigation system).

Our starting point is that climate change in Sri Lanka's rice systems will influence the probability distribution of experiencing low rainfall conditions (Burchfield and de la Poterie, 2018; Kim *et al*., 2013; Lobell *et al*., 2011), and therefore will increase the risk of crop loss due to water stress (Madduma Bandara and Wickramagamage, 2004; De Silva *et al*., 2004). As farmers' perceptions of climate risk change, the expected utility derived from the adoption of practices to mitigate this risk increases (Deressa *et al*., 2009). However, while farmers seek to maximize their utility through farm practice choices, they face a utility optimization problem, as they are unable to predict if, in any given season, a drought will occur. This optimization problem is further confounded by uncertainties and opportunity costs associated with climate adaptation practices themselves and the alternative risk management strategies households have at their disposal.

Whether or not the adoption of a practice promoted to reduce sensitivity to water stress achieves this objective, relative to conventional rice production practices, depends on a wide range of factors. This includes how well the practice was implemented, the duration of implementation, and the appropriateness of the practice to the local environment, among many others (Esham and Garford 2013; Imbulana *et al*., 2006). We therefore anticipate that not all practices considered in this analysis will have a measurable impact on water stress sensitivity.

Moreover, even if the adoption of a practice does reduce the sensitivity of a system to water stress, this may not necessarily contribute to improvements in economic welfare gains relative to non-adopters (Barrett *et al*., 2001a, 2007; Reardon *et al*., 1998). There are several reasons for this. First, the choice to adopt one practice over another entails trade-offs between the allocations of production factors and their opportunity costs. For example, the choice to adopt a labour-intensive adaptation practice, such as building and maintaining erosion control structures, will divert labour away from other income opportunities. In Sri Lanka, where off-farm income sources are often more remunerative than farm activities, the opportunity costs of this investment choice are potentially high (Deininger *et al*., 2007). If the positive effect on water stress sensitivity is not sufficient to compensate for reductions in off-farm income resulting from this investment choice, the net income effect of the practice will be negative relative to those not adopting. Second, trade-offs can also exist between the overall impact of a practice on productivity and its impact on reducing water stress sensitivity. For example, some practices can reduce losses from wilting, but may also reduce overall productivity by lower planting densities or increased weed pressure relative to alternative practices. Finally, practices that entail changes in cropping systems, for example the adoption of more drought tolerant crops, may reduce sensitivity to water stress, but also expose farmers to more thinly traded, less competitive market conditions than those in rice markets.

In order to effectively evaluate the impacts of the practices considered, our empirical approach must, therefore, distinguish between the welfare impacts of adopting a specific practice that are derived indirectly through a reduction in water stress sensitivity from those obtained directly through other channels such as productivity and factor allocations. The combination of these two impact pathways shapes the net impact of the practice. Disentangling these two impact pathways provides insights into the complementarities and trade-offs between the objectives of increasing the climate resilience and improving household livelihood conditions.

The final element of our conceptual framework seeks to understand factors associated with the adoption of the adaptive practices under consideration. In the context of partial or incomplete markets, where production choices are linked to consumption outcomes, as is the case for many producers in Sri Lanka, investments that reduce risk are often prioritized over profitability maximizing activities (Holden and Bingwanger, 1998). This is further conditioned by a range of socio-economic and institutional factors, which affect households' ability and willingness to cope with production related risks, and their capacity to allocate production factors to a practice, relative to alternative investment options. For example, larger households are likely to be in a better position to invest in labour intensive practices. Conversely, wealthier households may be in a better position to adopt capital intensive practices, or higher risk practices, than poorer households. Given the heterogeneity of practices considered in this analysis, we anticipate that the socio-economic and institutional factors associated with their adoption will be diverse, and will be linked to the underlying characteristics of the practices, which may also vary spatially (upland/lowland fields) and temporally (*Maha/Yala* seasons). Our empirical approach must account for this heterogeneity, in order to reduce concerns over endogeneity due to self-selection into the treatment and to identify the constraints and the barriers to the adoption of practices.

These characteristics include farmers' human capital endowments (education) and physical assets (land, wealth, and livestock), which influence the propensity of households to adopt practices with different capital, land, or labour factor intensities. In addition, variations in off-farm income earning opportunities [2] and their associated effects on the opportunity costs for household labour are likely to be important (Deininger *et al.*, 2007). Farm households that derive a large share of their income from off-farm sources are in a better position to invest in capital intensive farm technologies and practices and are relatively less prone to adopt relative labour-intensive practices. Moreover, access to off-farm income may, in principle, help to spread the livelihood risks associated with climate or market induced volatility in the farm sector. The type and share of irrigated land controlled by a household is also a potential determinant in the choice of adaptation strategy, as this mediates the relative risk of water stress a household is exposed to. Finally, access to institutional support systems such as input subsidies, concessionary production loans, and insurance is also likely to shape heterogeneous adaptive strategies among the farmers. These programmes mediate farmer's risk expose and thus their propensity to adopt risk mitigating practices. Our empirical strategy must therefore account for these factors to reduce sources of potential bias in our analysis.

[2] Off-farm opportunities are particularly relevant in Sri Lanka as they produce approximately 80 percent of agricultural GDP (Deininger *et al.*, 2007).

4 Estimation strategy

The estimation procedure used in this analysis relies on an inverse weighted probability simultaneous equations model. This approach is expected to address selection bias through a doubly robust estimation procedure of the effects of adopting a specific adaptation strategy on sensitivity to water stresses, measured as the probability of experiencing crop wilting, and two welfare indicators (Hirano, Imbens and Ridder, 2003; Bang and Robins, 2005), namely the total value of the harvest and gross household income.

4.1 Addressing self-selection to measure the effect of adopting the practices on the water stress sensitivity

As self-selection into the climate adaptation treatment is hypothesized to be dependent on observable characteristics mentioned above, weights for these variables have been obtained using the propensity score method proposed by Rosenbaum and Rubin (1983). In our framework, each treatment regime has been defined with a binary variable T which is equal to 1 if the household adopts the strategy and 0 otherwise. Participation into the treatment is estimated using the vector of pre-exposure characteristics W, including all the determinants discussed in the conceptual framework. Subsequently, the predicted probabilities have been inverted and normalized[3] to obtain a vector of weights, w, for the sub-sample of households on *common support*.

Formally the probability of treatment given the pre-exposure covariates is:

$$e(W) = P(T = 1|W) = E\{I(T = 1)|W\} = E(S|W)$$

This has been modelled using a binomial logit function such that:

$$P(T = 1|W) = (W, \beta) = \frac{\exp(\beta_0 + W^T \beta_1)}{1 + \exp\,(\beta_0 + W^T \mathrm{B}_1)}$$

The intuition behind this approach is that, instead of using the difference of simple averages between treated and control, the treatment effect, Δ , is estimated by the difference of the inverse propensity score weighted average:

$$\widehat{\Delta_{IPW}} = n^{-1} \sum_{i=1}^{n} \frac{T_i Y_i}{e(X_i, \widehat{\beta})} - n^{-1} \sum_{i=1}^{n} \frac{T_i Y_i}{1 - e(X_i, \widehat{\beta})}$$

[3] The normalization of the vector of weights relaxes the concerns on the finite sample performance of the inverse probability weighting (IPW) methods, reducing the variance of the estimated treatment effect due to extreme weights (Chiba, 2018).

4.2 Estimate the direct, the indirect (via water stress sensitivity) and the net impact of each selected practice on different welfare outcomes

Once having estimated the normalized inverse probability weights, the empirical strategy consists of a simultaneous estimation of a weighted system of partially recursive equations.[4] Empirically, the re-weighting procedure creates a pseudo-population in which measured confounders can be equally distributed between treatment and comparison groups, thus relaxing concerns of endogeneity. Furthermore, the simultaneous estimation of the two outcome equations is expected to accommodate the correlation among the error terms, and to control for a wide set of additional covariates. This doubly robust procedure ensures the consistency of the estimator even when either the propensity score model or the regression model are incorrectly specified, thus addressing an important challenge with propensity score models. (Robins *et al.*, 1994).

In particular, as sensitivity to water stresses is assumed to be a latent variable, S_i^*, it is proxied by an observed binary outcome S_i which is equal to 1 when farmers harvest an area smaller than the area planted because of wilting and 0 otherwise,

$$S_i = \begin{cases} 1 \; if \; S_i^* > 0 \\ 0 \; otherwise \end{cases}$$

The weights are integrated into the simultaneous linear estimation of the following system of two equations[5]:

$$\begin{cases} \mathrm{S_{I,j}} = \beta_0 + \beta_1 \mathrm{T_{ij}} + \beta_i \mathrm{X_{1i}} + \mathrm{u_{1\,I,j}} \\ \mathrm{Y_{I,j}} = \beta_0 + \beta_1 \hat{\mathbf{S}}_{\mathrm{I,j}} + \beta_2 \mathrm{T_{I,j}} + \beta_i \mathrm{X_{2i}} + \mathrm{u_{2\,I,j}} \end{cases}$$

where, S_{ij} represents the observed proxy for sensitivity of the household i due to the adoption of the practices j; T_{ij} is a dummy variable that is equal to 1 if the household i adopts the practice j, and zero otherwise, X_{1i} is a vector of exogenous household and farm characteristics, and $u_{1\,i,j}$ represents the random error term that is assumed to be uncorrelated with the explanatory variables but correlated with the error term $\mathrm{u_{2\,I,j}}$ of the second equation of the system. Moreover, $\mathrm{Y_{I,j}}$ is the selected welfare outcome for the household i depending on the estimated sensitivity to water shock $\hat{\mathbf{S}}_{\mathrm{I,j}}$, the direct effect of the adoption of the practice $\mathrm{T_{I,j}}$ and a vector of household characteristics $\mathrm{X_{2i}}$, including all the household variables included in X_{1i} but excluding field level ones (in order to insure identification of the system).

This estimation procedure allows for a mediation analysis, since it is able to test the indirect effect of the adoption of practices on the welfare outcome through the impact on a mediator

[4] The tables and the figures containing the diagnostic and the tests of the balancing properties of the inverse weighted samples of the treated and controls are fully reported in the Annex 2.

[5] We acknowledge that using a linear estimator for both the equations regardless of the binary nature of the variable proxing the farmers' sensitiveness to water shock is a second-best choice. This was chosen to facilitate the decomposition of the net treatment effect in the two constituting components (direct and indirect). However, in order to test the robustness of the results, a specification considering the binomial nature of the dependent variable in the first equation has also been estimated. The results are largely in line with those presented for this analysis and are available upon request.

variable, which is the water stress sensitivity dummy. It, therefore, enables us to disentangle the direct impact of the adoption on welfare (which is the partial derivative of the welfare outcome relative to the adoption of the practice $\frac{\Delta Y_j}{\Delta T_j}$) from the indirect impact through the sensitivity (which is given by the product by the partial derivative of the welfare outcome relative to the estimated sensitivity and the partial derivative of the sensitivity relative to the adoption of the practice $\frac{\Delta Y_j}{\Delta \hat{S}_j} * \frac{\Delta S_j}{\Delta T_j}$). Finally, the net effect is given by adding the impacts through the direct and indirect channels (i.e. $\frac{\Delta Y_j}{\Delta \hat{S}_j} * \frac{\Delta S_j}{\Delta T_j} + \frac{\Delta Y_j}{\Delta T_j}$ which also corresponds with the partial derivative of the welfare outcome relative to the adoption of the practice into a reduced form specification).

4.3 Estimation of the determinants and the barriers to the adoption of adaptive strategies

In order to investigate the barriers and the determinants to the adoption of each adaptive practice, the farm household is modelled within a random utility framework in which farmers decide to adopt a specific practice if the expected utility from adoption is higher than any other available alternative. We derive the choice of adopting an adaptive practice from a latent variable model. Assuming that the latent variable U_j is the utility difference between the treatment and the alternative, farmers select an adaptive strategy when the expected utility from adoption is higher than that from alternative strategies.

Formally, the adoption model is:

$$T_{ij}^* = X_i\beta_i + v_{ij}, j = 1, \dots, J \; and \; i = 1, \dots, N$$

where T_{ij}^* is a latent variable capturing the demand and/or preference of farm household i for the strategy *j*, X_i is a vector of field and household sociodemographic, infrastructural and institutional characteristics affecting the adoption of the strategy *j*; and v_{ij} is a stochastic error term (Kassie *et al.,* 2013). We assume that the latent variable T_{ij}^* is the utility difference between adopting a practice or not, and if the difference is positive the farmer would adopt the practice in question. This latent variable is proxied by the following observed binary outcome T_{ij} which is

$$T_{ij} = \begin{cases} 1 \; if \; T_{ij}^* > 0 \\ 0 \; otherwise \end{cases}$$

Similar to the model used to estimate the weights in the previous section, the probability of the treatment has been modelled using a binomial logit function such that:

$$P(T = 1|X) = (X, \beta) = \frac{\exp(\beta_0 + X^T\beta_1)}{1 + \exp\,(\beta_0 + X^T \mathrm{B}_1)}$$

In this exercise the estimated values are not used to establish a causal relationship between the treatment and an outcome variable. However, we include a larger number of potential explanatory variables in vector X_i, among which several can be conceivably assumed to be pre-existent and/or exogenous to the adaptive practice.

5 Data sources

The analysis takes advantage of a unique dataset of rice producing households in Anurādhapura District, Sri Lanka. The data were gathered as part of a joint effort between the Economic and Policy Analysis of Climate Change unit of the Food and Agriculture Organization of the United Nations (FAO) and the Environmental and Water Resources Management Division of Hector Kobbekaduwa Agrarian Research and Training Institute (HARTI). In total, 1 100 rice producing households were interviewed using a sampling procedure that ensures representativeness of the rice producing population in the Anurādhapura District. More details on the sampling can be found in Annex 1.

The dataset is multilevel, and includes modules at the household, individual, field, activity, and crop level. At field level, detailed information on all the plots owned or used by the household during the 2017/18 agricultural year, including owned cultivated parcels, sharecropped or rented parcels, and other pieces of land (such as home gardens, orchards, fallow fields, virgin lands) were collected. To capture variations in seasonal practices, the questionnaire contains separate modules for the 2017/2018 *Maha* season, the 2018 *intermediate* season, and the 2018 *Yala* season. The questionnaire distinguishes lowlands from uplands, and captures specific seasonal information on agricultural activities, from land preparation to harvesting[6].

[6] A complete summary of the descriptive data is presented in Annex 2.

6 Empirical results: impacts of practices on sensitivity to water stress and household welfare

In this section we examine the impacts of adopting the identified practices on water stress sensitivity, value of harvest and household income, while differentiating between the direct, indirect, and net impacts of the practice on the welfare indicators. Table 2 reports only the estimated marginal effects of each selected adaptive strategies.[7] Of the 11 field and season specific practices considered, five are found to significantly reduce sensitivity to water stress. Farmers using short-duration seeds on lowland fields during *Yala* are about 5 percent less likely to experience production loss due to wilting than non-adopters, controlling for other factors. Growing other field crops reduces sensitivity to water stress by 10 percent on lowlands during *Yala*, relative to households growing only rice. All else equal, trees retained on lowland fields reduce the water stress sensitivity by 7 percent during *Yala*, relative to fields without trees. Finally, retaining the residues on lowland fields during *Maha* for at least five agricultural years, and enhancing their decomposition rate by adding water or urea, decreases water sensitivity of about 15.5 percent relative to fields where traditional residue retention is practiced.

Despite the positive impacts of the practices on reducing water stress sensitivity, the welfare impacts of the practices are more limited. Only one practice is found to generate positive indirect effects on the value of crops harvested. In particular, cultivating other crops on uplands during *Maha* statistically significantly increases the total value of harvest by 12.7 percent. However, these indirect effects do not translate into a statistically significant positive net-effect on the outcome. Weakness in markets for other field crops may explain why reduced sensitivity to water stress does not lead to a net improvement in value of crops harvested.

Planting short duration rice seeds on lowland fields during *Yala* is found to increase the overall value of the harvest (+21.7 percent), relative to other seed maturation lengths. Similarly, adoption of improved residue retention methods on lowlands during *Maha* produce a positive net effect on the value of crops harvested (+54.4 percent), as does the adoption of soil erosion control structures in upland *Yala* fields (+33.4 percent), relative to non-adopters. In these three cases, both the direct and indirect effects are not significantly different from zero. However, when measured jointly the positive effect is statistically significant. This is likely to arise from synergies between the direct and indirect effects that, when combined, produce an overall positive net income effect.

An important trade-off emerges from farmers cultivating crops other than rice during the *Yala* season. The results show that the gain in terms of a reduction in sensitivity to water stress (-9.8 percent) is also associated with a significant loss of the total value of the harvest (-36.3 percent). This finding, again, is likely associated with challenges in markets for other field crops, which are characterized by significant price volatility and uncertainty (Jayawardene and Weerasena, 2001).

[7] The complete results for each model estimated are reported in Annex 4.

Table 2. Summary table of the main results from the impact assessment

	Sensitivity	Direct effect	Indirect effect	Net effect	Direct effect	Indirect effect	Net effect
		Total value of harvest			Gross total income		
Short duration rice seeds (low-*maha*)	-0.008	0.019	0.018	0.037	-0.007	0.005	-0.002
Short duration rice seeds (low-*yala*)	-0.052*	-0.181	0.398	0.217	-0.306	0.379	0.073
Other crops in the field (low/*yala*)	-0.098***	-0.155	-0.208	-0.363*	-0.091	0.063	-0.028
Cultivating maize (up/*maha*)	0.049	-0.137	-0.08	-0.217	0.096	-0.032	0.065
Retaining trees (up-*maha*)	0.051	-0.154	-0.071	-0.225	0.06	-0.029	0.031
Retaining trees (low-*yala*)	-0.066*	-0.418	0.421	0.003	0.315	-0.396	-0.081
Retaining trees (up-*yala*)	-0.002	-0.114	0.004	-0.11	-0.026	0.003	-0.023
Soil erosion barriers (up-*maha*)	0.037	-0.042	-0.067	-0.109	0.131	-0.017	0.114
Soil erosion barriers (up-*yala*)	-0.053	0.236	0.097	0.334**	0.023	0.065	0.088
Residues retention [+5yrs and wat/urea] (low-*maha*)	-0.156**	0.274	0.27	0.544***	-0.105	0.192*	0.088
Residues retention [+5yrs and wat/urea] (low-*yala*)	0.028	0.474***	-0.033	0.441***	0.185**	-0.01	0.175*

Notes: It is worth highlighting that the doubly robust IPW results represent the average treatment effect (ATE) i.e. the effect that would have been observed had the entire population been treated. The causal interpretation and the comparability of the empirical findings rely on the traditional assumptions of "strong ignorability" and stable unit treatment value assumption (SUTVA) characterizing the empirical procedure based on the propensity score as they are limited to the overlapping cases i.e. the observations on the common support.

Source: Authors' own elaborations. Notes: Level of significances are * p<0.10; ** p<0.05; ***p<0.01.

Finally, the adoption of improved residues retention methods is found to both directly affect the value of harvest (+47.4 percent) on lowland fields during *Yala* the overall value of harvest (+44.1 percent), but no indirect welfare impacts. It is important to note that conventional residue retention is widespread in Sri Lanka. Therefore, these results show the impact of improved residue management practice relative to conventional practices. Thus, while improved residue practices do not produce impacts on sensitivity, relative to conventional practices, they do contribute to increases in direct and net welfare impacts, likely through improvements in productivity.

The generally positive picture found in the analysis of the total value of harvest changes when the focus is shifted to total gross income. The mismatch between the two measures is likely due to the labour intensiveness of many of the practices considered, which diverts labour from off-farm income generating activity. Importantly, none of the practices affecting sensitivity to water stresses produce a significant positive net-effect on gross household income variable. The implementation of improved residues retention methods on lowlands during *Yala* is the only practice found to increase the gross income (+17.5 percent), although, the positive effect appears to stem from a direct effect on yield (+18.5 percent) and not through reduced wilting. The results show that only the adoption of improved residue retention on uplands during *Maha* (+19.2 percent) have positive indirect effects on gross income. However, this does not translate into an overall increase in household income.

These findings highlight the challenges faced in Sri Lanka in terms of addressing emerging climate vulnerabilities, which are likely to become more pronounced in the future. The results show that current practices that are promoted to reduce drought sensitivity, and which are adopted by a non-trivial number of farmers in the Anurādhapura District, are not translating reductions in water stress sensitivity into measurable welfare gains, particularly in terms of gross income.

7 Adoption determinants of selected practices

In this section the factors associated with the adoption of each adaptive strategy are explored, focusing specifically on those practices that were found to reduce sensitivity to water stress.[8] The results, although relevant in themselves, can be also used to shed more light on the findings arising from the previous analysis.

Table 3. Adoption determinants of practices affecting sensitivity to water stress

Variables list	Improved residues retention on lowlands Maha	Short duration rice seeds on lowlands Yala	Other crops in the field on lowlands Yala	Retaining trees on lowlands Yala	Manual direct seeding methods on uplands Maha
Gender of HH head (1=female)	0.04	0.001	-0.06	0.07	-0.27***
Age of HH head	-0.001	-0.001	-0.001**	0.001	-0.001
Highest education of HH head	-0.001	-0.001	0.001	0.01	-0.001
HH family size	-0.01	0.03	0.03**	0.01	-0.02
Field area	-0.001	0.01	-0.01	-0.001	0.01
Normalized ag asset wealth index (0–1)	-0.12	-0.26	0.42**	0.17*	-0.16
HH raised or owned livestock	-0.04	0.04	-0.07	0.02	0.01
Sole ownership of largest field	-0.08***	-0.09**	0.04	-0.02	0.02
Total field area under agro-wells (acres)	0.01**	-0.01	-0.001	-0.02	-0.01
Off-farm head's primary employment	0.05	-0.05	-0.04	-0.05	0.01
Subsidy for fertilizers or other input	-0.001	0.01	-0.21***	0.05	0.05
HH received food aid	-0.001	-0.08*	0.03	-0.04	0.07
HH received a loan for ag. activity	-0.06**	-0.06	0.03	0.03	0.01
Crop insurance scheme	-0.04	0.07*	-0.07	-0.03	0.02
Receives information from public source	0.08**	-0.01	0.001	-0.03	0.04
Tractors rented	-0.02	-0.001	0.07	0.02	-0.13**
Input from commercial sources	0.05	-0.04	0.05	-0.001	0.33***
Commercialization Index: other crops	-0.05	0.03	-0.27***	-0.05	0.01
Log. distance (km) to ASC	-0.03	0.02	0.001	0.05***	0.02
Log. distance (km) to marketplace	-0.01	0.02	0.01	0.001	0.01
Log. distance (km) to fertilizers retailer	0.03*	-0.05**	0.01	-0.03**	-0.02
Share of land that is irrigated	-0.02	0.28***	-0.15	0.06	0.01
Irrigation: Major	-0.06	2.03***	-0.01	-0.26**	-0.07
Irrigation: Minor	-0.07	2.14***	-0.12	-0.24***	0.01
Irrigation: *Maha*weli	-0.01	2.16***	-0.07	-0.21**	0.06
FO leave-out mean of adoption	-0.33***	0.31***	0.48***	0.05	0.41***
Observations	707	427	426	427	513

Source: Authors' own elaborations. Notes: Level of significances are * p<0.10; ** p<0.05; ***p<0.01.

[8] The results for each of the practices analysed are available in Annex 4.

The first notable result in Table 3 is that the factors explaining adoption are highly specific to the practice selected. We argue that this reflects the interplay between the factor intensities of the practices and the factor endowments of the households. As shown in Table 3, the gender of the household head is found to reduce the probability of cultivating other crops on upland during *Maha*, holding other factors constant. This is likely driven by structural inequalities between men and women in terms of mobilizing labour and accessing capital required to adopt these practices. Similarly, the age of the head of household is found to be negatively associated with the adoption of other field crops in *Yala* lowland fields. Taken together, the results show that where diversification into other field crops is occurring, it is driven primarily by younger and male headed households. In addition, cultivation of other field crops in the uplands during *Maha* are positively associated with the level of education. This suggests that the promotion of crop diversification is not limited only by capital and labour, but is also knowledge intensive.

Family size is a proxy for household labour. The results show a positive association between family size and crop diversification on lowlands during *Yala.* These findings highlight the importance of addressing labour constraints in order to achieve widespread adoption of this practice. On the one hand, the results show that more labour endowed households are more likely to diversify their lowland fields in the *Yala* season. On the other hand, the results also illuminate why reductions in sensitivity to water stress associated with growing crops other than rice do not translate into measurable indirect welfare effects, as diversion of labour to this practice likely undermines positive welfare benefits.

Rural assets availability, proxied by the normalized wealth index, increases the probability of adopting crop diversification and retaining trees on lowland fields. This finding highlights the importance of resource endowments to manage the costs and risks of adopting these practices. Interestingly, an increase in asset endowments is associated with a reduced probability of cultivating other crops on the uplands during *Maha*. This indicates that wealthier farmers, who may have lower subjective risk levels, are less likely to diversify their production during the *Maha*, and instead are more likely to concentrate their efforts on lowland rice production.

The extent of the land owned with access to agro-well irrigation is positively related with the probability of improved crop residues management on lowlands during *Maha*. Although agro-wells are concentrated in upland fields, they do also exist in lowland fields. Access to supplemental lowland irrigation through agro-wells is likely driving this effect. Water supply to irrigation schemes is typically reduced or turned off after the harvest. Farmers with agro-wells in their fields are able to access irrigation water to apply to their crop residues even when water from irrigation schemes is not available.

Fertilizer and/or other input subsidies reduce the probability of crop diversification on lowlands during *Yala*. Although subsidies are given to both rice and other field crop producers in lowlands, the results suggest that the subsidies are associated with increased incentives for rice cultivation.

The results also show that a range of risk management tools – food aid, access to credit and crop insurance – reduce the probabilities of using short duration rice seeds on lowland during *Yala* and improved residues retention methods on lowlands during *Maha*. These results suggest that when formal risk mitigation instruments are available, farmers are less prone to invest labour and capital into these farm level climate adaptation strategies. Public extension information, by contrast, is found to increase the probability of adopting improved residue management strategies.

One of the most meaningful results to explain the trade-offs between water stress sensitivity reduction and welfare outcomes is related to the commercialization index of other field crops. The index is calculated as a ratio between the value of these crops sold and the total value of these crop harvested. Higher index values indicate greater levels of commercialization. The negative association with the probability of crop diversification on lowlands during *Yala* may appear paradoxical. It suggests that farmers who are more likely to diversify into other crops are less able to commercialize these crops. This result supports the interpretation that market weaknesses for other field crops influence the lack of positive welfare impacts from diversification. Moreover, it highlights the trade-offs farmers make under current market arrangements between adopting diversification to reduce water stress sensitivity and maximizing returns through commercialization.

The availability of water, captured through the share of irrigated land and the irrigation type, is associated with the adoption of short duration rice seeds on lowlands during *Yala*. This relationship is likely driven by the fact that rice production during the *Yala* season is of short duration and is concentrated in irrigated farm systems. Conversely, farmers in rain-fed systems are more likely to retain trees on these fields, likely because these systems are not constrained by thin bunds between fields that limit space in irrigated systems.

Finally, it is worth highlighting the existence of substantial peer effects within farmers' organizations for almost all of the practices. In particular, with the only exceptions of improved residues retentions methods on lowland during *Maha* and having trees on the lowland fields during *Yala*, the greater is the share of farmers within a farmers' organization adopting the practice, the more likely is a household to also adopt the practice. Leveraging these positive peer effects through group level extension approaches can generate positive adoption impacts. The negative peer effect associated with improved residues retention method on lowlands during the *Maha* season may be due to limitations on the availability of water within farm organizations, which may in turn affect the ability of other farmers in the organization to apply water to residues. Further investigation on this finding are crucial as this adaptive strategy is the only one that has proven to reduce the water stress and increase the total value of the harvest through this channel.

8 Conclusions

This paper shows that only two of the 11 practices adopted by farmers and included in this analysis, namely improved residue retention methods on lowland during *Maha* and short-duration rice seeds on lowlands during *Yala*, simultaneously reduce water stress sensitivity and increase the value of total harvest. None of the practices considered are simultaneously associated with a significant effect on water stress sensitivity reduction and increased total household income.

The reasons for this vary by practice. In some cases, the high investment in terms of labour allocation associated with the practice create significant opportunity costs for farmers. A farm that dedicates labour to these practices gives up off-farm income opportunities, which may negate the positive benefits of the practice. In these cases, identifying options to replace labour with capital, through the development of service markets or mechanization options, will help to improve overall welfare outcomes. In other cases, such as with other field crops, thin and non-competitive markets help to explain why planting crops that are less sensitive to water stress does not lead to a significant improvement in crop or household income relative to those not planting these crops. In these cases, value chain support and other improvements in marketing arrangements may be necessary.

Ultimately, these results highlight the challenges faced by Sri Lanka's extension services and agricultural research institutions. They demonstrate that developing and promoting practices and technologies that reduce the adverse impacts of water stress and other climate related risks is necessary, but not sufficient to achieve widespread adoption, and more profitable and productive farm level outcomes. To be effective, these interventions must be developed with a focus on the needs of farmers and the constraints to capital, markets, and labour they face. To address this challenge, research and extension must look beyond field experiments and trials, and explore options to bundle together the promotion of better practices with complementary support to market institutions, such as appropriate mechanization services, value chain support for other field crops, and input supply systems. In this way, farmer friendly packages of technologies that support climate risk reduction and lead to more profitable farm-level outcomes can be developed.

References

Bandara, J.M.R.S. 2007. *Nature Farming: Integration of traditional knowledge systems with modern farming in rice*. Leusden, ETC/COMPAS.

Burchfield, E.K. & de la Poterie, A.T. 2018. Determinants of crop diversification in rice-dominated Sri Lankan agricultural systems. *Journal of Rural Studies*, 61: 206–215.

Bambaradeniya, C.N.B., Edirisinghe, J.P., De Silva, D.N., Gunatilleke, C.V.S., Ranawana, K.B. & Wijekoon, S. 2004. Biodiversity associated with an irrigated rice agro-ecosystem in Sri Lanka. *Biodiversity & Conservation*, 13(9): 1715–1753.

Chithranayana, R.D. & Punyawardena, B.V.R. 2014. Adaptation to the vulnerability of paddy cultivation to climate change based on seasonal rainfall characteristics. *Journal of the National Science Foundation of Sri Lanka*, 42(2).

De Silva, C.S., Weatherhead, E.K., Knox, J.W. & Rodriguez-Diaz, J.A. 2007. Predicting the impacts of climate change: A case study of paddy irrigation water requirements in Sri Lanka. *Agricultural Water Management*, 93(1–2): 19–29.

Deininger, K., Jin, S. & Sur, M. 2007. Sri Lanka's rural non-farm economy: Removing constraints to pro-poor growth. *World Development*, 35(12): 2056–2078.

Department of Census and Statistics (DCS). 2019. Paddy extent statistics. In: *DCS* [online] Sri Lanka [Cited November 2019] www.statistics.gov.lk/agriculture/Paddy%20Statistics/PaddyStats.htm

Deressa, T.T., Hassan, R.M., Ringler, C., Alemu, T. & Yesuf, M. 2009. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, 19(2): 248–255.

Economic and Social Commission for Asia and the Pacific (ESCAP). 2010. *Economic and Social Survey of Asia and the Pacific. Sustaining Recovery and Dynamism for Inclusive Development.* Bangkok.

Esham, M. & Garforth, C. 2013. Agricultural adaptation to climate change: insights from a farming community in Sri Lanka. *Mitigation and Adaptation Strategies for Global Change*, 18(5): 535–549.

Ford, J.D., Keskitalo, E.C.H., Smith, T., Pearce, T., Berrang-Ford, L., Duerden, F. & Smit, B. 2010. Case study and analogue methodologies in climate change vulnerability research. *Wiley Interdisciplinary Reviews: Climate Change*, 1(3): 374–392.

Handawela, J. & Kendaragama, K.M.A. 1995. *Soil management for rain-fed farming on Alfisols in Sri Lanka*.

Howden, S.M., Soussana, J.F., Tubiello, F.N., Chhetri, N., Dunlop, M. & Meinke, H. 2007. Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences*, 104(50): 19691–19696.

Howell, K.R., Shrestha, P. & Dodd, I.C. 2015. Alternate wetting and drying irrigation maintained rice yields despite half the irrigation volume, but is currently unlikely to be adopted by smallholder lowland rice farmers in Nepal. *Food and Energy Security*, 4(2): 144–157.

Imbulana, L. 2006. Integrated Water Resources Management: Global Theory, Emerging Practice and Local Needs. In L. Imbulana, P.P. Mollinga, A. Dixit & K. Athukorala. *Water allocation between agriculture and hydropower: A case study of Kalthota irrigation scheme, Sri Lanka,* pp. 219–248.

International Union for Conservation of Nature (IUCN). 2016. *Conservation of soil resources.* IUCN programme on Restoring Traditional Cascading Tank Systems Technical Note No. 6. Colombo: 52.

Kim, H.Y., Ko, J., Kang, S. & Tenhunen, J. 2013. Impacts of climate change on paddy rice yield in a temperate climate. *Global Change Biology*, 19(2): 548–562.

Kumara, A.D.S. & Bandara, D.C. 2002. Effect of nitrogen fertilizer on yield and quality parameters of three sugarcane varieties. *Tropical Agricultural Research*, 14: 117–127.

Lobell, D.B., Schlenker, W. & Costa-Roberts, J. 2011. Climate trends and global crop production since 1980. *Science*, 333(6042): 616–620.

Madduma Bandara, C.M. & Wickremagamage, P. 2004. Climate change and its impact on upper watersheds of the hill country of Sri Lanka. Proceedings of the International Conference on Sustainable Water Resources Management in Changing Environment of the Monsoon Region, 2004, Colombo.

Mahendrarajah, E.S. 2003. Agroforestry as a Means of Alleviating Poverty in Sri Lanka. Proceedings from the XII World Forestry Congress, 21–28 September 2003, Québec, Canada.

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. & White, K.S., eds. 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge, UK, Intergovernmental Panel on Climate Change, Cambridge University Press.

Moser, C.M. & Barrett, C.B. 2002. The system of rice intensification in practice: Explaining low farmer adoption and high disadoption in Madagascar. In H. Bouman, B. Hengsdijk, P.S. Bindraban, T.P. Tuong & J.K. Ladha, eds. *Water-Wise Rice Production*, pp. 103–118. Proceedings of the International Workshop on Water-wise Rice Production, 8–11 April 2002, Los Baños, Philippines, International Rice Research Institute.

Nayakakorale H.B. 1998. Human induced soil degradation status in Sri Lanka. *Journal of the Soil Science Society of Sri Lanka*, 10: 1–35.

Reidsma, P., Ewert, F., Lansink, A.O. & Leemans, R. 2010. Adaptation to climate change and climate variability in European agriculture: the importance of farm level responses. *European Journal of Agronomy*, 32(1): 91–102.

Rosenbaum P.R. & Rubin D.B. 1983. The central role of the propensity score in observational studies for causal effects. *Biometrika*, 70(1): 41–55.

Shand, R. 2002. *Irrigation and Agriculture in Sri Lanka.* Colombo, Institute of Policy Studies.

Smit, B. & Skinner, M.W. 2002. Adaptation options in agriculture to climate change: a typology. *Mitigation and Adaptation Strategies for Global Change*, 7(1): 85–114.

Thibbotuwawa, M. 2010. Better Targeting of Transfers: The Fertilizer Subsidy. In: *Talking economics* [online]. [Cited 16 August 2010]. www.ips.lk/talkingeconomics/2010/08/16/better-targeting-of-transfers-the-fertilizer-subsidy

Truelove, H.B., Carrico, A.R. & Thabrew, L. 2015. A socio-psychological model for analysing climate change adaptation: A case study of Sri Lankan paddy farmers. *Global Environmental Change*, 31: 85–97.

Weerakoon, W.M.W., Mutunayake, M.M.P., Bandara, C., Rao, A.N., Bhandari, D.C. & Ladha, J.K. 2011. Direct-seeded rice culture in Sri Lanka: Lessons from farmers. *Field Crops Research*, 121(1): 3–63.

World Food Programme (WFP). 2017. *Sri Lanka's Food Production Hit by Extreme Drought Followed by Floods* [online]. Rome. [Cited 15 November 2019]. www.wfp.org/news/sri-lankapercentE2percent80percent99s-food-production-hit-extreme-drought-followed-floods

Wijetunga, C.S. & Saito, K. 2017. Evaluating the Fertilizer Subsidy Reforms in the Rice Production Sector in Sri Lanka: A Simulation Analysis. *Advances in Management and Applied Economics*, 7(1): 31.

Zander, R. 1994. Barriers to credit access in rural Sri Lanka. *Financial Landscapes Reconstructed*, 18.

Zubair, L. 2002. El Nino–southern oscillation influences on rice production in Sri Lanka. *International Journal of Climatology*, 22(2): 249–260.

Annexes

Annex 1. Sampling procedure

A Multistage Stratified Random Sampling procedure was used to insure the representativeness of the sample at district level as well as the proportional random selection of famers from each of the four irrigation systems in Sri Lanka.[9] The number of farm households within each Divisional Secretariat (DS) and within each Irrigation System (IR) were used to draw a proportional random sample of 11 DS and 110 farmers organization from which 1 100 households (corresponding to 3 954 seasonal fields) have been interviewed (Table A1). Figure A1, shows the geographic dispersion of the sampled households, where the geographic location of the households are displayed at the finest administrative resolution available, the *Grama Niladhari Division* (GND).[10] The sampling procedure used ensures that the sample is representative of rice farmers of the Anurādhapura District.

Table A1. Sampled households

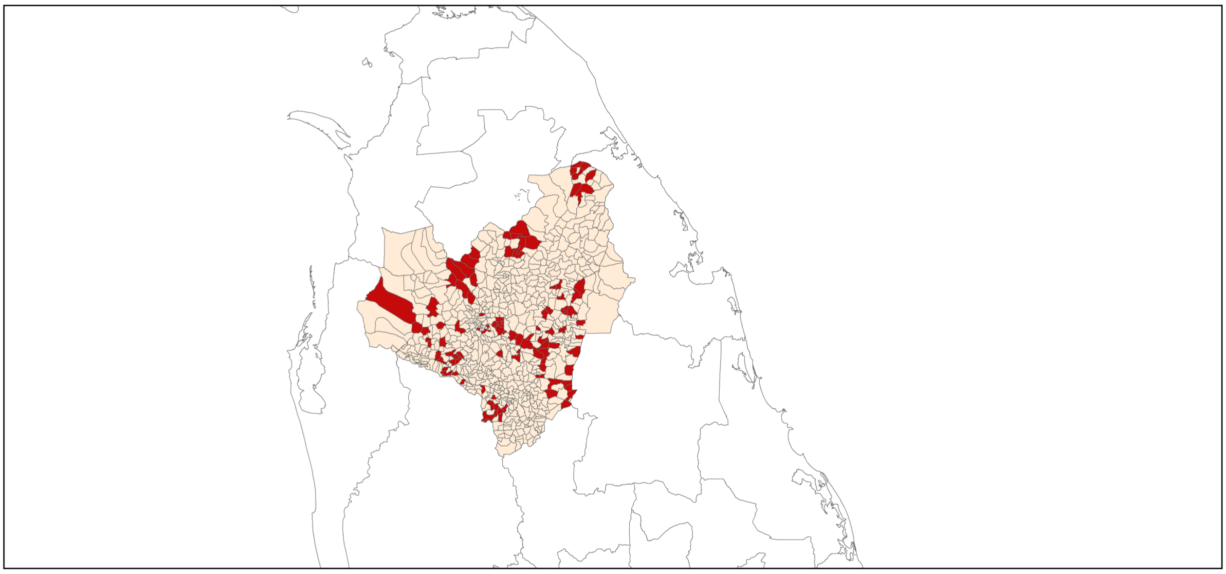
Cluster (DS)	Number of farm family				Total	Sample of farmer organization			
	Major	Minor	RF	*Maha*weli		Major	Minor	RF	*Maha*weli
Padaviya	2 392	2 649	30	0	5 071	5	5	0	0
Medawachchiya	0	9 067	0	0	9 067	0	10	0	0
Nuwargam Palatha Central	76	4 997	0	0	5 073	1	9	0	0
Kahatagasdigiliya	0	10 209	0	0	10 209	0	10	0	0
Galenbidunuwewa	2 993	8 308	0	0	11 301	3	7	0	0
Nuwargam Palatha eastern	417	1 029	301	0	17 470	2	6	2	0
Nochchiyagama	0	5 467	0	6 125	11 592	0	5	0	5
Thabuththegama	0	0	0	4 150	4 150	0	0	0	10
Thirappane	312	2 728	161	0	3 201	1	8	1	0
Palugaswewa	0	3 170	0	0	0	0	10	0	0
Galnewa	110	5 336	0	1 994	7 440	0	7	0	3
Total						**12**	**77**	**3**	**18**

Source: HARTI elaboration from District Statistical Branch, Anurādhapura, Department of Census and Statistics.

[9] Even though Mahaweli systems is also a major irrigation system, for the purpose of the study, it was considered as a separate system because of its different management aspects and objectives.

[10] GND are DS sub-unit and are defined by the competencies boundaries of a public village officer (Grama Niladhari) appointed by the central government to carry out administrative duties within the area.

Figure A1. Households sampled location at aggregate by Grama Niladhari Division (red polygons)



Source: FAO, 2021. Conforms to map from Sri Lanka Government, 2019 with authors' own elaboration.

Annex 2. Descriptive summary

This annex provides the descriptive statistics at household (Table A2) and field level (Table A3) on the main variables included in the empirical analysis. For the household level statistics, the inter-quintile difference between the highest and the lowest quintile for each variable is reported and has been tested against the null hypothesis that it is equal to zero.

Table A2. Descriptive household level statistics for selected variables

HH-level means	Mean	Diff. 5th -1st quintiles*
Gender of HH head (1=female)	0.036	-0.040
Age of HH head	53.825	-5.380
Highest education of HH head	10.138	1.320
HH size	3.943	1.248
Field area (acres)	6.391	4.405
Normalized ag asset wealth index (0–1)	0.146	0.140
HH has raised or owned livestock (1=yes)	0.192	-0.019
HH has sole ownership of its largest field (1=yes)	0.752	0.110
HH head's primary employment is off farm (1=yes)	0.135	0.130
HH received food aid (1=yes)	0.416	-0.222
HH received a loan for ag. Activity	0.453	0.050
HH participated in crop insurance scheme (1=yes)	0.436	0.115
HH has received info related to the ag. Production (1=yes)	0.879	0.036
HH received subsidy for fertilizers or other input	0.677	0.190
Total field area with agro-wells (acres)	0.685	0.842
HH rented a tractor	0.671	0.010
HH sold other crop on the market	0.816	0.209
HH bought input from commercial sources	0.821	0.191
Distance (km) to agrarian services center	6.301	0.293
Distance (km) to established marketplace	13.170	5.601
Distance (km) to fertilizers retailer	4.205	0.057
Share of land that is irrigated	0.663	0.082
Off farm income share (of gross income)	0.443	0.176
Income share from transfers (of gross income)	0.074	-0.252
Agricultural income share (of gross income)	0.480	0.089
Off-farm income (rupees)	343 300.2	635 856.8
Value of transfer (rupees)	20 958.5	-16 775.7
Total value of harvest production	433 240.5	922 042.4
Gross income (rupees)	832 270	1 910 546.9
Obs.	1 100	

Source: Authors' own elaborations. Notes: With the only exception of the "distance from fertilizer retailers", all the inter-quintile difference are statistically different from zero at 1percent significance levels.

The summary statistics in Table A2 highlight that the average family size is relatively small, about 4 members, and only 3 percent of the households is female headed. The household head is on average middle age (53 years old), with an average of 10 years of formal education level. The total size of all the plots owned or cultivated on average is 6.4 acres (about 2.5 hectares), and 75.2 percent of households are sole owners of their largest field. Livestock ownership is not widespread, only 19.2 percent of households raise livestock. Most households consider farming as their primary source of employment and only 13.5 percent of the sample considers off-farm employment as their primary income source. However, 44 percent of household gross income, on average, comes from off-farm sources.

At a field level (Table A3) the data show significant variations between the farm practices, technologies, input use, crop choice, and productivity between field types and season. The total area cultivated is, on average, slightly higher during the *Maha* season and generally higher for uplands, where extensive cultivation is practiced. In particular, on average rice producers in the district cultivated 2.2 acres in the lowlands and 2.5 acres in the uplands during *Maha* season. This reduces to about 1.9 acres in the lowlands and 2.47 acres in the uplands during *Yala,* when rains are less consistent, and the season is shorter. Rice is almost exclusively cultivated on lowlands and more intensively during the main season (*Maha*). Accordingly, the average productivity on lowlands is about 1 700 kg per acre during the *Maha season* and about 1 670 kg per acre during the *Yala* season.

The reference period used for this analysis was characterized by a below-average rainfall during the *Maha* 2017/18, coupled with low irrigation water availability, which resulted in significant cuts in the area planted (FAO Global Information and Early Warning System, 2018). Water availability started to recover during the *Yala* season 2018 but was still below the historical average. As a result, all the farmers within the district operated under conditions of water stress during the reference period, and their ability to cope with this was likely linked to some combination of household characteristics as well the implementation of different adaptation practices. The descriptive data show that during the *Maha* season, 24.4 percent of lowland fields and 41.4 percent of upland fields experienced crop wilting that resulted in farmers harvesting less of their field than was planted. In the *Yala* season, conditions improved slightly, but crop loss due to wilting was still reported in 10.7 percent of lowland fields and 14.4 percent of upland fields.

Table A3. Descriptive field level statistics for selected variables

Variable	*Maha* season		*Yala* season	
	Lowland	Upland	Lowland	Upland
Characteristics of the fields and production				
Rice yield (kg/acre)	1712.492	66.286	1667.393	12.611
Field harvested less than planted due to wilting (1=yes)	0.244	0.414	0.107	0.144
Field area (acres)	2.189	2.533	1.944	2.469
Field applied with inorganic fertilizer (1=yes)	0.993	0.890	0.993	0.593
Quantity of inorganic fertilizer used (kg) on field	276.189	371.764	219.957	159.087
Quantity of inorganic fertilizer used (kg/acre) on field	133.845	165.583	139.040	100.825
Field applied with organic fertilizer (1=yes)	0.043	0.035	0.029	0.058
Quantity of organic fertilizer used (kg) on field	17.743	30.155	10.765	19.684
Quantity of organic fertilizer used (kg/acre) on field	14.064	22.726	8.291	23.713
Field sprayed with herbicide (1=yes)	0.936	0.579	0.851	0.130
Times herbicide was sprayed on field	1.162	0.652	1.208	0.170
Quantity of herbicide used (kg/acre) on uplands	0.881	0.428	0.933	0.115
Field preventatively weeded(1=yes)	0.032	0.046	0.066	0.061
Field acquired via *bethma* (1=yes)	0.028	-	0.108	-
Gini-Simpson index (land area) of crop cultivated	0.021	0.078	0.097	0.127
Adjusted Gini-Simpson index (land area) of crop cultivated	0.013	0.041	0.044	0.055

Variable	*Maha* season		*Yala* season	
	Lowland	Upland	Lowland	Upland
Conventional practices				
Field mechanically ploughed (1=yes)	0.994	0.931	0.984	0.914
Field levelled with mechanized methods (1=yes)	0.125	0.045	0.081	0.030
Field sown with manual direct seeding methods(1=yes)	0.030	0.630	0.139	0.343
Retained crop residues on field (1=yes)	0.971	0.714	0.952	0.690
Adaptation practices				
Field sown with short duration rice seeds(1=yes)	0.364	0.036	0.264	0.0014
HH grew maize on field (1=yes)	0.0018	0.534	0.049	0.026
HH grew other crops(1=yes) on the field	0.048	0.864	0.209	0.995
Field with improved water management practices (1=yes)	0.0019	0.0018	0.013	0.014
Retained trees on field (1=yes)	0.085	0.234	0.103	0.221
Soil erosion barriers on field (1=yes)	0.014	0.151	0.013	0.155
Retained crop residues for 5 *yrs* and added water/urea (1=yes)	0.118	0.0014	0.125	0.0017
Obs.	1 013	629	508	336

Source: Authors' own elaborations.

Levels of crop diversification vary between season and field types. Rice is the dominant crop in lowland fields during the *Maha* season, with more than 95 percent of fields dedicated to rice. However, due to reductions in water availability during the *Yala* season, many lowland fields shift out of rice to produce other field crops. In total, 21 percent of the lowland fields in the *Yala* are used to produce other crops, with maize accounting for 5 percent of the cases. In the uplands, where water for irrigation is limited to agro-wells, more than 85 percent of the fields are devoted to the cultivation of other crops, which have lower water requirements. On these fields during *Maha* season, maize is a dominant crop, and is cultivated on 53.4 percent of the fields, while during the *Yala* other crops are prevalent.

In terms of the practices under consideration in this analysis, the descriptive data show that the use of short duration rice varieties is not widespread. The data collected shows that when they are used exclusively in lowland fields and most predominantly in the *Maha* season (36.4 percent against 26.4 percent during *Yala*). In terms of OFCs, the descriptive figures confirm that farm household cultivate crops other than rice mainly on uplands (86.4 percent during *Maha* and 99.5 percent during *Yala*) but there is also a high percentage of farmers cultivating other crop on lowland fields during *Yala* (20.9 percent). Among these other crops, maize is cultivated almost exclusively on upland during *Maha* (53.4 percent).

The descriptive statistics shows that agroforestry in the district is primarily passive, and involves retaining beneficial trees in fields, not establishing new agroforestry systems. In cultivated upland fields, trees are found on over 20 percent of fields, and on about 10 percent of lowland fields. The figure shows that cultivated fields having soil erosion barriers are exclusively on uplands, with roughly 15 percent of upland fields having soil erosion barriers.

Finally, the descriptive statistics shows that more than on 95 percent of the lowland fields, crop residues are retained, regardless of the season. The percentage decreases to 70 percent for uplands but is still very high. Improved residue retention, which involves long duration of adoption and the use of urea or water to speed decomposition, is less widespread, but is sufficiently adopted to enable an empirical analysis. In total, 11.8 percent of lowlands during *Maha* and the 12.5 percent of lowlands during *Yala* have been managed through improved residue retention practices. It is important to note that given the widespread adoption of residue retention, the interpretation of the impacts of improved residue retention is relative to basic residue retention.

Annex 3. Balancing tests of covariates

Figure A2. Propensity score probability distribution by treatment variable

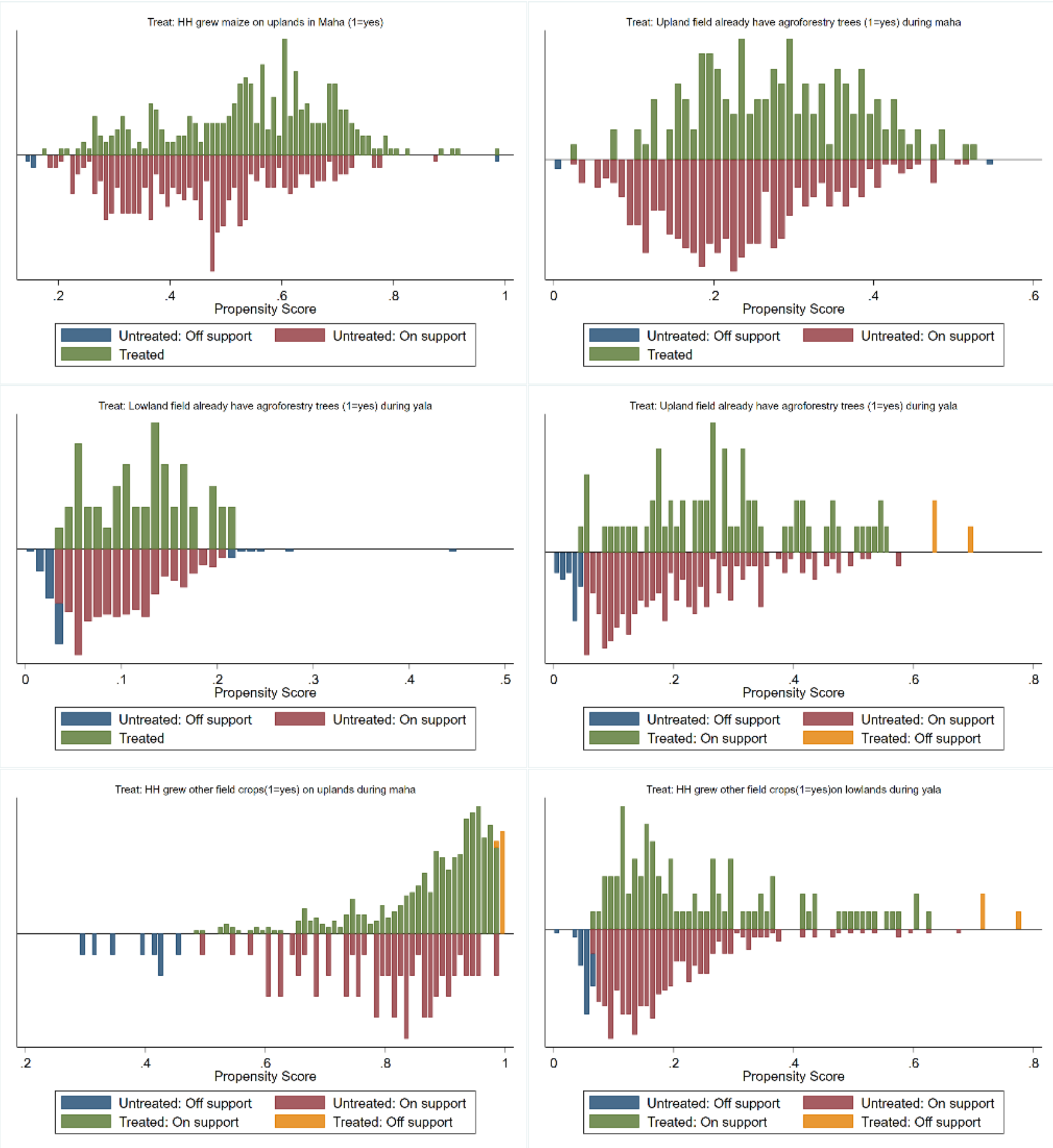
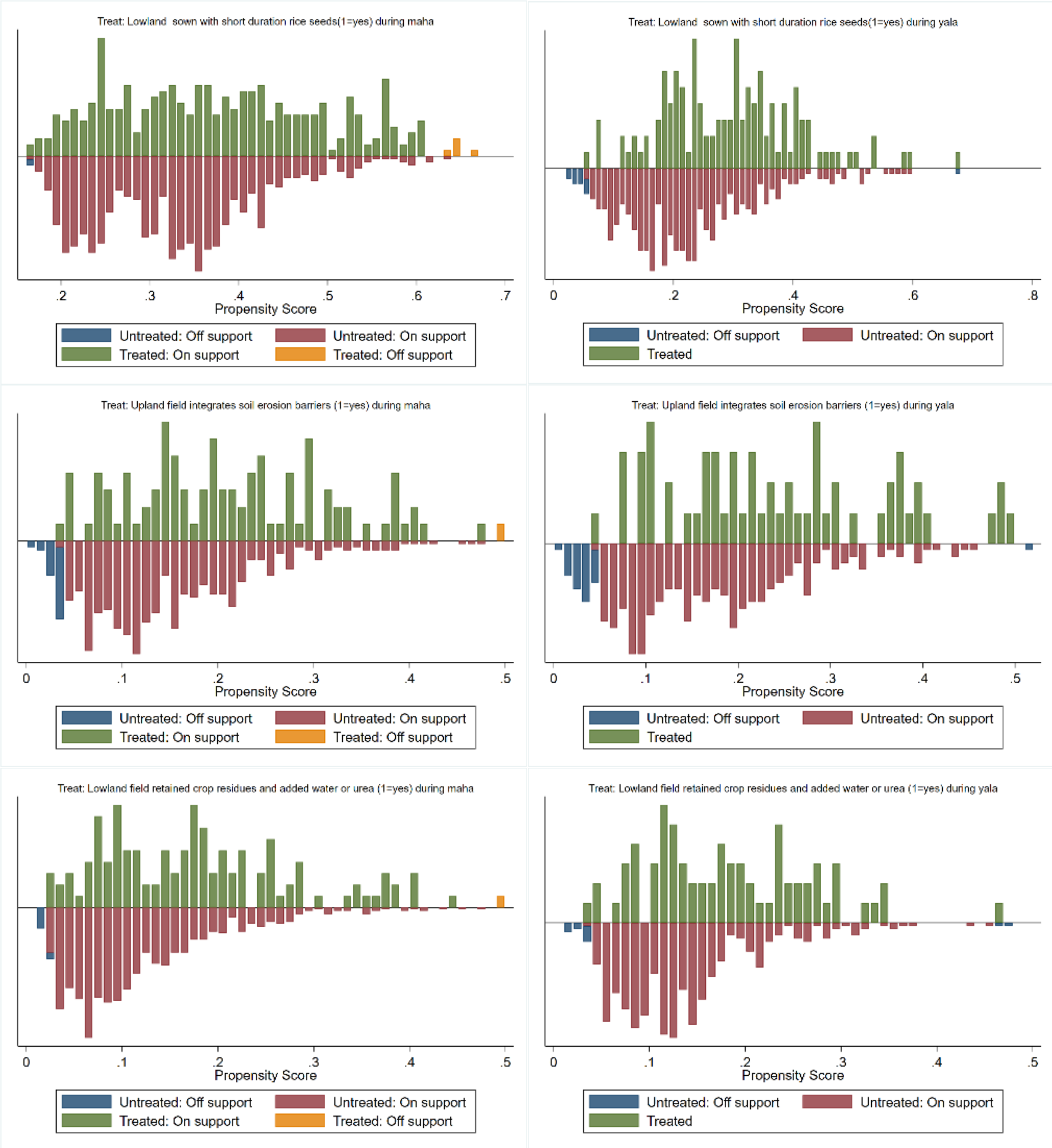


Figure A2. Propensity score probability distribution by treatment variable (cont.)



Source: Authors' own elaborations.

Figure A3. Balancing test of covariates distribution before and after the propensity model

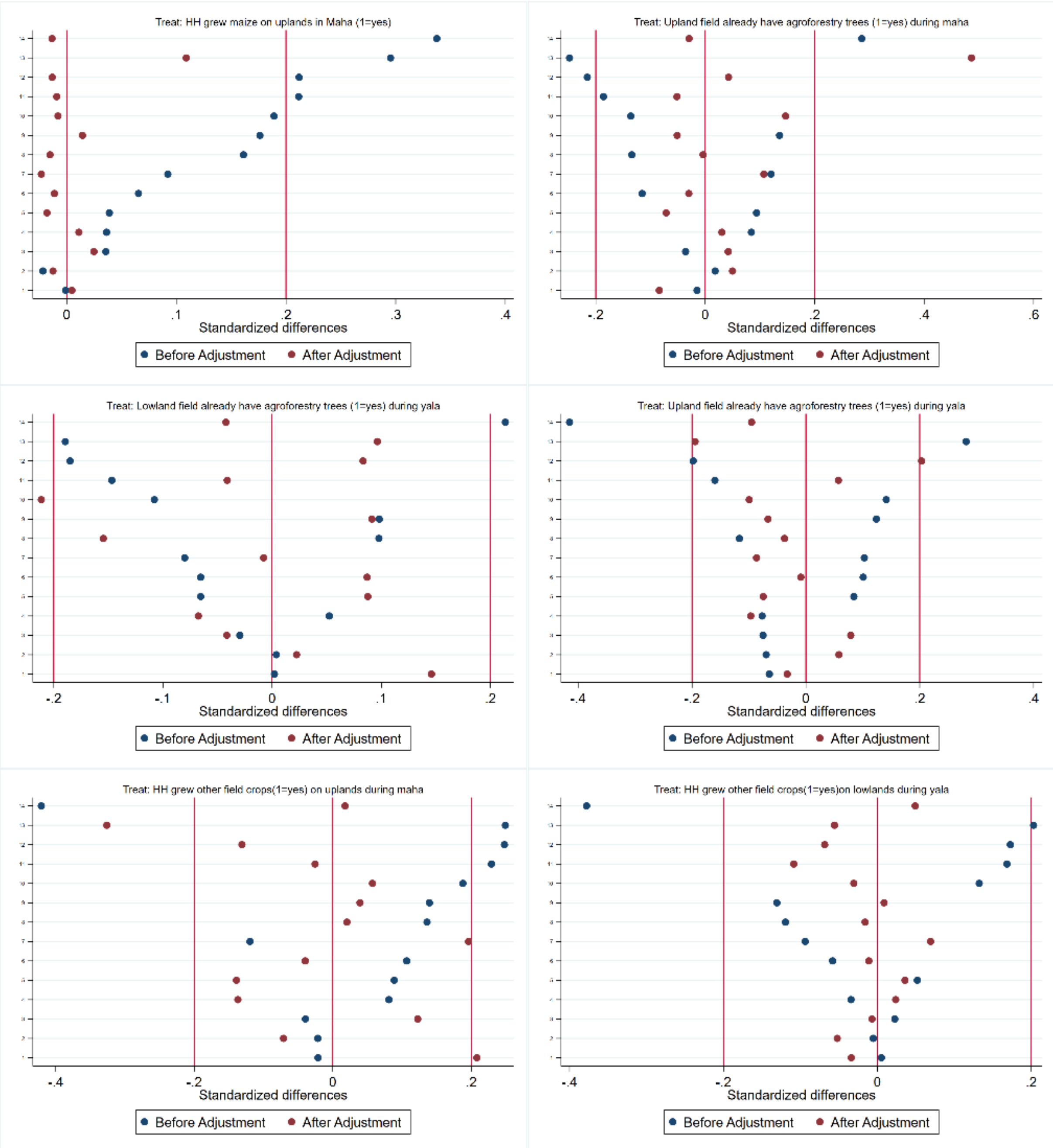
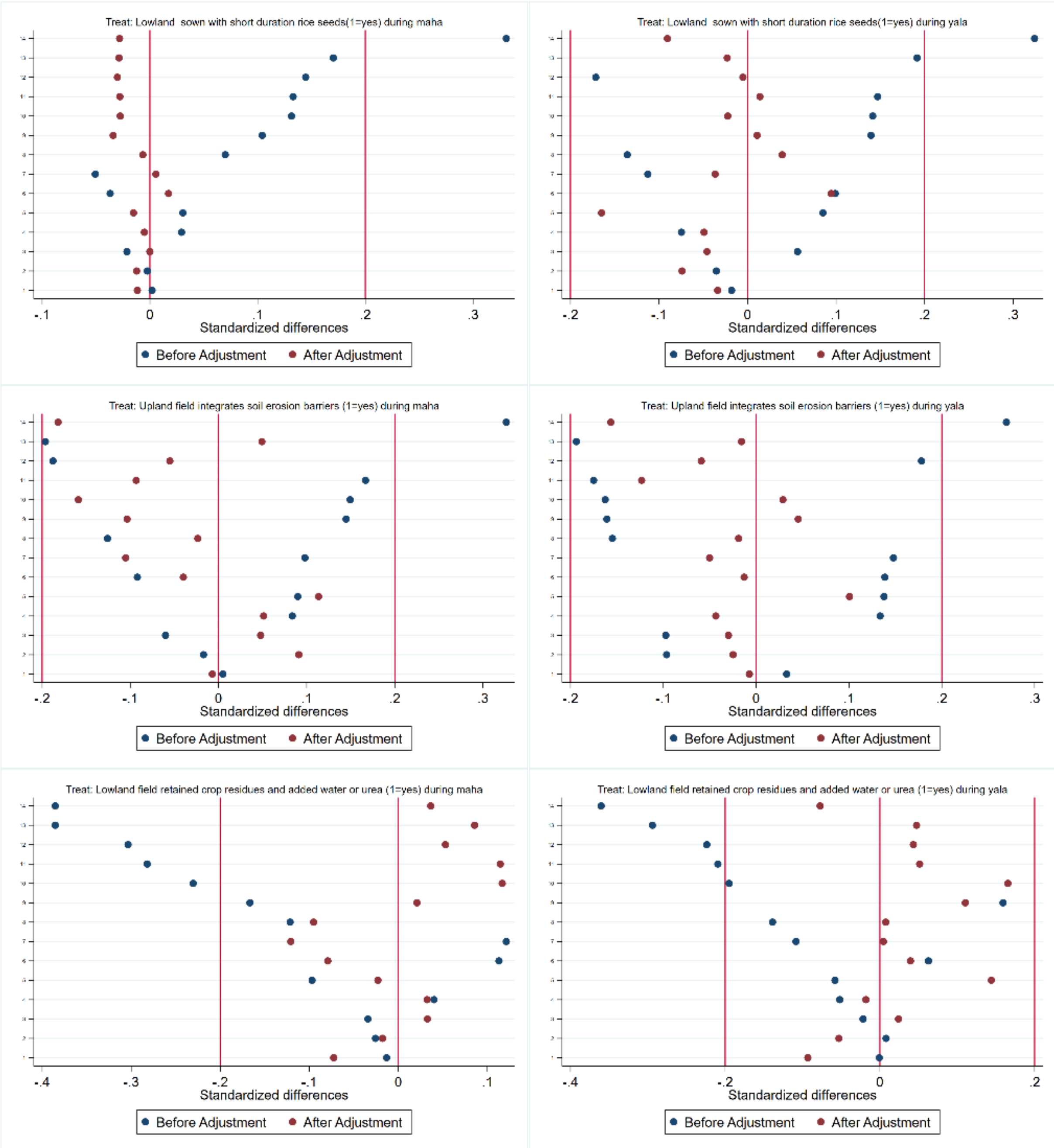


Figure A3. Balancing test of covariates distribution before and after the propensity model (cont.)



Source: Authors' own elaborations.

Annex 4. Complete model results of impacts

Table A4. Treatment effect of lowlands practices on value of harvest by seasons

Variables list	1	2	3	4	5	6
	Maha		Yala			
Sensitivity						
Treatment effect	-0.01	-0.156***	-0.052*	-0.098***	-0.066*	0.03
Field area (acres)	0.02	0.02	0.03	0.026*	0.02	0.00
Less water issued than decided in pre-*kanna* meetings	0.151*	0.196*	0.04	0.03	0.08	0.22
Field acquired via *bethma*	-0.11	-0.160**	0.04	0.06	0.04	0.01
Highest education of HH head	-0.01	0.00	0.00	0.00	0.01	0.00
HH size	0.02	0.00	0.01	0.00	0.00	0.00
Normalized ag asset index	-0.13	-0.15	0.02	0.00	0.08	-0.08
Raised or owned livestock	0.111**	0.08	0.107*	0.112*	0.13	0.10
Sole ownership of largest field	-0.098**	-0.132**	-0.02	0.02	-0.09	-0.03
HH head's off-farm main employ	0.139**	0.135**	-0.01	0.02	-0.01	-0.04
Subsidy fertilizers or other input	-0.232***	-0.14	0.103***	0.099***	0.149**	0.137***
HH received food aid	0.04	0.00	0.0739*	0.07	0.03	0.09
Loan for ag. activity	-0.02	0.01	0.00	-0.02	-0.01	-0.03
Crop insurance scheme	0.05	0.04	0.04	0.0734*	0.03	0.03
Info on improved seeds	-0.05	-0.04	-0.05	-0.03	-0.01	-0.02
Info on new ag. technologies	-0.02	-0.03	0.03	0.00	-0.08	0.05
Share of land that is irrigated	-0.229***	-0.246**	-0.212**	-0.123*	-0.235*	-0.18
Constant	0.605***	0.627***	0.05	0.03	0.11	0.05
Welfare						
Treatment effect	0.02	0.27	-0.18	-0.16	-0.42	0.474***
Gender of HH head (1=female)	-0.40	-0.80	-0.12	0.94	-0.18	0.23
Age of HH head	-0.01	-0.014*	-0.01	-0.01	-0.012*	-0.01
Highest education of HH head	0.03	0.00	0.02	0.06	0.03	0.03
HH family size	-0.05	-0.08	0.02	-0.08	0.00	-0.03
Total field area (acres)	0.07	0.101**	0.33	0.17	0.21	0.150***
Normalized ag asset index	3.145***	3.021***	2.719**	2.276***	3.196***	3.138***
Raised or owned livestock	-0.07	-0.14	0.89	-0.21	0.82	0.06
Sole ownership of largest field	0.20	0.26	0.20	0.44	-0.55	0.09
HH head's off-farm main employ	-0.74	-0.899**	-0.56	-1.17	-0.07	-0.61
Subsidy fertilizers or other input	0.59	0.22	1.39	-0.04	0.84	0.38
HH received food aid	0.27	0.17	0.69	-0.02	0.03	0.06
Loan for ag. activity	0.10	0.04	0.18	-0.14	-0.09	0.13
Crop insurance scheme	0.02	-0.12	0.34	0.01	0.08	-0.09
Info on improved seeds	-0.01	0.19	-0.29	-0.625*	-0.04	-0.07
Info on new ag. technologies	-0.03	0.08	-0.31	-0.01	-0.85	-0.24
Area with agro-wells (acres)	0.07	0.069*	0.04	0.190*	0.05	0.02
Input from commercial sources	1.249**	0.837**	0.345*	0.526*	0.352*	0.21
Log. Distance (km) to ASC	-0.06	0.04	0.01	0.13	0.04	0.08
Log. distance (km) to market	-0.07	-0.257***	-0.05	0.07	-0.03	-0.08
Log. distance (km) to fertilizer	0.00	-0.02	-0.05	-0.18	0.05	-0.14
Share of land that is irrigated	1.01	0.921*	-0.43	1.24	-1.04	0.68
Irrigation: Major	-0.834*	-1.391**	-1.319***	0.15	1.08	-0.96
Irrigation: Minor	-1.391***	-1.644***	-1.570***	-0.44	1.05	-0.86
Irrigation: *Maha*weli	-0.64	-1.190**	-1.148**	0.50	1.350*	-0.70
Constant	11.12***	13.15***	12.37***	10.50***	11.90***	12.23***
Sensitivity	-2.19	-1.74	-7.63	2.11	-6.40	-1.21
Observations	1 006	996	496	465	450	497

Source: Authors' own elaborations. Note: The dependent variables according to the specification number are: (1) short duration rice seeds; (2) improved residues retention; (3) short duration rice seeds; (4) other crops in the field; (5) retaining trees; (6) improved residues retention.

Table A5. Treatment effect of lowlands practices on gross income by seasons

Variables list	1	2	3	4	5	6
	Maha		Yala			
Sensitivity						
Treatment effect	-0.01	-0.154***	-0.052*	-0.098***	-0.07*	0.03
Field area (acres)	0.02	0.021*	0.03	0.026*	0.01	0.00
Less water issued than decided in pre-*kanna* meetings	0.157**	0.203*	0.00	0.03	0.05	0.22
Field acquired via *bethma*	-0.09	-0.12	0.03	0.05	-0.02	0.01
Highest education of HH head	-0.01	0.00	0.00	0.00	0.01	0.00
HH size	0.02	0.00	0.01	0.00	0.00	0.00
Normalized ag asset index	-0.13	-0.15	0.02	0.00	0.08	-0.08
Raised or owned livestock	0.110**	0.08	0.107*	0.112*	0.13	0.10
Sole ownership of largest field	-0.098**	-0.132**	-0.02	0.02	-0.09	-0.03
HH head's off-farm main employ	0.139**	0.136**	-0.01	0.02	0.00	-0.04
Subsidy fertilizers or other input	-0.231**	-0.14	0.104***	0.098***	0.149**	0.137***
HH received food aid	0.03	0.00	0.075*	0.07	0.03	0.09
Loan for ag. activity	-0.02	0.01	0.00	-0.02	-0.01	-0.03
Crop insurance scheme	0.05	0.04	0.04	0.074*	0.03	0.03
Info on improved seeds	-0.05	-0.04	-0.05	-0.03	-0.01	-0.02
Info on new ag. technologies	-0.02	-0.03	0.03	0.00	-0.08	0.05
Share of land that is irrigated	-0.231***	-0.249**	-0.209**	-0.123*	-0.227*	-0.18
Constant	0.604***	0.626***	0.05	0.03	0.12	0.05
Welfare						
Treatment effect	-0.01	-0.11	-0.31	-0.09	0.32	0.185*
Gender of HH head (1=female)	0.15	0.16	-0.90	0.07	0.49	0.18
Age of HH head	-0.008*	-0.01	0.00	-0.01	-0.01	0.00
Highest education of HH head	0.02	-0.01	0.04	0.01	-0.04	0.01
HH family size	0.159***	0.175***	0.214*	0.168***	0.251**	0.156***
Total field area (acres)	0.076*	0.089***	0.25	0.12	-0.09	0.078***
Normalized ag asset index	1.412***	1.117**	2.204**	1.900***	1.07	2.236***
Raised or owned livestock	0.06	-0.05	0.99	0.08	-0.37	0.08
Sole ownership of largest field	0.17	0.14	0.18	0.399**	0.72	0.26
HH head's off-farm main employ	0.32	0.440**	0.45	0.653***	0.72	0.477***
Subsidy fertilizers or other input	0.16	0.05	1.39	0.37	-0.76	0.39
HH received food aid	-0.15	-0.161*	0.62	-0.09	-0.71	-0.12
Loan for ag. activity	-0.168*	-0.275***	0.00	-0.25	0.04	-0.07
Crop insurance scheme	0.06	0.10	0.26	-0.01	-0.32	-0.07
Info on improved seeds	0.00	0.17	-0.32	-0.10	-0.21	0.10
Info on new ag. technologies	-0.07	0.00	-0.04	0.05	0.33	-0.08
Area with agro-wells (acres)	0.04	0.08	0.03	0.01	0.04	0.05
Input from commercial sources	0.06	0.04	0.11	0.523**	0.599***	0.06
Log. Distance (km) to ASC	0.00	-0.04	0.00	0.04	0.00	0.01
Log. distance (km) to market	-0.03	-0.0714*	-0.05	0.01	0.09	-0.06
Log. distance (km) to fertilizer	-0.073*	-0.087*	-0.135*	-0.13	-0.11	-0.193***
Share of land that is irrigated	0.05	-0.05	-0.83	0.45	1.76	0.34
Irrigation: Major	-0.02	-0.87	-3.113**	0.23	0.33	-2.08
Irrigation: Minor	-0.28	-1.17	-3.127**	-0.01	0.29	-1.92
Irrigation: *Mahaweli*	-0.18	-1.20	-3.127**	0.07	0.16	-2.22
Constant	12.74***	14.31***	14.44***	11.40***	10.72***	13.70***
Sensitivity	-0.70	-1.247*	-7.33	-0.64	5.63	-0.36
Observations	1006	996	496	465	450	497

Source: Authors' own elaborations. Note: The dependent variables according to the specification number are: (1) short duration rice seeds; (2) improved residues retention; (3) short duration rice seeds; (4) other crops in the field; (5) retaining trees; (6) improved residues retention.

Table A6. Treatment effect of uplands practices on value of harvest by seasons

Variables list	1	2	3	4	5	6
	Maha				Yala	
Sensitivity						
Treatment effect	-0.124*	0.049	0.051	0.037	-0.002	-0.053
Field area (acres)	0.013	0.013	0.016***	0.015*	0.015	-0.004
Field applied inorganic fertilizer	0.016	0.020	0.123	0.108	-0.169***	-0.182***
Insufficient water availability	0.587***	0.573***	0.599***	0.515***	0.365***	0.316***
Highest education of HH head	-0.020**	-0.010	-0.010	-0.0191*	0.002	0.008
HH size	-0.011	0.002	-0.007	-0.024	-0.0525**	-0.009
Normalized ag asset index	-0.130	-0.039	-0.013	-0.137	-0.280	-0.066
Raised or owned livestock	-0.015	-0.015	-0.010	-0.061	0.060	0.041
Sole ownership of largest field	-0.074	-0.057	-0.056	-0.039	0.040	0.081
HH head's off-farm main employ	-0.194	0.006	-0.023	0.039	0.118	-0.017
Subsidy fertilizers or other input	0.187**	0.021	0.062	0.051	0.034	0.060
HH received food aid	0.021	-0.008	0.023	0.060	-0.063	-0.006
Loan for ag. activity	-0.049	0.017	-0.038	-0.064	0.002	-0.045
Crop insurance scheme	-0.024	-0.015	-0.021	-0.087	-0.017	-0.061
Info on improved seeds	-0.015	-0.122**	-0.0981*	-0.086	-0.159**	-0.015
Info on new ag. technologies	0.016	0.029	0.022	-0.074	-0.100	-0.111*
Share of land that is irrigated	-0.217*	-0.093	-0.146*	-0.192	0.192*	0.064
Constant	0.508***	0.229*	0.184	0.488**	0.227	0.069
Welfare						
Treatment effect	0.023	-0.137	-0.154	-0.042	-0.114	0.236
Gender of HH head (1=female)	-4.465***	-1.898**	-1.562**	-2.459**	-0.120	0.043
Age of HH head	0.000	-0.011	-0.008	-0.006	-0.0169*	-0.005
Highest education of HH head	0.065	0.052	0.032	0.041	-0.016	0.033
HH family size	0.032	0.023	0.025	0.059	-0.091	-0.036
Total field area (acres)	0.053	0.118**	0.122***	0.106**	0.164*	0.085**
Normalized ag asset index	1.559**	1.298*	0.944	1.094*	-0.022	0.948
Raised or owned livestock	0.197	-0.108	0.106	-0.216	-0.167	-0.222
Sole ownership of largest field	0.154	0.266	0.031	0.425	0.434	0.074
HH head's off-farm main employ	-0.210	-0.358	-0.436	-1.366*	-0.087	-0.498*
Subsidy fertilizers or other input	0.978***	0.482*	0.554*	0.671	0.442**	0.477**
HH received food aid	0.337	0.323	0.412*	0.692	0.063	0.011
Loan for ag. activity	-0.004	0.392	-0.028	-0.134	-0.033	0.013
Crop insurance scheme	-0.086	0.100	-0.050	-0.065	0.424**	0.189
Info on improved seeds	0.281	0.334	0.522**	0.163	0.148	0.157
Info on new ag. technologies	-0.038	0.068	0.073	0.200	-0.146	-0.327
Area with agro-wells (acres)	-0.027	0.041	0.009	0.133*	0.093	0.103**
Input from commercial sources	2.118	2.144*	1.806*	2.600*	0.747*	1.040**
Log. Distance (km) to ASC	0.194	-0.308	-0.218*	-0.245	0.029	-0.010
Log. distance (km) to market	0.488***	0.274*	0.347***	0.100	0.030	0.032
Log. distance (km) to fertilizer	-0.041	-0.045	-0.002	0.012	-0.181*	-0.147*
Share of land that is irrigated	2.011**	1.247**	1.391**	0.010	0.794*	0.272
Irrigation: Major	0.477	0.782	1.236	-0.304	0.452	0.533
Irrigation: Minor	-0.059	0.285	0.694	-0.826*	0.375	0.384
Irrigation: *Mahaweli*	1.352	1.460	1.505	0.560	0.891*	0.868*
Constant	5.958**	8.251***	8.044***	9.651***	11.67***	10.78***
Sensitivity	-1.023***	-1.646***	-1.388***	-1.818***	-1.722***	-1.836***
Observations	595	626	627	589	315	308

Source: Authors' own elaborations. Note: The dependent variables according to the specification number are: (1) other crops in the field; (2) cultivating maize; (3) retaining trees; (4) soil erosion barriers; (5) retaining trees; (6) soil erosion barriers.

Table A7. Treatment effect of uplands practices on gross income by seasons

Variables list	1	2	3	4	5	6
		Maha			Yala	
Sensitivity						
Treatment effect	-0.123*	0.050	0.051	0.037	-0.002	-0.053
Field area (acres)	0.013	0.013	0.016***	0.015*	0.015	-0.004
Field applied inorganic fertilizer	0.039	0.011	0.097	0.099	-0.165***	-0.188***
Insufficient water availability	0.586***	0.572***	0.599***	0.515***	0.368***	0.312***
Highest education of HH head	-0.020**	-0.010	-0.010	-0.0191*	0.002	0.008
HH size	-0.011	0.002	-0.007	-0.024	-0.0524**	-0.009
Normalized ag asset index	-0.132	-0.038	-0.013	-0.136	-0.281	-0.063
Raised or owned livestock	-0.016	-0.015	-0.009	-0.060	0.060	0.042
Sole ownership of largest field	-0.076	-0.057	-0.055	-0.038	0.041	0.080
HH head's off-farm main employ	-0.195	0.006	-0.023	0.040	0.118	-0.017
Subsidy fertilizers or other input	0.186**	0.021	0.064	0.051	0.035	0.060
HH received food aid	0.023	-0.009	0.024	0.059	-0.062	-0.008
Loan for ag. activity	-0.050	0.017	-0.038	-0.064	0.002	-0.045
Crop insurance scheme	-0.026	-0.014	-0.019	-0.086	-0.018	-0.061
Info on improved seeds	-0.016	-0.122**	-0.099*	-0.086	-0.159**	-0.015
Info on new ag. technologies	0.018	0.028	0.021	-0.075	-0.100	-0.110*
Share of land that is irrigated	-0.218*	-0.092	-0.144*	-0.193	0.191*	0.065
Constant	0.490***	0.235*	0.201	0.496**	0.223	0.075
Welfare						
Treatment effect	0.186	0.096	0.060	0.131	-0.026	0.023
Gender of HH head (1=female)	-0.126	-0.236	-0.099	-0.223	0.131	0.220
Age of HH head	-0.0184*	-0.009	-0.015*	-0.010	-0.009	-0.003
Highest education of HH head	-0.003	-0.002	-0.002	-0.002	-0.041	-0.007
HH family size	0.190***	0.149***	0.148***	0.139***	0.106*	0.103*
Total field area (acres)	0.042	0.079***	0.081***	0.071***	0.107	0.100**
Normalized ag asset index	1.670***	1.076***	0.959***	0.924***	0.169	1.115*
Raised or owned livestock	-0.082	0.154	0.157	0.103	0.053	0.089
Sole ownership of largest field	-0.049	0.021	-0.049	0.011	0.475*	0.178
HH head's off-farm main employ	0.633***	0.378***	0.245*	0.323**	0.504**	0.168
Subsidy fertilizers or other input	-0.095	0.109	0.123	0.324**	0.121	0.280*
HH received food aid	-0.363*	-0.152	-0.023	-0.153	-0.337*	-0.356**
Loan for ag. activity	0.025	-0.176*	-0.254*	-0.093	-0.280*	-0.175
Crop insurance scheme	0.022	0.085	0.048	0.059	0.023	0.015
Info on improved seeds	0.023	0.210*	0.240**	0.196	-0.105	0.066
Info on new ag. technologies	0.130	-0.007	0.038	0.084	-0.020	0.012
Area with agro-wells (acres)	0.026	0.026	0.008	0.048	0.032	0.029
Input from commercial sources	0.202	-0.055	0.105	0.259	0.242	0.144
Log. Distance (km) to ASC	0.148	0.070	0.100	0.086	0.052	-0.032
Log. distance (km) to market	-0.029	0.024	0.028	-0.013	-0.063	0.024
Log. distance (km) to fertilizer	0.120	-0.012	0.038	0.070	-0.175*	-0.074
Share of land that is irrigated	0.202	-0.007	0.100	-0.087	0.537	0.267
Irrigation: Major	0.223	0.001	-0.048	-0.638*	-0.210	-0.544
Irrigation: Minor	-0.273	-0.266	-0.308	-0.670**	-0.207	-0.620
Irrigation: *Maha*weli	-0.122	0.075	-0.247	-0.547	-0.315	-0.646
Constant	12.57***	12.90***	13.05***	12.94***	13.38***	13.12***
Sensitivity	-0.047	-0.629***	-0.565***	-0.448*	-1.245***	-1.223**
Observations	595	626	627	589	315	308

Source: Authors' own elaborations. Note: The dependent variables according to the specification number are: (1) other crops in the field; (2) cultivating maize; (3) retaining trees; (4) soil erosion barriers; (5) retaining trees; (6) soil erosion barriers.

Annex 5. Complete model results of determinants

Table A8. Adoption determinants of selected practices by type of land during the Maha season

Variables list	1	2	3	4	5	6
	Lowlands		Uplands			
Gender of HH head (1=female)	-0.16	0.04	-0.04*	-0.12	0.02	-0.15
Age of HH head	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
Highest education of HH head	-0.01	-0.00	0.00**	0.02	0.01	0.01*
HH family size	0.00	-0.01	0.00	0.01	-0.01	0.02
Field area	-0.00	-0.00	0.01***	0.01	-0.01*	-0.00
Normalized ag asset wealth index (0–1)	0.11	-0.12	-0.08**	-0.26	-0.06	-0.07
HH raised or owned livestock	0.05	-0.04	0.01	-0.02	-0.01	0.03
Sole ownership of largest field	-0.04	-0.08***	0.02	0.05	0.04	-0.01
Total field area under agro-wells (acres)	-0.00	0.01**	-0.00	-0.05***	0.01	0.01
Off-farm head's primary employment	-0.03	0.05	0.01	0.11	-0.01	-0.16***
Subsidy for fertilizers or other input	-0.08	-0.00	-0.04**	0.11	0.07	-0.00
HH received food aid	-0.04	-0.00	0.02*	0.11	0.03	-0.02
HH received a loan for ag. activity	0.08**	-0.06**	0.01	0.05	0.04	0.03
Crop insurance scheme	0.02	-0.04	-0.00	0.02	-0.09**	-0.09***
Info on agriculture production	0.06	-0.11***	0.03	0.12	0.01	-0.06
Info by public supplier	-0.04	0.08**	0.00	0.01	0.02	0.03
Tractors rented	0.04	-0.02	-0.01	-0.16**	-0.12**	0.06
Input from commercial sources	0.05	0.05	0.02	0.83***	-0.13	-0.01
Commercialization Index: Other Crops	0.00	-0.05	-0.07**	0.26*	0.05	-0.09
Log. distance (km) to ASC	0.03	-0.03	0.00	0.02	0.01	-0.04*
Log. distance (km) to marketplace	-0.01	-0.01	0.01	0.03	-0.01	-0.02
Log. distance (km) to fertilizers retailer	-0.05*	0.03*	-0.00	0.01	-0.05**	0.02
Share of land that is irrigated	0.07	-0.02	0.02	-0.08	0.11	0.12*
Irrigation: Major	0.07	-0.06	-0.02	-0.04	-0.07	-0.03
Irrigation: Minor	0.11	-0.07	0.02	0.02	0.01	-0.08
Irrigation: *Mahaweli*	0.04	-0.01	-	0.15	-0.27	-0.23
FO leave-out mean of adoption	0.46***	-0.33***	0.06**	1.06***	-0.38***	0.15*
Observations	707	707	498	513	513	513

Source: Authors' own elaborations. Note: The dependent variables according to the specification number are (1) short duration rice seeds; (2) improved residues retention; (3) other crops in the field; (4) cultivating maize; (5) retaining trees; (6) soil erosion barriers.

Table A9. Adoption determinants of selected practices by type of land during the Yala season

Variables list	1	2	3	4	5	6
	Lowlands				Uplands	
Gender of HH head (1=female)	0.00	-0.06	0.07	0.03	-0.18	-
Age of HH head	-0.00	-0.00**	0.00	-0.00*	0.00	0.00
Highest education of HH head	-0.00	0.00	0.01	-0.01**	0.01	0.01
HH family size	0.03**	0.03**	0.01	-0.01	0.01	0.01
Field area	0.01	-0.01	-0.00	-0.00	-0.01*	-0.00
Normalized ag asset wealth index (0–1)	-0.26	0.42**	0.17*	-0.27	0.02	-0.15
HH raised or owned livestock	0.04	-0.07	0.02	-0.01	0.03	0.08*
Sole ownership of largest field	-0.09**	0.04	-0.02	-0.04	-0.06	0.07
Total field area under agro-wells (acres)	-0.01	-0.00	-0.02	0.01	0.00	0.02
Off-farm head's primary employment	-0.05	-0.04	-0.05	0.02	-0.03	-0.21**
Subsidy for fertilizers or other input	0.01	-0.21***	0.05	0.05	0.07	-0.06
HH received food aid	-0.08*	0.03	-0.04	-0.03	0.03	-0.05
HH received a loan for ag. activity	-0.06	0.03	0.03	-0.07***	0.07	-0.05
Crop insurance scheme	0.07*	-0.07	-0.03	-0.02	-0.15***	-0.03
Info on agriculture production	-0.00	-0.08	0.01	-0.17***	0.07	-0.04
Info by public supplier	-0.01	0.00	-0.03	0.14***	-0.01	0.02
Tractors rented	-0.00	0.07	0.02	-0.08*	-0.13**	0.13**
Input from commercial sources	-0.04	0.05	-0.00	0.11*	-0.22**	0.08
Commercialization Index: Other Crops	0.03	-0.27***	-0.05	-0.07	0.01	-0.11
Log. distance (km) to ASC	0.02	0.00	0.05***	-0.00	-0.11***	-0.03
Log. distance (km) to marketplace	0.02	0.01	0.00	-0.02	-0.01	-0.06**
Log. distance (km) to fertilizers retailer	-0.05**	0.01	-0.03**	0.05**	-0.02	-0.03
Share of land that is irrigated	0.28***	-0.15	0.06	-0.00	0.20*	0.04
Irrigation: Major	2.03***	-0.01	-0.26**	0.13	0.06	-0.13
Irrigation: Minor	2.14***	-0.12	-0.24***	0.05	0.15	-0.01
Irrigation: *Maha*weli	2.16***	-0.07	-0.21**	0.09	-	-
FO leave-out mean of adoption	0.31***	0.47***	0.05	-0.36***	-0.39**	0.16
Observations	427	426	427	427	301	293

Source: Authors' own elaborations. Note: The dependent variables according to the specification number are: (1) short duration rice seeds; (2) other crops in the field; (3) retaining trees; (4) improved residues retention; (5) retaining trees; (6) soil erosion barriers.

FAO AGRICULTURAL DEVELOPMENT ECONOMICS WORKING PAPERS

This series is produced by the Food and Agriculture Organization of the United Nations (FAO) since 2001 to share findings from research produced by FAO and elicit feedback for the authors.

It covers different thematic areas, such as food security and nutrition global trends and governance; food security and resilience; sustainable markets, agribusinesses and rural transformations; and climate-smart agriculture.

The complete series is available at:
www.fao.org/economic/esa/working-papers

The Agrifood Economics Division (ESA) is the focal point for FAO's research and policy analysis on agricultural and economic development. The Division produces evidence-based policy analysis and strengthens the capacity of member countries to improve decision-making on food security and nutrition, resilience, climate-smart agriculture, sustainable markets, agribusinesses and rural transformations.

CONTACTS

Economic and Social Development – Agrifood Economics
ESA-Director@fao.org
www.fao.org/economic/agricultural-development-economics
www.fao.org/economic/esa

Food and Agriculture Organization of the United Nations
Rome, Italy

ISBN 978-92-5-133974-9 ISSN 2664-5785

9 789251 339749
CB3384EN/1/02.21