Investing in rural people

How the adoption of drought-tolerant rice varieties impacts households in a non-drought year: Evidence from Nepal

by
Kate Vaiknoras
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Abstract

Stress-tolerant rice varieties (STRVs) are bred to be high yielding and tolerant to climate shocks such as drought. In Nepal, several drought-tolerant STRVs have been released and widely adopted. This paper estimates the impacts of the adoption of STRVs on first- and higher-order household outcomes in a non-drought year. It controls for selection bias using correlated random effects models to eliminate unobserved plot and household-level heterogeneity. STRVs have a higher yield, a lower yield variance and a shorter growing duration than traditional landrace varieties. In addition, households apply more early-season chemical fertilizer and land preparation labour to plots planted to STRVs compared to landraces. This indicates that the first-order impacts of the adoption of STRVs induce behavioural changes that help to modernize agricultural practices. Finally, this study conducts a randomized experiment in which half of the sampled households provided additional detail on their agricultural inputs. Collecting these more detailed data does not affect estimates of first-order treatment effects. However, it allows for a more nuanced exploration of higher-order treatment effects. Results indicate that the adoption of STRVs can improve household resiliency and incomes through their first- and higher-order impacts even in non-drought years. Policymakers can consider these results when evaluating the returns on investment in the development and dissemination of STRVs.

1. Introduction

Farmers in unfavourable rice environments are vulnerable to weather shocks, especially as climate change makes weather patterns more extreme and less predictable. A common shock is drought, which can reduce crop yields and even result in total crop losses in rain-fed rice environments. Stress-tolerant rice varieties (STRVs) have been developed to reduce the impacts of climate shocks such as drought. STRVs are high yielding compared to traditional landrace varieties and reduce yield loss due to climate shocks compared to landrace varieties and other improved varieties. They thus have the potential to improve incomes and resilience to climate change. In addition, drought-tolerant varieties are also short-duration varieties. This can allow households to plant legumes or vegetables on their rice plots after the rice harvest, potentially improving nutrition and/or incomes, as households can consume or sell these crops. Between 2005 and 2008, several STRVs were validated and released in the drought-prone western development region of Nepal through a collaboration between the Nepal Agriculture Research Council (NARC), the Institute of Agriculture and Animal Science (IAAS), a local agricultural college and the International Fund for Agricultural Development (IFAD). Most of these varieties were bred to be tolerant to drought.

This paper estimates the impacts of the adoption of STRVs on first-order (mean yield, yield variation and growing duration) and higher-order impacts (labour, fertilizer use and the planting of vegetables and legumes) using data collected from 900 households in 2018, a non-drought year. The methods control for potential selection bias by estimating correlated random-effects (CRE) models that eliminate unobserved plot and household-level heterogeneity. In addition, this study examines how survey design affects household responses and estimated treatment effects by running an experiment in which half of the households receive a more detailed module on agricultural inputs.

Results find that even in a non-drought year, STRVs have a higher yield, reduced yield variance and shorter growing duration than local landrace varieties. Planting any kind of improved variety or hybrid induces households to apply more chemical fertilizer to plots, while STRVs and older improved varieties are planted to plots with more early-season chemical fertilizer and land preparation labour. Including more detailed input data collected from the longer survey version does not impact estimates of first-order treatment effects. It does allow for a more thorough examination of higher-order impacts of adoption, providing information on early-season fertilizer use and land preparation labour.

Our results have important implications for policymakers, and this study contributes to the literature in several ways. First, the first-order impacts of drought-tolerant varieties have not been widely studied, and the evidence is currently inconclusive. One study in India found that a popular drought-tolerant variety provides a yield advantage over other varieties, while another found that it reduces yields, even in a drought year (Yamano et al., 2018; Dar et al., 2020). Our results provide evidence that in a non-drought year in Nepal, STRVs offer a unique set of first-order benefits to farmers, increasing mean yield while reducing variance and growing duration. These benefits can increase incomes and reduce poverty via increased sales or reduced purchases of rice. Because rice is a staple crop for so many households, this could also improve food security. Combined with reduced yield losses in drought years, STRVs can substantially increase farmers' resilience to climate change. It is important for policymakers to understand the first-order impacts of the adoption of STRVs in typical non-drought years to evaluate returns on investments in STRVs. In addition, uncertainty about whether drought will occur may be a barrier to the adoption of STRVs. If farmers are aware that STRVs perform at least as well as other modern varieties during non-drought years, this could facilitate adoption.

Our findings on higher-order outcomes also greatly improve understanding of how the development of STRVs can affect rural communities. For instance, studies such as Mottaleb et al. (2017) that make ex-ante predictions of productivity increases due to STRVs can use our results to improve their predictions. According to Emerick et al. (2016), who find that adoption of a flood-tolerant variety in India causes higher-order effects such as increased fertilizer and labour use, these effects can arise for a few reasons. First is an income effect: STRVs provide higher expected yields on average, which increase households' expected incomes. This, in turn, may increase input use because farmers are wealthier. Second, there could be a marginal productivity effect if yields of STRVs are more responsive to inputs relative to other varieties. Finally, there could be a risk effect: farmers may be more willing to invest resources in a variety that is less likely to fail. The authors argue that it is crucial for policymakers to take these higher-order impacts of the adoption of STRVs into consideration when evaluating returns on investments. Thus far, there has been little research on higher-order impacts of drought-tolerant varieties, and none in Nepal. It is necessary to explore whether the impacts found by Emerick et al. hold in this context, particularly because drought-tolerant varieties have the added advantage of being short-duration varieties that could induce higher-order impacts such as growing legumes after the rice harvest (Yamano et al., 2018; Dar et al., 2020).

Our paper provides a methodological contribution to the literature by using CRE models to estimate treatment effects. These models eliminate household-level unobserved heterogeneity and, for first-order outcomes, plot-level unobserved heterogeneity. They subtract within-group unobserved heterogeneity in the same way as fixed-effects (FE) models, but unlike FE models they allow for the estimation of coefficients for variables with no within-group variation. This is an important contribution, as randomized data are not always available, and it improves on other commonly used methods that use observational data to estimate treatment effects. We argue that this approach leads to unbiased estimates more reliably than commonly used instrumental-variable approaches, as it is often difficult to find a valid instrument, and when it is possible, these are usually at the household level rather than the plot level. When households cultivate multiple fields, they are likely to target STRVs toward certain fields (for instance, drought-tolerant varieties are likely to be planted on plots prone to drought). Not accounting for this source of endogeneity could lead to selection bias and an inability to identify treatment effects. Panel data methods, as used in Yorobe et al. (2016), can eliminate this bias, but they require more than one year of data collection, which can be cost-prohibitive.

Finally, we contribute to the literature on survey design by examining the practical importance of collecting more detailed data on agricultural inputs when estimating treatment effects of an STRV. Previous studies provide evidence that data on labour are sensitive to survey design and recall period, while data on other inputs are not (Beegle et al., 2012; Dillon et al., 2012; Bardasi et al., 2011; Deininger et al., 2011; Arthi et al., 2018). Like these papers, we use an experimental method to examine the effect of survey design on collecting data on agricultural inputs. Our main contribution is testing how these different data affect results in two ways: first, the precision of first-order impacts when inputs are used as explanatory variables, and, second, whether having more granular data to use as dependent variables provides greater nuance regarding the higher-order impacts of the adoption of STRVs. This will help researchers determine whether they should devote data collection resources to conduct longer survey questionnaires.

The next section of the paper describes the data collected for this study. This is followed by a section explaining the empirical strategy, including detailed descriptions of outcome and explanatory variables. Next, we provide an overview of our results, and finally we offer conclusions to our work.

2. Data

This study uses data from household and community surveys conducted in 75 villages in Lamjung, Tanahu and Gorkha districts in November and December 2018. The 12 villages with a Consortium for Unfavorable Rice Environments (CURE) seed producer group (SPG) were selected, 12 villages that were adjacent to these villages were randomly selected, and 51 additional villages were randomly selected. These 51 villages were selected from an area that includes the Village Development Committees[1] (VDCs) in which the SPG villages are located, and all surrounding VDCs. The study area is represented by the yellow area in Figure 1. We sampled villages in this way so that we could estimate the impact of SPGs on the adoption of STRVs (findings from this study, as well as more detail regarding data collection, can be found in Vaiknoras et al., 2020) and to increase the likelihood of sampling a sufficient number of households that adopted STRVs.

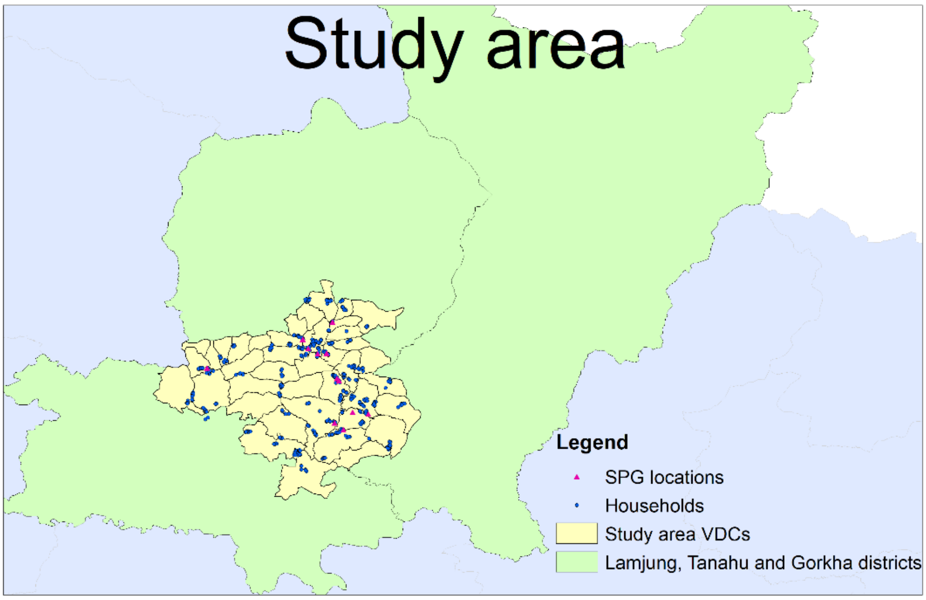

Figure 1. Map of Lamjung, Tanahu and Gorkha districts showing study area. Source: Vaiknoras et al. (2020).

Respondents from 12 randomly selected households were interviewed in each of the 75 selected villages for a total of 900 households. The survey included questions on household socio-economic characteristics, and GPS coordinates were collected for all households. The bulk of the survey collected detailed information on rice cultivation in the 2018 monsoon season (Nepal's main rice-growing season that runs from June to November) using three modules. The first of these identified each rice variety grown by the household in that season. Each variety was classified as either a traditional landrace variety, an old (released prior to 1990) modern improved variety (MV), a new MV (released in 1990 or later), an STRV, which is a subset of MVs, or a hybrid variety. This classification is important, as each of these variety types has a different yield potential.

The next module collected information on each plot cultivated by the household in that season, including the size of the plot and plot characteristics such as slope, whether it was irrigated during the 2018 monsoon season, and how prone to drought it is. Plots were defined as continuous parcels of land for which soil conditions were similar and input use was constant. For plots that had rice, additional questions on inputs were asked. Questions on labour asked about the application of labour per plot: how many people (household, paid and other unpaid) worked on the plot, the average number of days worked per person, and the average number of hours worked per day. Respondents were asked to consider all tasks for rice production on the plot from nursery and land preparation labour to threshing. This module also collected data on the quantity of organic fertilizer, chemical fertilizer and pesticides applied to all plots. All households answered these questions.

[1] A VDC is an administrative unit larger than a village but smaller than a district.

Half of the households, randomly selected, were administered a longer version of the questionnaire with an additional module that contained more detailed questions on labour and input use. This module asked the number of person-days by paid and unpaid men, paid and unpaid women and unpaid children spent on the following tasks (per plot): i) nursery, land preparation and planting; ii) weeding and pest control; iii) harvesting; and iv) threshing. It also asked more detailed questions on the application of fertilizer and pesticides: the number of times fertilizer was applied, the day in the season this occurred (with day 0 being the day of transplanting the rice seedlings into the field), the quantity per application, and for chemical fertilizer and pesticides, the type (diammonium phosphate (DAP), potash or urea for chemical fertilizer; herbicide, fungicide or insecticide).

Finally, the survey included a third module that linked the cultivated varieties to the households' plots and collected information at the variety-plot level. This included the quantity of seed of each variety planted on the plot, the area of the plot under which each variety was grown, and the quantity of grain of each variety harvested on the plot. This information allowed us to calculate yield, the multiplication ratio (quantity of seed harvested/quantity of seed planted) and seeding rate at the variety-plot level. For each variety on each plot, farmers also reported the age of seedlings on the day of transplantation, and the week and month of planting and harvesting, which allowed us to calculate growing duration at the variety-plot level. If households cultivated multiple varieties on one plot or cultivated the same variety on multiple plots, we identify these as separate observations. Plots were identified as contiguous parcels of land on which the same level of inputs was applied; therefore, all varieties in our data that were identified as being on a certain plot should have received the same amount of fertilizer, labour and pesticides.

The community survey interviewed village leaders regarding village services and amenities. Its purpose was to supplement the information collected at the household level. In particular, the community survey included questions about the presence of farmers' associations in the village and distance to extension services.

3. Descriptive statistics

To check whether survey length was truly assigned randomly to households, we compare descriptive statistics between households that received the long and short versions of the survey (Table A1). We look at general household descriptive statistics and characteristics that may have pushed enumerators to administer the shorter survey, such as those influencing difficulty reaching the household and survey length (e.g. number of cultivated plots). We find no differences in responses between assignment groups, indicating that assignment was random. Short-survey input responses also do not vary depending on survey assignment, providing additional evidence that assignment was random (Table 1).[2]

We compare short-survey responses to the sum of long-survey responses for fertilizer and labour to test whether they differ depending on how this information is collected (Table 1). The average quantity of organic and chemical fertilizer and pesticides does not vary by whether the household was administered a long or short version of the survey. Households applied about 8,600 kg/ha of organic fertilizer, 120 kg/ha of chemical fertilizer and 0.35 l/ha of pesticides according to both survey modules (pesticide use was low overall, and they were applied by only about 12 per cent of households). By contrast, estimates of labour use were far greater in the short-survey responses than long-survey responses. This could indicate that farmers are including labour for tasks beyond the ones specifically asked about or

[2] Although 50 per cent of households should have received the long survey version, only 45 per cent of households did. For 43 plot-level observations across 22 households, enumerators entered at the start of the survey that they would give the long version, but households did not answer the extended survey modules. We include these as short-survey observations so that we do not lose these observations; this does not affect the statistical similarity between the short-survey and long-survey groups of observations.

misunderstood the task categories. It could also mean that farmers are either over-reporting labour if asked about it generally or under-reporting if asked to remember labour by task, gender and unpaid vs. paid.

Our results are consistent with the literature. Beegle et al. (2012) found very little evidence of recall bias for fertilizer application but some bias for labour. They argue that fertilizer use may be less susceptible to recall bias than labour use because labour is used throughout the entire season, while fertilizer is generally applied only a few times. This holds true in our data; households that applied organic fertilizer or pesticides to their plots did so once on average per plot, and households that applied chemical fertilizer to their plots did so twice on average per plot. Other studies also found that the method of data collection and/or survey design (in particular, how labour tasks are defined) affected household responses for labour (Arthi et al. 2018; Dillon et al. 2012; Bardasi et al. 2011).

Table 1. Means (standard deviations) of inputs at the plot level, short-version vs. long-version survey responses

Variable	Short-survey responses from plots of households only assigned the short survey	Short-survey responses from plots of households assigned the long survey	Long-survey responses from plots of households assigned the long survey
Organic fertilizer (kg/ha): short-survey responses compared to sum of long-survey responses	8,682.94 (10,046.27)	8,635.81 (9,720.60)	7,974.79 (10,627.71)
Chemical fertilizer (kg/ha): short-survey responses compared to sum of urea, DAP and potash responses of long-survey responses	120.30 (106.74)	121.27 (113.11)	121.87 (112.77)
Pesticides (l/ha): short-survey responses compared to sum of long-survey responses	0.41 (1.94)	0.38 (2.10)	0.34 (1.65)
Labour (person-days/ha): short-survey responses compared to sum of weeding, land preparation, harvesting and threshing responses of long-survey responses	619.06 (575.95)	576.67 (488.53)	323.59 (193.98) ***
Number of observations	660	544	544

Note: */**/*** denotes statistical significance at 10, 5 and 1 per cent, respectively. Organic fertilizer estimate is based on 1,200 total observations, while chemical fertilizer is based on 1,199 observations due to missing responses. We also tested differences in short-survey responses between households that were assigned the short vs. the long survey and found that they did not differ from one another.

Households grow a mixture of rice variety types: 14 per cent of the household-plot-variety observations in our sample were local varieties; 19 per cent were old MVs; 24 per cent were non-STRV new MVs; 20 per cent were STRVs; and 23 per cent were hybrids (Table 2). STRVs were the most prevalent variety type (meaning there was more seed of STRVs planted to the plot than any other type) on 21 per cent of plots, compared to local varieties (9 per cent), old MVs (21 per cent), other new MVs (27 per cent) and hybrids (22 per cent).

Table 2. Distribution of rice seed types and mean (standard deviation) of characteristics of different rice variety types, 2018

Variety type	Distribution of varieties, % (N)	Most prevalent type on plot	Mult. ratio	Seeding rate, kg/ha	Season duration, weeks	Planting week (from first week of year)	Harvest week (from first week of year)	Grown on irrigated plot (1= yes)	Grown on plot prone to drought (1 = yes)
Local	14.38% (235)	9.18%	51.26 (51.29) ***	89.99 (79.29)	19.43 (2.52) ***	11.19 (2.15) **	30.62 (1.51) ***	0.89 (0.31) ***	0.52 (0.03) **
Old MV	18.79% (307)	20.70%	52.98 (47.85) ***	121.44 (70.80) ***	18.66 (1.72) ***	11.05 (11.64) ***	29.71 (1.38) ***	0.91 (0.29) ***	0.44 (0.50) ***
New MV	23.75% (388)	27.21%	72.91 (63.56)	97.63 (69.80)	18.38 (2.52) ***	11.07 1.91) ***	29.46 (1.43)	0.92 (0.27) ***	0.44 (0.50) ***
STRV[1]	19.77% (323)	21.04%	73.30 (75.46)	93.40 (75.78)	17.72 (2.52)	11.64 (2.19)	29.36 (1.52)	0.73 (0.45)	0.65 (0.48)
Hybrid	23.32% (381)	21.87%	315.14 (135.71) ***	22.09 (29.75) ***	17.96 (2.14)	11.43 (1.88)	29.36 (1.52)	0.88 (0.32) ***	0.50 (0.50) ***
Total	100% (1,634)	100%	121.77 (135.51)	82.35 (73.35)	18.34 (2.22)	11.28 (1.21)	29.62 (1.49)	0.87 (0.34)	0.51 (0.50)

Note: */**/*** denotes that the mean is different from that of STRVs at a 10, 5 or 1 per cent level of significance.

[1] Of the nine STRVs grown by farmers in our sample, eight were drought-tolerant, and one was submergence-tolerant, Swarna sub1. Swarna sub1 made up 6 per cent of the STRV observations in our sample; 90 per cent of observations for this variety were planted on irrigated plots, and 30 per cent on plots prone to drought.

The average multiplication ratio of STRVs is statistically identical to that of old and other new improved varieties, significantly higher than that of local varieties and lower than that of hybrid varieties. The seeding rate for STRVs was significantly higher than for hybrids and lower than for old MVs. The growing duration of STRVs is 17.72 weeks, which is nearly 2 weeks less than local varieties and also less than that of old and new MVs. All varieties were planted during the 11th week of the year, which corresponds to the first week of the month of Ashad,[3] but STRVs were planted later in the week on average than landraces, old and other new MVs. STRVs were harvested about a third of the way through the 29th week of the year, or the second week of Kartik,[4] about 2.5 days earlier than old MVs and over a week before local varieties. A majority of STRVs were planted on irrigated plots (73 per cent), although this is less than any other type of variety. A majority of STRVs (65 per cent) were grown on plots prone to drought, which is more than any other type of variety.

[3] This spans the months of June and July.
[4] This spans October and November.

Table 3. Means (standard deviations) of plot-level outcome variables and characteristics

Variable	Plots on which STRVs are the most prevalent type	Plots on which non-STRVs are the most prevalent type
Labour (person-days/ha)	626.81 (580.66)	594.69 (527.58)
Organic fertilizer (kg/ha)	9,266.12 (9,940.20)	8,515.27 (9,903.92)
Chemical fertilizer (kg/ha)	116.07 (99.44)	122.04 (112.38)
Pesticides (l/ha)	0.49 (2.70)	0.35 (1.68)
Grew legumes and/or vegetables in monsoon season (1= yes)	0.35 (0.48)	0.32 (0.46)
Slope (1 = yes)	0.79 (0.41)	0.68 (0.47) ***
Suffered from drought, 2018	0.08 (0.28)	0.03 (0.18) ***
Suffered from drought, 2017	0.21 (0.41)	0.09 (0.28) ***
Number of observations	252	946

Note: */**/*** denotes statistical significance at 10, 5 and 1 per cent, respectively.

The average quantities of labour, organic and chemical fertilizer, and pesticides do not differ between plots on which STRVs are most prevalent and other plots (Table 3). Plots on which STRVs are most prevalent are not more likely to have been cultivated with legumes and/or vegetables once rice is harvested. Detailed input values from the long survey version also do not vary by STRV and other plots, except that households use more threshing labour on STRV plots (Table A2). This includes fertilizer use applied over the entire season and fertilizer applied on or before the day of transplantation, which is true for the majority of organic fertilizer and about half of chemical fertilizer.

In 2018, drought was not common but was more prevalent on plots that were primarily planted with STRVs than other plots: 8 per cent of STRV plots suffered from drought, compared to 3 per cent of other plots. In 2017, drought was more common but displayed the same pattern: 21 per cent of STRV plots suffered from drought, while 9 per cent of other plots suffered from drought. This is consistent with STRVs being more likely to be planted on plots that are prone to drought and not irrigated. There is variation in plot susceptibility to drought at the household level (not shown in the table): about 11 per cent of households have at least one plot that is prone to drought and at least one that is not prone to drought. About 54 per cent of households that reported that a plot suffered from drought in 2018 and 42 per cent of households that reported the same for 2017 also had at least one plot that did not suffer drought in the corresponding year.

4. Estimating treatment effects

We observe first-order outcomes $O1_{ijk}$ (mean yield, yield variance and growing duration) of each variety *k* on plot *j* by household *i*:

$$O1_{ijk} = \beta_0 + \beta_1 T_{ijk} + \beta_2 S_{ijk} + \beta_3 P_{ij} + \beta_4 I_{ij}^{l} + \beta_5 H_i + \mu_i + c_{ij} + \epsilon_{ijk} \quad (1)$$

Each combination of *i, j,* and *k* is unique, meaning that if household *i* grew two varieties on plot *j*, this is two observations. Similarly, if household *i* grew the same variety on two different plots, this is also two separate observations. If a household cultivated only one variety, then it would have only one observation. Most households (73 per cent) grew more than one rice variety in 2018, while 24 per cent of plots were cultivated under more than one variety.[5] The first-order outcome variables in equation 1 are mean yield, yield variance and growing duration. As a proxy for yield, we use the logged value of the multiplication ratio for variety *k* grown on plot *j* by household *i*. The multiplication ratio is the quantity of grain harvested in kg divided by the quantity of seed planted in kg. The benefit of using the multiplication ratio over yield is that the multiplication ratio does not require an accurate estimate of land size and may, therefore, be a more accurate measure of productivity. Farmer-reported plot sizes can be inaccurate, especially if the plots are on sloped land and non-standard units of measurement are used in reporting size, both of which are common in Nepal (Keita et al., 2010; Carletto et al. 2015). We use the logged value because the distribution of multiplication ratios is highly skewed to the right. We also examine equation 1 using quantity in kg/land planted in ha as the dependent variable to determine whether there are differences in results between the two measures of yield.

We also estimate the impact of the adoption of STRVs on yield variability over space. Following the moment-based approach developed by Antle (1983) and the estimation procedures described by Wossen et al. (2017), variability is measured as the squared estimation errors from equation 1 or 3. We compute the estimation errors after estimating the yield regression by subtracting the predicted outcome value by actual outcome value. Next, we square these errors and use them as the dependent variable, regressed on the same treatment and explanatory variables as the mean yield equation. The final first-order outcome is the duration of the growing season, measured as the number of weeks between when the rice seedlings were transplanted into the field and when rice was harvested.

T_{ijk} refers to the seed type of variety *k* growing on plot *j* by household *i*; it includes four dummy variables, each of which equals 0 when the variety is a landrace type. The first dummy equals 1 when the variety is an old MV (released in 1990 or before); the second equals 1 when the variety is a new MV but not an STRV; the third equals 1 if the variety is an STRV; and the fourth equals 1 if the variety is a hybrid. We consider each variety type because each has a different potential yield, yield variance and growing duration. Under normal rainfall conditions, we expect that hybrids will have the highest yields, followed by STRVs and other new MVs, followed by older MVs and, finally, landraces. Since most farmers in our study area did not experience drought in the 2018 monsoon season, we do not expect the yield of STRVs to differ significantly from the yield of other MVs. We expect that the yield variance of STRVs will be lower than for traditional landraces, as their yields are less likely to vary due to variations in the availability of water, potentially even in a non-drought year. We do not expect other improved variety types or hybrids to have reduced variance. Because STRVs are bred to be short-duration varieties, they are expected to have a shorter growing duration than local varieties. Some other improved or hybrid varieties may have the same short-duration trait as STRVs, so they may also have a shorter growing duration.

S_{ijk} in equation 1 refers to variables related to the seed and seedlings of variety *k* grown on plot *j* by household *i*. This includes the seeding rate (the rate of seeds planted on the plot in kg/ha) and age of seedlings in days on the day of transplantation, and a dummy variable equal to 1 if the seed for this variety was certified (and 0 if it came from recycled planting material of household *i* or another household). SPG member farmers in the area were trained to lower their seeding rates to increase yields, so we expect that higher seeding rates will reduce yields. Finally, it also includes the area on plot *j* in ha on which variety *k* was cultivated.

[5] Of the households that grew an STRV in 2018, 15 per cent also grew a local variety, 19 per cent grew an old improved variety, 31 per cent grew another new improved variety, and 33 per cent grew a hybrid variety. Of the plots that had an STRV, 8 per cent also had a local variety, 10 per cent had an old improved variety, 11 per cent had another new improved variety, and 13 per cent had a hybrid variety.

Variables in P_{ij} refer to the plot characteristics of plot *j*. The slope variable is a dummy variable equal to 0 if the plot is flat and 1 if it has a gentle, moderate or steep slope. We also include a dummy variable equal to 1 if the respondent reported that the plot is susceptible to drought, and 0 otherwise. The irrigation dummy variable is equal to 1 if the plot is irrigated, and 0 otherwise.

I_{ij}^{l} is a vector of inputs applied on plot *j*. When the superscript *l* = 1, the vector includes input variables computed from the short version of the questionnaire, and when *l* = 2, the vector includes inputs measured from the long survey version. Both vectors include a dummy variable equal to 1 if the household applied pesticides[6] to plot *k*. Vector *l* = 1 also includes the total quantity of organic fertilizer and chemical fertilizer applied per ha to plot *k*, and the total amount of labour in person-days/ha applied to plot *k*. Vector *l* = 2 instead includes the quantity of organic fertilizer (kg/ha), which is the sum of all applications collected from the longer survey, the quantity of urea, DAP and potash (kg/ha) each, and four variables to capture labour: land preparation, weeding, harvesting and threshing, each in person-days/ha on the plot. These are each aggregated over paid and unpaid and over men, women and children.[7] We expect that higher quantities of fertilizer and labour will increase yields.

Household-level variables (H_i) included in the models are the sex of the household head (1 = female) and a dummy variable equal to 1 if the household head is literate. We also include the elevation of the household dwelling in metres above sea level (masl). Finally, this vector includes a dummy variable equal to 1 if the household resides in a village where there is an SPG, which has been found to increase adoption of STRVs and use of some best management practices that could affect the outcomes of interest (Vaiknoras et al., 2020).

Equation 1 is a random-effects (RE) model that assumes that additional unmeasured factors exist that affect outcomes of interest. Some of these factors, such as unobserved farmer ability, vary only across households and are included in μ_i. Others vary within households and across plots, such as soil quality; these are included in c_{ij}. All remaining factors that might also vary across variety-plot observations of the seed of variety *k* grown on plot *j* (such as quality of seed) are included in the error term ϵ_{ijk}. Unobserved household and plot characteristics are likely to be correlated with the adoption of STRVs, biasing treatment effect estimates. We eliminate this bias by de-meaning our data to the greatest extent possible and estimating CRE models which produce within-group effects that are identical to FE models but also estimate between-effects (Schunck, 2013):

$$O1_{ijk} = \beta_0 + \beta_1 T_{ijk} + \beta_2 S_{ijk} + \beta_3 P_{ij} + \beta_4 I_{ij}^{l} + \beta_5 H_i + \pi_1 \overline{T_{ij}} + \pi_2 \overline{S_{ij}} + \pi_3 \overline{P_i} + \pi_4 \overline{I_i} + v_{ij} + m_i + \epsilon_{ijk} \quad (2)$$

Equation 2 includes the plot-level means $\overline{T_{ij}}$ and $\overline{S_{ij}}$ of the variables in T_{ijk} and S_{ijk}. This removes the between-plot effects of these variables, including those coming from unobserved plot characteristics such as soil quality. Thus, β_1 and β_2 are estimates of the within-plot effects of variables T_{ijk} and S_{ijk}, respectively, free of plot-level selection bias that arises when households target varieties or practices towards plots with certain characteristics. Coefficients $\pi_1$and π_2 measure the between-plot effects of variables in T_{ijk} and S_{ijk}, respectively. Adding $\overline{P_i}$ and $\overline{I_i}$, which represent household means for plot-level characteristics and inputs used, respectively, removes the between-household effects for these variables, rendering β_2 and β_3

[6] Pesticide use is very low in the area, so we include it only as a dummy variable. Only 51 households that received the longer module applied any pesticides, and they mostly only applied one type once. Thus, the longer module did not provide much new information about pesticides.
[7] We did not convert these to an adult-equivalent measure because a negligible quantity of labour was done by children: only 0.91 per cent of plots had any child labour used on them.

estimates of their within-household effects. This ensures that the estimated coefficients in β_2 and β_3 are free from household selection bias. Coefficients $\pi_3$and π_4 measure the between-household effects of variables P_{ij} and I^l_{ij}. β_5 remains the between-household effect of household-level variables in H_i.

Second-order outcomes $O2_{ij}$ (input use and legume/vegetable cultivation) are observed for each plot *j* cultivated by household *i*. The RE version of these models is:

$$O2_{ij} = \beta_0 + \beta_1 T_{ij} + \ \beta_3 P_{ij} + \beta_5 H_i + \mu_i + c_{ij} \quad (3)$$

Second-order outcomes in $O2_{ij}$ include total quantity of organic fertilizer in kg/ha, total quantity of chemical fertilizer in kg/ha and total person-days of labour applied per hectare on plot j. We do not estimate the effect on pesticides because pesticide use was so low in our sample. We hypothesize that farmers who grow an STRV will use more fertilizer and more labour due in part to the reduction in the risk of yield loss due to drought. For inputs applied at the start of the season, this should hold true regardless of whether there is drought that season, because farmers do not yet know what weather conditions will be, and we expect that households are more willing to invest in inputs for crops that are less likely to fail. As the season continues, farmers observe the weather conditions. In the case of drought, we expect STRVs to receive far more inputs than non-STRVs, as the likelihood of non-STRV crop failure increases. In the case of normal weather/no drought, input use for STRVs and non-STRVs should equalize as the season continues, as risk of crop failure due to drought lowers and converges to zero for all varieties. While 2018 was not a drought year, the vast majority of organic fertilizer and about half of chemical fertilizer were applied at the start of the season, so we expect to see effects of the adoption of STRVs on those outcomes. To investigate further, we estimate effects on early-season fertilizer applications and land preparation labour using responses from the long survey version.

Because STRVs are short-duration varieties, their adoption provides households with an opportunity to cultivate legumes or vegetables on the plot once rice is harvested (legumes and vegetables were combined because fewer than 2 per cent of plots had vegetables cultivated on them). Therefore, we also estimate the impact of adoption of STRVs on the probability that a household grows legumes and/or vegetables on the plot during the monsoon season.

In equation 3, the treatment variable vector T_{ij} again refers to variety type as in equations 1 and 2. Because plots may have had more than one variety cultivated on them, this represents the variety type that has the greatest quantity of seed planted on the plot, using a series of dummy variables for which 0 = landrace for each. For the first dummy variable, 1 equals old MV; for the second, 1 equals new MV but not STRV; for the third, 1 equals STRV; and for the fourth, 1 equals hybrid. P_{ij} and H_i are the same plot- and household-level variables included in equations 1 and 2, with the addition of plot size in P_{ij}.

To estimate the CRE model for equation 3, $\overline{T_i}$ and $\overline{P_i}$ are included, which eliminate between-household effects of variety choice and plot characteristics:

$$O2_{ijk} = \ \beta_0 + \beta_1 T_{ij} + \beta_3 P_{ij} + \beta_5 H_i + \pi_1 \overline{T_i} + \pi_3 \overline{P_i} + \ m_i + c_{ij} \quad (4)$$

CRE models remove major sources of potential bias in the treatment effect estimates, but they do not eliminate all bias. In equation 2, there could remain factors that vary over *i, j* and *k* in ϵ_{ijk} that could bias results. For example, seed of certain varieties could be of higher quality than others. We include variety-level variables to control for as much of this heterogeneity as possible, reducing the likelihood of bias. In model 4, there is a greater chance of bias because unobserved plot-level heterogeneity remains. Even if households were to target certain varieties towards plots with specific unobserved characteristics, treatment effects in model 2 (β_1) would not be biased; however, the treatment effects in model 4 (β_2) could be biased. In addition, the CREs do not eliminate bias that could be present in β_5, π_1, π_2, or π_3, as they can still be correlated with the remaining error terms v_{ij} and m_i. This does not affect our treatment estimates in either model but means that household-level covaraites and plot and household between effects should not be interpreted as causal.

β_1 and β_2 from model 2 are estimated using only within-plot variation, and they lose efficiency when there is little within-plot variation. Likewise, β_3 and β_4 from models 2 and 4 only use within-household variation. We examine whether these households and plots are representative of all households and plots and find that they differ in several ways (Tables A3 and A4). Households that grew more than one variety in 2018 grew 2.37 varieties on average and have an older head of household on average and a greater number of household members. They live farther away from roads and at a higher elevation. Not surprisingly, they cultivated a greater number of plots in 2018. Plots with more than one variety were larger, less likely to be sloped, and have less labour and less fertilizer applied per ha. These differences mean that our results from models 2 and 4 are not necessarily representative of the greater population; this is important to keep in mind as we interpret our estimates.

We perform an augmented regression test on the statistical significance of π_1, π_2, and π_3 to test whether the between-group estimate is significantly different from the within-group estimate (Baltagi, 2008). If they are not significantly different (if π_1, π_2, or π_3 is not statistically significant), then selection bias does not affect our results and the RE model is valid. It is also likely to be more efficient than the CRE model.

Table 4. Explanatory variables used in analysis

Variable	Description
S_{ijk} Variety-level variables	
Seeding rate	Seeding rate or density of seedlings planted in kg/ha of variety *k* on plot *j*
Age of seedlings	Age of seedlings (in days) when transplanted to the field
Certified seed	At least 50% of planting material was certified or truthfully labelled
Area cultivated	Area on plot *j* that variety *k* was grown on in hectares
I_{ij} Input variables (*l* = 1)	
Chemical fertilizer	Total quantity of chemical fertilizer in kg/ha applied on plot
Organic fertilizer	Total quantity of organic fertilizer in kg/ha applied on plot
Labour	Total person-days of labour/ha (both unpaid and hired) applied on plot
Pesticides	Household applied pesticides to plot *k* (1 = yes)
I_{ij} Input variables (*l* = 2)	
Urea	Total quantity of urea in kg/ha applied on plot
DAP	Total quantity of DAP in kg/ha applied on plot
Potash	Total quantity of chemical potash in kg/ha applied on plot
Organic fertilizer (detailed)	Sum of organic fertilizer applications in kg/ha applied on plot, obtained from detailed questioning of fertilizer applications
Pand preparation and planting labour	Total person-days/ha of paid and unpaid labour devoted to nursery preparation, land preparation and planting
Weeding/pest control labour	Total person-days/ha of paid and unpaid labour devoted to weed and pest control
Harvesting labour	Total person-days/ha of paid and unpaid labour devoted to harvesting
Threshing labour	Total person-days/ha of paid and unpaid labour devoted to threshing
Pesticides	Household applied pesticides to plot (1 = yes)
P_{ij} Plot characteristics	
Irrigated	Plot is irrigated (1 = yes)
Slope	0 = flat; 1 = gentle, moderate or steep slope
Prone to drought	Susceptibility of rice plots to drought, as assessed by the farmer (0 = not at all; 1 = somewhat; average; very; extremely)
Plot size	Size of plot in hectares
H_i Household characteristics	
Elevation	Elevation of the household, in metres above sea level (masl)
Sex	Sex of head of household (1 = female)
Literate	Head of household is literate (1 = yes)
SPG village	There is an SPG in the village

5. Results

5a. Impact of the adoption of STRVs on first-order outcomes

To obtain the most precise yield estimates possible, we first estimate the first-order impact equations using the more basic input vector (l = 1) for all households (Table 5). Next, to compare the precision of first-order estimates between the basic (l = 1) and more detailed (l =

2) input vectors, mean yield, yield variance and growing duration equations are estimated with only the sub-sample of households that received the longer survey questionnaire.

The coefficients on the means of each variety type for all three first-order outcome variables are not significant, indicating that between effects do not vary significantly from within effects. Thus, our treatment effects are not driven by selection bias, and the RE models are valid, so we discuss our results as ranges between the two estimates. Estimated STRV treatment effects across RE and CRE results are similar, indicating that relying only on plots with more than one variety does not affect results by much. Compared to landraces, old MVs increase yield by 21 per cent, new (non-STRV) MVs increase yield by 28 per cent, STRVs by 27 per cent according to RE results and by 30 per cent according to CRE results, and hybrids by 124 per cent according to RE results and by 119 per cent according to CRE results. Each of these effects is statistically significant at 1 per cent for RE results; STRV and hybrid coefficients are also statistically significant at 1 per cent in the CRE model. These effects all represent the within-plot effects – i.e. the effect of growing an STRV or other variety type vs. a landrace on a particular plot. In the RE model, the 95 per cent confidence intervals for STRVs overlap those of old and new MVs, providing evidence that the yield gain of STRVs is equivalent to that of old and other new MVs.

STRVs reduce the squared residuals from the yield equation, which represents yield variance, by 0.20 to 0.45 from local landraces (representing a reduction of about 50–100 per cent); this is significant at 5 per cent for both RE and CRE models. We find no evidence that other MVs or hybrids reduce yield variance relative to landraces.

Table A1 shows results for which the dependent variable is mean yield and yield variance, where yield is measured as quantity of rice harvested in kg/area planted in ha. Results for impacts of STRV and other MVs on mean yield are similar to those in Table 5, while coefficients for hybrids are much smaller (though still significant). For yield variance, STRV results are similar, but now in the RE results, other new MVs also reduce variance.

STRVs reduce the number of weeks between seedling transplantation and harvest by 1.26–1.32 weeks (significant at 1 per cent). Similarly, hybrids reduce this time by 1.07–1.51 weeks (significant at 1 per cent). Non-STRV new MVs reduce this duration by 0.64–0.65 weeks (significant at 1 per cent). The 95 per cent confidence intervals for STRVs overlap those of other new MVs and hybrids. There is no evidence that old MVs have a shorter growing duration than landraces.

Other variety-specific characteristics are significant as well. Increasing the seeding rate reduces yields by 0.7–0.8 per cent for every additional kg/ha of seed planted. Using certified seed increases yield by 17 per cent; this is not significant in the CRE model, but the plot mean is also not significant, indicating that the RE result is valid. An additional kg/ha in the seeding rate increases yield variance by 0.001 according to RE results. Being planted on an additional hectare of land increases yield by 39 per cent. However, plots on which more land is cultivated reduce yield by 81 per cent for each additional hectare. This indicates that larger plots produce lower yields, but for an individual variety, being planted on more land increases yield. It could be that farmers plant larger areas with varieties they believe will be high yielding.

Several plot-level variables are significant determinants of yield in the RE but not CRE models: in the RE model, an additional kg/ha of chemical fertilizer increases yield by 0.1 per cent, growing rice on a sloped field reduces yield by 7.5 per cent, and growing rice on an irrigated field increases yield by 11.8 per cent. While the CRE results are not significant for these variables, neither are their household means, providing evidence that RE results are valid. An additional kg/ha of chemical fertilizer has a small effect on variance, reducing the squared residuals of mean yield by 0.001. An additional kg/ha of chemical fertilizer reduces growing duration by 0.002 weeks according to RE results. Being planted on an irrigated field increases the duration by 0.55 weeks according to RE results. While slope increases the duration in the RE model results, it is not significant in the CRE model, while the household mean slope is significant in the CRE model. Thus, we conclude that slope does not have a true effect on the duration.

Finally, households with a literate head of household achieve durations that are 0.39 weeks shorter than households with a non-literate head of household. An additional masl reduces yield by 0.02 per cent and increases growing duration by 0.001 weeks. Living in a village with an SPG increases yield by about 15.4 per cent.

Table 5. Coefficient (standard error) of RE and CRE estimates of the impact of variety type and covariates on mean yield, yield variance and growing duration

Variables	(1) Yield mean: Plot RE	(2) Yield variance: Plot RE	(3) Season duration: Plot RE	(4) Yield mean: Plot CRE	(5) Yield variance: Plot CRE	(6) Season duration: Plot CRE
T_{ijk}						
Variety type						
Old MV	0.208***	-0.014	-0.321*	0.151	-0.093	-0.165
	(0.069)	(0.134)	(0.176)	(0.122)	(0.145)	(0.216)
New MV (not STRV)	0.278***	-0.118	-0.646***	0.159	-0.150*	-0.637***
	(0.064)	(0.077)	(0.194)	(0.102)	(0.088)	(0.234)
STRV	0.268***	-0.196**	-1.316***	0.297**	-0.450***	-1.264***
	(0.064)	(0.089)	(0.222)	(0.120)	(0.174)	(0.317)
Hybrid	1.242***	-0.057	-1.068***	1.190***	-0.143	-1.513***
	(0.071)	(0.092)	(0.238)	(0.115)	(0.132)	(0.346)
$\overline{T_{ij}}$						
Mean old MV				0.086	0.134	-0.389
				(0.136)	(0.248)	(0.362)
Mean new MV (not STRV)				0.178	0.053	-0.121
				(0.121)	(0.154)	(0.380)
Mean STRV				-0.018	0.385*	-0.144
				(0.138)	(0.226)	(0.455)
Mean hybrid				0.093	0.132	0.562
				(0.143)	(0.194)	(0.488)
X_{ijk}						
Seeding rate (kg/ha)	-0.008***	0.001**	0.001	-0.007***	0.002	-0.003
	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.002)
Age of seedlings (days)	-0.005	-0.004	0.011	-0.011	-0.028	-0.036
	(0.004)	(0.004)	(0.019)	(0.014)	(0.018)	(0.059)
Certified (1 = yes)	0.169***	-0.012	0.089	0.116	0.019	0.218
	(0.038)	(0.048)	(0.134)	(0.087)	(0.101)	(0.225)
Area cultivated (ha)	-0.259*	-0.124	0.780**	0.390**	-0.114	1.186*
	(0.133)	(0.209)	(0.358)	(0.199)	(0.264)	(0.641)

$\overline{X_{ij}}$						
Mean seeding rate (kg/ha)				-0.000	-0.001	0.006**
				(0.001)	(0.001)	(0.002)
Mean age of seedlings (days)				0.006	0.029	0.057
				(0.014)	(0.019)	(0.061)
Mean certified seed (1 = yes)				0.054	-0.034	-0.210
				(0.100)	(0.118)	(0.282)
Mean area cultivated (ha)				-0.812***	0.049	-0.663
				(0.259)	(0.377)	(0.784)
I_{ij}						
Pesticides (1 = yes)	0.085*	-0.041	-0.305	-0.170	-0.115	-0.058
	(0.045)	(0.052)	(0.219)	(0.155)	(0.118)	(0.630)
Organic fertilizer (kg/ha)	0.000	0.000	0.000*	-0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Chemical fertilizer (kg/ha)	0.001***	-0.001**	-0.002***	0.001	0.000	0.000
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.002)
Labour (person-days/ha)	-0.000	0.000	0.000**	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\overline{I_i}$						
Mean pesticides (1 = yes)				0.275*	0.070	-0.244
				(0.158)	(0.123)	(0.658)
Mean organic fert (kg/ha)				0.000	-0.000	0.000
				(0.000)	(0.000)	(0.000)
Mean chemical fert (kg/ha)				0.000	-0.001*	-0.003
				(0.000)	(0.001)	(0.002)
Mean labour (person-days/ha)				-0.000	0.000	-0.000
				(0.000)	(0.000)	(0.000)
P_{ij}						
Slope (1 = yes)	-0.075**	0.097**	0.753***	-0.104	-0.022	-0.413
	(0.033)	(0.048)	(0.145)	(0.099)	(0.094)	(0.549)
Irrigated (1 = yes)	0.118**	0.016	0.550***	0.097	-0.006	0.284
	(0.048)	(0.074)	(0.209)	(0.099)	(0.080)	(0.502)
Prone to drought (1 = yes)	-0.006	0.053	-0.002	-0.114	0.068	-0.595
	(0.034)	(0.070)	(0.135)	(0.092)	(0.099)	(0.411)
$\overline{P_i}$						
Mean slope (1 = yes)				0.031	0.132	1.231**
				(0.105)	(0.107)	(0.572)
Mean irrigation (1 = yes)				0.004	0.081	0.283
				(0.112)	(0.116)	(0.544)
Mean prone to drought (1 = yes)				0.131	-0.018	0.682
				(0.099)	(0.115)	(0.431)

H_i						
Elevation (masl)	-0.000***	0.000	0.001***	-0.000***	0.000	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Sex (1 = female)	-0.032	-0.028	-0.002	-0.033	-0.028	0.014
	(0.034)	(0.033)	(0.152)	(0.034)	(0.031)	(0.152)
Literate (1 = yes)	0.009	0.063	-0.393***	0.006	0.068	-0.376***
	(0.034)	(0.054)	(0.140)	(0.034)	(0.053)	(0.140)
SPG village (1 = yes)	0.156***	-0.010	0.070	0.154***	-0.034	0.097
	(0.038)	(0.042)	(0.168)	(0.037)	(0.038)	(0.169)
Constant	4.487***	0.196	17.073***	4.485***	0.011	16.850***
	(0.147)	(0.170)	(0.639)	(0.161)	(0.227)	(0.717)
Number of observations	1,467	1,467	1,443	1,467	1,467	1,443
Number of plots	1,117	1,117	1,106	1,117	1,117	1,106

Note: */**/*** denotes statistical significance at 10, 5 and 1 per cent, respectively. All standard errors are robust to heteroscedasticity.

5b. Comparing results between long- and short-survey responses

Table 6 presents mean yield, yield variance and growing duration RE results for the sub-sample of households that were randomly assigned to the longer version of the household questionnaire. Only RE results are presented because the plot means of the treatment variables in the CRE (presented in Table 5) are not significant, and reducing the sample by half already reduces the variance in the results. Columns 1–3 present results using the basic input vector (l = 1), while columns 4–6 present results using the more detailed input vector (l = 2) explained in Table 1. We include these two sets of results to provide a valid comparison, since standard errors are expected to increase due to the reduction in sample size alone.

Reducing the sample by half but leaving the covariates the same as the models in Table 5 changes some of the coefficients and standard errors of the treatment variable; in particular, old MVs no longer have an effect on yield but do have a negative effect on yield variance. In general, we consider the results from Table 5 more reliable because they use a larger sample. Comparing the results from columns 1–3 and columns 4–6, we see that adding the more detailed input variables has a negligible effect on our treatment effect estimates; coefficients change only slightly. Thus, obtaining the more detailed input variables makes no real difference in estimating the treatment effects of the adoption of STRVs on mean yield, yield variance and season duration. In addition, we gain little insight into the role of inputs on our first-order outcomes; in the models where l = 2, urea and DAP have similar effects on yield and yield variance as chemical fertilizer does when l = 1, indicating that we are able to assess the role of chemical fertilizer with only basic questions. Potash is not significant, which could be meaningful; estimating the role of nutrients individually could provide an indication of which nutrients are needed more than others. Only one of the labour variables is significant; threshing is negatively associated with growing duration. Early harvesting could leave households more time for threshing at the end of the season.[8]

[8] Because harvesting and threshing are done after yields have been realized, we also estimated this model using only land preparation and weeding labour variables as part of the set of detailed labour variables; the remaining labour variables are still insignificant.

Table 6. Coefficient (standard error) of RE estimates of the impact of variety type and covariates on mean yield, yield variance and growing duration, comparing basic with detailed input variables for households that received the long survey version

Variables	(1) Yield mean: Plot RE l = 1	(2) Yield variance: Plot RE l = 1	(3) Season duration: Plot RE l = 1	(4) Yield mean: Plot RE l = 2	(5) Yield variance: Plot RE l = 2	(6) Season duration: Plot RE l = 2
T_{ijk}						
Variety type						
Old MP	0.188*	-0.213**	-0.477**	0.195*	-0.206**	-0.466*
	(0.108)	(0.103)	(0.242)	(0.106)	(0.100)	(0.240)
New MP (not STRV)	0.263**	-0.134	-0.646**	0.275***	-0.135	-0.656**
	(0.106)	(0.106)	(0.301)	(0.105)	(0.105)	(0.304)
STRV	0.226**	-0.246**	-1.334***	0.227**	-0.244**	-1.325***
	(0.104)	(0.115)	(0.313)	(0.103)	(0.117)	(0.320)
Hybrid	1.190***	-0.019	-1.019***	1.199***	-0.016	-1.069***
	(0.130)	(0.134)	(0.343)	(0.130)	(0.137)	(0.350)
X_{ijk}						
Seeding rate (kg/ha)	-0.008***	0.002*	0.001	-0.007***	0.002*	0.001
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)
Age of seedlings (days)	-0.015***	-0.003	0.000	-0.015***	-0.003	-0.004
	(0.005)	(0.006)	(0.028)	(0.005)	(0.006)	(0.028)
Certified seed (1 = yes)	0.131**	0.046	0.004	0.126**	0.054	0.068
	(0.062)	(0.058)	(0.203)	(0.061)	(0.058)	(0.205)
Area cultivated (ha)	-0.363**	-0.088	0.751	-0.431**	-0.127	0.382
	(0.179)	(0.143)	(0.625)	(0.190)	(0.144)	(0.667)
$I_{ijl=1}$						
Pesticides (1 = yes)	0.138**	-0.108***	-0.299	0.128**	-0.114***	-0.324
	(0.062)	(0.041)	(0.407)	(0.062)	(0.042)	(0.402)
Organic fertilizer (kg/ha)	-0.000	0.000	0.000			
	(0.000)	(0.000)	(0.000)			
Chemical fertilizer (kg/ha)	0.001***	-0.001**	-0.003***			
	(0.000)	(0.000)	(0.001)			
Labour (person days/ha)	0.000	0.000	0.000			
	(0.000)	(0.000)	(0.000)			
$I_{ijl=2}$						
Organic fertilizer from detailed survey (kg/ha)				-0.000	0.000	-0.000
				(0.000)	(0.000)	(0.000)
Urea (kg/ha)				0.001***	-0.001***	-0.002
				(0.000)	(0.000)	(0.002)

DAP (kg ha)				0.001**	-0.001*	-0.002
				(0.000)	(0.000)	(0.002)
Potash (kg ha)				0.001	-0.001	-0.006
				(0.002)	(0.002)	(0.007)
Land preparation labour (person-days/ha)				-0.000	-0.000	0.001
				(0.000)	(0.000)	(0.001)
Weeding labour (person-days/ha)				-0.000	-0.000	-0.001
				(0.000)	(0.001)	(0.002)
Harvesting labour (person-days ha)				0.000	0.000	0.005*
				(0.001)	(0.001)	(0.003)
Threshing labour (person-days/ha)				-0.000	-0.000	-0.008**
				(0.001)	(0.001)	(0.003)
P_{ij}						
Slope (1 = yes)	-0.073	0.067	0.666***	-0.055	0.068	0.660***
	(0.047)	(0.048)	(0.215)	(0.050)	(0.051)	(0.220)
Irrigated (1 = yes)	0.113	0.058	0.470	0.111	0.076	0.544*
	(0.070)	(0.077)	(0.312)	(0.070)	(0.088)	(0.313)
Prone to drought (1 = yes)	-0.036	0.087	-0.139	-0.034	0.102	-0.073
	(0.048)	(0.071)	(0.205)	(0.051)	(0.080)	(0.211)
H_i						
Elevation (masl)	-0.000**	0.000**	0.001**	-0.000**	0.000**	0.001
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)
Sex (1 = female)	-0.089**	-0.079*	0.095	-0.091**	-0.092**	0.097
	(0.046)	(0.045)	(0.235)	(0.046)	(0.045)	(0.227)
Literate (1 = yes)	-0.031	-0.020	-0.376*	-0.027	-0.021	-0.330
	(0.048)	(0.081)	(0.210)	(0.049)	(0.085)	(0.211)
SPG village (1 = yes)	0.203***	0.041	-0.021	0.194***	0.040	-0.025
	(0.058)	(0.053)	(0.229)	(0.057)	(0.047)	(0.221)
Constant	4.877***	0.038	17.745***	4.927***	0.072	18.234***
	(0.230)	(0.256)	(0.969)	(0.233)	(0.250)	(0.943)
Number of observations	644	644	636	645	645	637
Number of plots	499	499	497	500	500	498

Note: */**/*** denotes statistical significance at 10, 5 and 1 per cent, respectively. All standard errors are robust to heteroscedasticity. Differences in sample sizes are due to missing observations. Pesticides is listed as being under $I_{ijl=1}$, but it is also in $I_{ijl=2}$.

5c. Impact of the adoption of STRVs on second-order outcomes

Plots cultivated mainly under STRVs[9] have between 21 and 44 additional kg/ha of chemical fertilizer applied to them compared to plots cultivated under landraces (Table 7). Households

[9] We also estimated these models using only plots that were cultivated with one type of variety (Tables A2 and A3). Results are very similar to those presented in Table 7, except that all MV and hybrid variety types have increased male land preparation labour.

apply between 25 and 41 additional kg/ha of chemical fertilizer to plots cultivated under hybrids, new MVs and old MVs compared to those under landraces; the 95 per cent confidence interval of STRVs overlaps those of these other variety types. We find no effect of cultivation of STRVs (or hybrid or other MVs) on labour or organic fertilizer use. In contrast to previous research (Yamano et al., 2018; Dar et al., 2020), we find no effect on legume/vegetable cultivation (Table 7). Although we expected to observe effects of the adoption of STRVs on organic fertilizer use and legume/vegetable cultivation, the descriptive statistics shed light on why these treatment effects are not significant. Households apply a large amount of organic fertilizer to all of their plots regardless of variety type. In addition, although households do achieve shorter growing durations with STRVs compared to landraces (Table 5), this reduction is split between slightly later planting and slightly earlier harvesting (Table 2).

Other plot characteristics also correlate with second-order outcomes. While irrigation and being prone to drought have a positive affect on labour in the RE model, neither is significant in the CRE results, indicating that households with irrigated and drought-prone fields tend to use more labour. Sloped fields are more likely to be cultivated under legumes or vegetables according to RE results, but this is not significant in CRE results. The larger the plot, the less labour and organic and chemical fertilizer applied in both RE and CRE models.

Household characteristics also affect second-order outcomes (though we are not able to explore the potential endogeneity of these characteristics). As elevation rises, households apply less labour, less organic fertilizer and less chemical fertilizer to their plots. Households in SPG villages apply less labour and less chemical fertilizer but are more likely to cultivate legumes and vegetables, which is consistent with Vaiknoras et al. (2020). Finally, women farmers are less likely to cultivate legumes and vegetables, while literate farmers are more likely to do so.

Table 7. Household RE and CRE estimates of the impact of the cultivation of STRVs on input use and legume and vegetable cultivation

Variables	(1) Labour RE	(2) Labour CRE	(3) Organic fertilizer RE	(4) Organic fertilizer CRE	(5) Chemical fertilizer RE	(6) Chemical fertilizer CRE	(7) Legumes/ vegetables RE	(9) Legumes/ vegetables CRE
T_{ij}								
Variety type								
Old MV	21.338	20.203	-1,339.139	239.124	31.501***	32.159**	0.034	0.014
	(56.805)	(98.829)	(1,228.495)	(2,074.673)	(10.240)	(15.523)	(0.052)	(0.089)
New MV (not STRV)	25.450	61.319	-1,937.891*	-511.770	30.882***	40.725***	0.021	0.005
	(58.249)	(105.933)	(1,176.528)	(1,799.364)	(9.126)	(12.808)	(0.050)	(0.079)
STRV	41.926	4.723	-267.888	1,180.376	21.477**	44.449***	0.046	0.038
	(57.113)	(99.138)	(1,196.429)	(1,864.116)	(8.888)	(13.230)	(0.051)	(0.082)
Hybrid	15.237	62.813	69.609	2,313.113	24.872***	29.024**	0.062	0.037
	(56.663)	(98.267)	(1,149.113)	(1,610.457)	(9.651)	(14.157)	(0.050)	(0.080)
$\overline{T}_i$								
Mean old MV		2.785		-2,800.395		0.078		0.024
		(128.506)		(2,469.195)		(21.250)		(0.110)
Mean new MV (not STRV)		-68.537		-2,680.027		-12.630		0.019
		(129.992)		(2,203.090)		(19.492)		(0.102)
Mean STRV		59.706		-3,076.955		-35.208*		0.003

		(132.364)		(2,264.393)		(19.678)		(0.106)
Mean hybrid		-100.321		-3,940.132*		-4.371		0.038
		(122.530)		(2,085.001)		(21.232)		(0.103)
P_{ij}								
Slope (1 = yes)	3.866	24.432	1,181.207*	1,137.309	4.096	3.452	0.195***	0.132
	(34.308)	(52.787)	(649.142)	(1,280.278)	(7.257)	(21.758)	(0.032)	(0.086)
Irrigated (1 = yes)	105.949**	-114.366	-1,394.989	-2,619.171*	4.214	4.383	-0.036	-0.030
	(46.707)	(83.289)	(859.735)	(1,352.192)	(11.755)	(19.422)	(0.039)	(0.066)
Prone to drought (1 = yes)	98.521***	-71.979	-457.838	421.579	22.430***	-14.684	-0.047*	-0.011
	(31.110)	(53.012)	(605.570)	(1,157.527)	(6.270)	(10.976)	(0.028)	(0.056)
Plot size (ha)	-682.358***	-1,373.152***	-7,813.246***	-12,520.615***	-86.087***	-101.083***	0.085	0.173
	(130.493)	(194.281)	(1,767.803)	(3,732.828)	(16.694)	(28.610)	(0.063)	(0.166)
$\bar{P}_i$								
Mean slope (1 = yes)		-22.184		209.840		-1.707		0.074
		(65.934)		(1,509.563)		(23.443)		(0.093)
Mean irrigated (1 = yes)		381.443***		2,709.067*		-5.652		-0.005
		(90.375)		(1,629.671)		(22.700)		(0.083)
Mean prone to drought (1 = yes)		231.706***		-1,322.509		55.921***		-0.049
		(66.564)		(1,366.498)		(14.079)		(0.065)
Mean plot size (ha)		847.748***		5,566.940		16.731		-0.101
		(219.071)		(4,036.266)		(34.567)		(0.180)
H_i								
Elevation (masl)	-0.264***	-0.264***	-10.808***	-11.153***	-0.066***	-0.064***	0.000	0.000
	(0.069)	(0.074)	(1.481)	(1.532)	(0.017)	(0.017)	(0.00)	(0.000)
Sex (1 = female)	-46.088	-37.437	205.386	261.928	3.235	3.756	-0.106***	-0.104***
	(42.414)	(42.860)	(828.074)	(829.253)	(8.927)	(8.700)	(0.038)	(0.038)
Literate (1 = yes)	-46.161	-44.354	629.534	648.517	10.178	10.419	0.095***	0.096***
	(39.002)	(38.117)	(710.925)	(708.749)	(7.179)	(6.996)	(0.033)	(0.033)
SPG village (1 = yes)	-133.081***	-130.530***	682.478	702.412	-17.547**	-14.719*	0.141***	0.140***
	(40.202)	(41.419)	(879.676)	(887.471)	(8.077)	(8.165)	(0.038)	(0.038)
Constant	825.517***	629.283***	17,842.507***	17,936.163***	137.891***	135.577***		
	(98.923)	(102.848)	(2,229.776)	(2,458.760)	(20.515)	(22.129)		
Number of observations	1,175	1,175	1,172	1,172	1,169	1,169	1,175	1,175
Number of households	872	872	870	870	868	868	872	872

Note: */**/*** denotes statistical significance at 10, 5 and 1 per cent, respectively. Standard errors are given in parentheses. All standard errors are robust to heteroscedasticity, except Logit CRE results which do not allow robust standard errors. The number of observations differs due to missing observations. Logit results are presented as marginal effects (delta method standard errors).

Higher-order outcomes are investigated in more depth using the detailed input variables from the long survey to investigate early-season inputs more clearly (Table 8). Households apply more chemical fertilizer on or before the day of transplantation to STRV plots than local variety plots by 17–29 kg/ha, significant at 5 per cent in both the RE and CRE models. According to RE results, old MVs get 21 kg/ha more early-season chemical fertilizer than landraces. This is not significant in the CRE results. Households apply 22 additional days of labour to STRV plots, and 24 to old MV plots, both significant at 5 per cent in the RE model. In the CRE results, STRV plots receive 30 additional person-days of labour, but this is significant only at 10 per cent. These increases can be attributed to increases in male labour: according to RE and CRE results, STRVs receive 13–24 additional hours of male land preparation labour, and old MVs receive 14–17 (though the CRE results for old MVs are significant only at 10 per cent).

Table 8. Household RE and CRE estimates of the impact of the cultivation of STRVs on early-season input use

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	Early-season chemical fertilizer (detailed) Household RE	Early-season chemical fertilizer (detailed) Household CRE	Land preparation labour (detailed) Household RE	Land preparation labour (detailed) Household CRE	Male land preparation labour (detailed) Household RE	Male land preparation labour (detailed) Household CRE	Female land preparation labour (detailed) Household RE	Female land preparation labour (detailed) Household CRE
T_{ij}								
Variety type								
Old MV	21.090**	20.437	24.072**	14.382	13.825**	17.318*	9.613	-2.114
	(10.741)	(18.868)	(11.076)	(20.741)	(5.605)	(10.526)	(6.852)	(11.599)
New MV (not STRV)	16.469*	21.102*	14.482	7.936	9.479*	17.284	3.856	-9.343
	(8.915)	(12.532)	(10.472)	(19.503)	(5.455)	(10.875)	(6.072)	(10.212)
STRV	17.105**	29.244**	21.690**	29.501*	12.664**	24.031**	7.894	5.056
	(8.526)	(11.567)	(10.882)	(17.015)	(5.945)	(9.414)	(6.327)	(9.100)
Hybrid	14.016	11.979	15.336	18.439	8.659	18.220*	5.444	0.232
	(8.969)	(9.550)	(10.454)	(17.138)	(5.376)	(10.437)	(6.242)	(9.415)
$\overline{T}_i$								
Mean old MV		1.927		11.711		-5.989		16.668
		(21.855)		(25.772)		(13.994)		(14.001)
Mean new MV (not STRV)		-3.234		6.988		-12.276		19.243
		(17.800)		(24.568)		(14.115)		(12.652)
Mean STRV		-13.784		-12.543		-15.713		3.582
		(17.173)		(23.572)		(13.417)		(12.125)
Mean hybrid		7.590		-5.679		-14.294		8.269
		(17.831)		(23.294)		(13.798)		(13.252)
P_{ij}								
Slope (1 = yes)	7.574	-1.368	27.968***	-30.763*	16.971***	-11.494	11.866***	-18.771*
	(5.555)	(16.356)	(7.462)	(17.965)	(4.039)	(10.675)	(4.047)	(9.650)
Irrigated (	6.925	20.196	-32.629***	-11.539	-10.774*	-1.030	-23.183***	-11.327

1 = yes)	(10.205)	(17.330)	(12.069)	(15.189)	(6.527)	(10.501)	(7.692)	(8.397)
Prone to drought (1 = yes)	13.674**	4.959	-5.366	8.331	-3.330	1.049	-2.953	6.662
	(5.691)	(9.216)	(7.535)	(15.102)	(4.104)	(9.195)	(4.500)	(9.720)
Plot size (ha)	-54.708***	-74.900***	-147.893 ***	-225.260 ***	-72.861***	-112.716 ***	-74.985***	-112.836 ***
	(11.456)	(27.738)	(27.394)	(63.586)	(14.447)	(33.046)	(14.675)	(39.397)
$\overline{P_i}$								
Mean slope (1 = yes)		10.702		69.100***		32.545***		36.277***
		(17.372)		(19.370)		(11.411)		(11.203)
Mean irrigated (1 = yes)		-28.463		-34.621		-14.324		-20.573
		(22.240)		(22.338)		(13.104)		(13.272)
Mean prone to drought (1 = yes)		13.448		-17.664		-5.470		-12.455
		(11.606)		(17.260)		(10.456)		(10.978)
Mean plot size (ha)		27.838		92.208		45.252		46.447
		(29.053)		(68.125)		(35.126)		(41.323)
H_i								
Elevation (masl)	-0.018	-0.020	0.006	0.002	0.012	0.009	-0.007	-0.007
	(0.021)	(0.020)	(0.019)	(0.019)	(0.010)	(0.010)	(0.011)	(0.011)
Sex (1 = female)	9.141	9.938	-18.930*	-16.554*	-14.899***	-14.145***	-4.311	-2.812
	(6.910)	(6.976)	(9.772)	(9.701)	(4.685)	(4.640)	(5.927)	(5.968)
Literate (1 = yes)	4.029	4.759	0.727	1.745	8.393*	9.015**	-7.120	-6.862
	(6.224)	(6.223)	(8.693)	(8.615)	(4.434)	(4.427)	(5.373)	(5.307)
SPG village (1 = yes)	-10.478	-9.843	6.207	8.036	3.081	3.974	3.270	4.081
	(6.923)	(7.088)	(11.783)	(12.032)	(6.700)	(6.750)	(6.184)	(6.495)
Constant	48.640***	55.028***	147.361***	152.492***	54.720***	59.954***	95.072***	94.373***
	(18.845)	(20.123)	(25.182)	(30.090)	(13.594)	(15.796)	(15.670)	(18.466)
Number of observations	524	524	525	525	525	525	525	525
Number of households	392	392	392	392	392	392	392	392

Note: */**/*** denotes statistical significance at 10, 5 and 1 per cent, respectively. Standard errors are given in parentheses. All standard errors are robust to heteroscedasticity. The number of observations differs due to missing observations.

6. Conclusions

STRVs are bred to help rice farmers mitigate climate shocks by reducing yield variability that arises from such shocks. In the mid-hills region of Nepal, where drought is the most significant climate concern, the adoption of STRVs has become common. This study estimates that about 20 per cent of the rice seeds planted in the 2018 monsoon season in the study area were drought-tolerant varieties. STRVs increase yield, reduce yield variance and reduce the growing duration compared to local landraces, outperforming them even in a non-drought year. Furthermore, there is no yield penalty for STRVs relative to other MVs in a non-drought year. This information can help policymakers allocate resources to the development of different varieties. It is also encouraging for adoption; if farmers are aware of the benefits of adoption in non-drought years, they may be more likely to adopt. This would offer additional protection in drought years, improving their resilience to climate shocks.

The higher-order outcomes of the adoption of STRVs and other MVs and hybrids have implications for agriculture in unfavourable rice environments. Households apply more fertilizer to STRV plots and to other MV and hybrid plots. Because only STRVs are expected to significantly reduce the risk of cultivation, this increase in fertilizer use is likely due to income or marginal productivity effects, as explained in Emerick et al. (2016). This implies that increased adoption of any of these variety types will induce households to increase fertilizer use, which could further increase yields. Only STRVs and old MVs have increased early-season fertilizer use and land preparation labour. For STRVs, this could be due to risk reduction or short growing duration, but old MVs have neither of those traits, so it is difficult to identify why they also receive more of these inputs.

We found no evidence that the adoption of STRVs or other varieties increases a household's likelihood of growing legumes and/or vegetables. If policymakers wish to increase cultivation of legumes or vegetables, adopters of STRVs and hybrid varieties could be educated about planting them after harvesting short-duration rice varieties. This may be impactful, given that other indicators of knowledge (being literate and living in an SPG village) make households more likely to cultivate legumes and/or vegetables. The adoption of STRVs would then have additional impacts on nutrition and/or income, as households could consume or sell their legume and/or vegetable harvest.

This study demonstrates how CRE models can be used to eliminate plot- and household-level selection bias in areas where farmers commonly grow multiple varieties on a plot and/or grow the same variety across different plots. With enough plot-level variation, unobserved plot heterogeneity can be eliminated to control for plot selection bias. In areas with little plot-level variation, household CREs can still be used to control for household selection bias if households grow multiple varieties per season. This provides researchers with a valid way to estimate treatment effects that does not require randomized data or an instrumental variable.

The experiment to randomize survey design offers insights for future researchers. Despite the differences in reported labour data across short and long survey questionnaires, this did not affect first-order treatment effects when added as covariates. Therefore, researchers may not need to collect very detailed data on inputs if their main goal is to estimate first-order outcomes. The main benefit of collecting more granular data was that it allowed more nuanced exploration of higher-order outcomes of the adoption of STRVs; without these data we would not have known the impacts of the adoption of STRVs on early-season fertilizer use or land preparation labour.

These results are important for researchers and policymakers who evaluate the impacts and returns on investment of STRVs. Because farmers do not experience drought in most years, knowing the performance of STRVs in non-drought years is crucial. More research is needed to estimate the effects of STRVs in drought years; in particular, it is important to know how STRVs perform relative to hybrids in drought years, since hybrids have higher mean yields than STRVs in non-drought years. Our results, along with further research, will provide policymakers with evidence of the benefits of STRVs in Nepal and other countries. This is crucial for developing and promoting technologies to help farmers adapt to a changing climate.

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8. Appendix

Table A1. Means (standard errors) of household characteristics, short-version vs. long-version survey responses

Variable	Households assigned to short survey only mean (std. dev.)	Households assigned to long survey mean (std. dev.)
Age of head of household	51.68 (13.12)	52.38 (13.43)
Sex of head of household (1 = female)	0.23 (0.42)	0.21 (0.41)
Head of household is literate (1 = yes)	0.74 (0.44)	0.69 (0.46)
Number of household members	3.85 (1.47)	3.89 (1.38)
Wealth index	-0.11 (1.55)	0.04 (1.54)
Distance to road (m)	43.44 (60.66)	45.49 (66.69)
Elevation (masl)	644.31 (212.71)	650.58 (206.89)
Number of plots cultivated in 2018	1.58 (0.67)	1.62 (0.64)
Number of rice varieties cultivated in 2018	1.78 (0.94)	1.73 (0.90)
Number of observations	492	406

Note: There were no statistically significant differences between groups. Two households were missing several responses so were not included in the table. Estimates for age, sex, literacy of the head of household were based on 880 total responses, while wealth index is based on 891 total responses due to missing observations.

Table A2. Means (standard deviations) of detailed inputs on plots where STRVs are the most prevalent kind vs. all other plots

Variable	Plots on which STRVs are the most prevalent type	Plots on which non-STRVs are the most prevalent type
Organic fertilizer (kg/ha)	8,164.91 (9,282.59)	7,864.10 (10,853.56)
Organic fertilizer (kg/ha) applied on or before day of seedling transplantation	7,420.15 (9,180.39)	7,348.58 (10,155.34)
Number of times organic fertilizer was applied (for households that applied organic fertilizer)	1.01 (0.11)	1.03 (0.16)
Urea (kg/ha)	69.27 (62.01)	74.21 (62.01)
DAP (kg/ha)	44.44 (46.68)	44.32 (54.97)
Potash (kg/ha)	3.65 (10.22)	6.44 (12.11)
Chemical fertilizer (sum of urea, DAP and potash) (kg/ha) applied on or before day of seedling transplantation	63.51 (69.07)	63.51 (59.76)
Number of times chemical fertilizer was applied (for households that applied chemical fertilizer)	2.06 (0.66)	2.19 (0.83)
Total hired labour (person-days/ha)	138.77 (165.48)	143.70 (405.12)
Total unpaid labour (person-days/ha)	208.45 (188.49)	190.58 (169.15)
Total land preparation labour (person-days/ha)	130.64 (92.48)	116.94 (82.44)
Total weeding labour (person-days/ha)	76.87 (59.90)	79.55 (65.94)
Total harvesting labour (person-days/ha)	74.37 (53.52)	66.03 (46.75)
Total threshing labour (person-days/ha)	64.54 (50.36)	55.44 (38.47) **
Number of observations	103	439

Note: ** denotes statistical significance at 5 per cent.

Table A3. Mean (std. dev.) household characteristics of households that grew one vs. more than one rice variety

Variable	Mean (std. dev.) households that grew one variety	Mean (std. dev.) households that grew more than one variety
Age of head of household	50.42 (12.83)	53.24 (13.46) ***
Sex of head of household (1 = female)	0.23 (0.42)	0.22 (0.41)
Head of household is literate (1 = yes)	0.74 (0.44)	0.70 (0.46)
Number of household members	3.74 (1.39)	3.96 (1.45) **
Wealth index	0.04 (1.59)	-0.11 (1.51)
Distance to road (m)	38.57 (52.08)	48.87 (70.90) **
Elevation (masl)	620.65 (198.15)	668.24 (216.87) ***
Number of plots cultivated in 2018	1.26 (0.45)	1.87 (0.68) ***
Number of rice varieties cultivated in 2018	1.00 (0.00)	2.37 (0.84) ***

Note: */**/*** denotes statistical significance at 10, 5 and 1 per cent, respectively.

Table A4. Mean (std. dev.) plot characteristics of plots with one vs. more than one variety

Variable	Mean (std. dev.) plots with one variety	Mean (std. dev.) plots with more than one variety
Labour (person-days/ha)	633.09 (556.53)	498.58 (464.93) ***
Organic fertilizer (kg/ha)	9,199.65 (10,281.75)	7,024.65 (8,424.01) ***
Chemical fertilizer (kg/ha)	126.58 (116.29)	102.93 (83.86) *
Grew legumes and/or vegetables in monsoon season (1 = yes)	0.32 (0.47)	0.33 (0.47)
Plot is sloped	0.74 (0.44)	0.60 (0.49) ***
Plot is irrigated	0.85 (0.36)	0.88 (0.32)
Plot is prone to drought	0.51 (0.50)	0.48 (0.50)
Size of plot (ha)	0.21 (0.16)	0.34 (0.28) ***

Note: */**/*** denotes statistical significance at 10, 5 and 1 per cent, respectively.

Table A5. Coefficient (standard error) of RE and CRE estimates of the impact of variety type and covariates on mean yield and yield variance using yield (quantity harvested in kg/area planted in ha) as dependent variable

	(1)	(3)	(2)	(4)
Variables	Yield mean: Plot RE	Yield mean: Plot CRE	Yield variance: Plot RE	Yield variance: Plot CRE
T_{ijk}				
Variety type				
Old MV	0.333***	0.254**	-0.042	-0.062
	(0.064)	(0.111)	(0.134)	(0.151)
New MV (not STRV)	0.392***	0.308***	-0.172**	-0.103
	(0.059)	(0.093)	(0.074)	(0.086)
STRV	0.333***	0.414***	-0.238***	-0.455***
	(0.060)	(0.109)	(0.085)	(0.174)
Hybrid	0.614***	0.685***	-0.162*	-0.219*
	(0.065)	(0.106)	(0.091)	(0.112)

$\overline{T_{ij}}$				
Mean old MV		0.108		0.054
		(0.126)		(0.243)
Mean new MV (not STRV)		0.118		-0.088
		(0.108)		(0.140)
Mean STRV		-0.097		0.336
		(0.126)		(0.220)
Mean hybrid		-0.087		0.086
		(0.122)		(0.166)
X_{ijk}				
Seeding rate (kg/ha)	0.002***	0.002***	0.000	0.001
	(0.000)	(0.001)	(0.000)	(0.001)
Age of seedlings (days)	-0.004	0.006	-0.001	-0.029
	(0.003)	(0.012)	(0.003)	(0.020)
Certified (1 = yes)	0.100***	0.081	-0.055	-0.063
	(0.030)	(0.071)	(0.039)	(0.078)
Area cultivated (ha)	-0.420***	0.154	-0.401**	-0.482**
	(0.086)	(0.172)	(0.165)	(0.227)
$\overline{X_{ij}}$				
Mean seeding rate (kg/ha)		-0.001		-0.001
		(0.001)		(0.001)
Mean age of seedlings (days)		-0.012		0.032
		(0.014)		(0.021)
Mean certified seed (1 = yes)		0.011		0.020
		(0.080)		(0.094)
Mean area cultivated (ha)		-0.735***		0.139
		(0.198)		(0.302)
I_{ij}				
Pesticides (1 = yes)	0.082**	-0.169	-0.016	-0.076
	(0.041)	(0.129)	(0.047)	(0.107)
Organic fertilizer (kg/ha)	0.000	-0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Chemical fertilizer (kg/ha)	0.001***	0.000	-0.001*	0.000
	(0.000)	(0.001)	(0.000)	(0.001)
Labour (person-days/ha)	0.000	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
$\overline{I_i}$				
Mean pesticides (1 = yes)		0.270**		0.060
		(0.132)		(0.111)
Mean organic fertilizer (kg/ha)		0.000		-0.000
		(0.000)		(0.000)

Mean chemical fertilizer (kg/ha)		0.001*		-0.001*
		(0.001)		(0.001)
Mean labour (person-days/ha)		-0.000		0.000
		(0.000)		(0.000)
P_{ij}				
Slope (1 = yes)	-0.080***	-0.042	0.118***	-0.073
	(0.027)	(0.101)	(0.042)	(0.089)
Irrigated (1 = yes)	0.114***	0.053	0.007	0.129
	(0.042)	(0.100)	(0.066)	(0.130)
Prone to drought (1 = yes)	0.009	-0.143*	0.037	0.156
	(0.030)	(0.083)	(0.066)	(0.102)
$\overline{P}_i$				
Mean slope (1 = yes)		-0.039		0.202**
		(0.105)		(0.100)
Mean irrigation (1 = yes)		0.050		-0.104
		(0.112)		(0.161)
Mean prone to drought (1 = yes)		0.182**		-0.141
		(0.087)		(0.115)
H_i				
Elevation (masl)	-0.000***	-0.000***	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Sex (1 = female)	-0.019	-0.020	-0.029	-0.030
	(0.029)	(0.029)	(0.026)	(0.024)
Literate (1 = yes)	-0.001	-0.004	0.076	0.082*
	(0.028)	(0.028)	(0.048)	(0.047)
SPG village (1 = yes)	0.095***	0.097***	-0.050	-0.067**
	(0.030)	(0.030)	(0.035)	(0.031)
Constant	7.863***	7.926***	0.339**	0.221
	(0.122)	(0.132)	(0.149)	(0.194)
Number. of observations	1,479	1,479	1,479	1,479
Number of plots	1,126	1,126	1,126	1,126

Note: */**/*** denotes statistical significance at 10, 5 and 1 per cent, respectively. Standard errors are given in parentheses. All standard errors are robust to heteroscedasticity. The number of observations differs due to missing observations.

Table A6. Household RE and CRE estimates of the impact of the cultivation of STRVs on input use and legume and vegetable cultivation for plots with only one variety

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(9)
Variables	Labour RE	Labour CRE	Organic fertilizer RE	Organic fertilizer CRE	Chemical fertilizer RE	Chemical fertilizer CRE	Legumes/ vegetables RE	Legumes/ vegetables CRE
T_{ij}								
Variety type								
Old MV	30.877	26.882	-1,256.569	269.031	38.495***	30.916*	0.020	0.019
	(66.957)	(111.044)	(1,540.400)	(2,258.184)	(11.861)	(16.801)	(0.061)	(0.097)
New MV (not STRV)	57.152	73.645	-2,444.230	-836.606	34.294***	39.516***	0.016	0.005
	(70.244)	(116.365)	(1,486.828)	(2,022.753)	(10.447)	(13.630)	(0.058)	(0.088)
STRV	40.656	-10.849	-440.950	930.113	22.605**	43.998***	0.044	0.020
	(67.377)	(109.896)	(1,527.441)	(2,086.561)	(10.119)	(14.147)	(0.060)	(0.091)
Hybrid	7.720	46.080	-22.171	2,494.262	25.711**	25.687*	0.045	0.017
	(66.519)	(108.374)	(1,411.773)	(1,806.849)	(10.683)	(15.326)	(0.058)	(0.087)
$\overline{T_i}$								
Mean old MV		13.753		-3,586.286		17.937		-0.006
		(154.967)		(2,951.043)		(26.041)		(0.127)
Mean new MV (not STRV)		-44.007		-3,983.109		0.582		0.007
		(153.586)		(2,709.866)		(24.326)		(0.119)
Mean STRV		105.792		-3,985.996		-32.592		0.023
		(157.389)		(2,786.548)		(24.172)		(0.123)
Mean hybrid		-86.142		-5,415.133**		8.316		0.037
		(142.589)		(2,568.400)		(26.112)		(0.118)
P_{ij}								
Slope (1 = yes)	-10.659	31.935	1,260.885	1,629.572	4.923	4.822	0.169***	0.128
	(39.573)	(61.126)	(802.975)	(1,507.381)	(8.461)	(25.990)	(0.038)	(0.095)
Irrigated (1 = yes)	88.066	-140.832	-1,915.260*	-3,584.379**	4.376	4.830	-0.010	-0.025
	(53.570)	(93.696)	(1,002.176)	(1,486.380)	(13.746)	(22.404)	(0.044)	(0.073)
Prone to drought (1 = yes)	117.279***	-96.827	-990.124	-400.561	26.808***	-13.285	-0.053*	-0.009
	(35.380)	(63.675)	(695.195)	(1,146.337)	(7.382)	(12.815)	(0.032)	(0.063)
Plot size (ha)	-830.966***	-1,460.330***	-10,632.080***	-15,744.479***	-108.904***	-106.879***	0.103	0.173
	(124.068)	(255.708)	(2,100.193)	(4,293.996)	(17.725)	(37.421)	(0.088)	(0.192)
$\overline{P_i}$								
Mean slope (1 = yes)		-58.375		-298.696		-3.355		0.053
		(76.758)		(1,795.874)		(27.785)		(0.103)
Mean irrigated (1 = yes)		395.368***		3,948.487**		-10.660		0.030
		(105.985)		(1,898.217)		(26.773)		(0.093)
Mean prone to		297.112***		-1,115.924		61.661***		-0.060

drought (1 = yes)		(79.775)		(1,467.443)		(16.597)		(0.073)
Mean plot size (ha)		834.570***		6,840.822		-5.278		-0.087
		(267.431)		(4,583.382)		(40.928)		(0.215)
H_i								
Elevation (masl)	-0.260***	-0.251***	-11.258***	-11.575***	-0.072***	-0.069***	0.000	0.000
	(0.082)	(0.088)	(1.781)	(1.842)	(0.020)	(0.020)	(0.00)	(0.000)
Sex (1 = female)	-29.943	-32.191	370.595	363.292	5.384	5.114	-0.125 ***	-0.122 ***
	(50.344)	(50.810)	(970.327)	(967.969)	(10.634)	(10.224)	(0.042)	(0.042)
Literate (1 = yes)	-61.373	-56.305	947.672	1,067.676	11.518	11.423	0.118***	0.118***
	(45.673)	(43.778)	(843.807)	(835.018)	(8.257)	(8.070)	(0.037)	(0.037)
SPG village (1 = yes)	-113.924 **	-110.223**	646.715	627.218	-16.649*	-13.313	0.150***	0.147***
	(49.405)	(50.623)	(1,056.586)	(1,067.159)	(9.394)	(9.473)	(0.042)	(0.042)
Constant	872.826 ***	649.452***	19,438.718 ***	19,693.789 ***	139.881 ***	134.872***		
	(113.440)	(123.727)	(2,696.022)	(3,106.307)	(24.224)	(27.036)		
Number of observations	940	940	937	937	935	935	940	940
Number of households	683	683	681	681	680	680	683	683

Note: */**/*** denotes statistical significance at 10, 5 and 1 er cent, respectively. Standard errors are given in parentheses. All standard errors are robust to heteroscedasticity, except Logit FE results which do not allow robust standard errors. The number of observations differs due to missing observations. Logit results are presented as marginal effects (delta method standard errors).

Table A7. Household RE and CRE estimates of the impact of the cultivation of STRVs on early-season input use for plots with only one variety

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	Early-season chemical fertilizer (detailed) Household RE	Early-season chemical fertilizer (detailed) Household CRE	Land preparation labour (detailed) Household RE	Land preparation labour (detailed) Household CRE	Male land preparation labour (detailed) Household RE	Male land preparation labour (detailed) Household CRE	Female land preparation labour (detailed) Household RE	Female land preparation labour (detailed) Household CRE
T_{ij}								
Variety type								
Old MV	29.517**	21.107	25.007*	23.041	15.961**	22.937**	8.960	1.432
	(12.794)	(19.563)	(14.044)	(22.846)	(6.797)	(11.694)	(8.650)	(12.493)
New MV (not STRV)	16.797	17.952	19.560	19.305	15.733**	26.725**	3.427	-6.460
	(10.711)	(13.359)	(13.238)	(23.210)	(6.618)	(13.198)	(7.453)	(11.419)
STRV	19.430**	28.961***	27.158**	40.986**	18.263***	33.119***	8.343	8.268
	(9.820)	(11.234)	(13.283)	(19.128)	(6.851)	(10.673)	(7.646)	(9.890)
Hybrid	15.309	10.900	19.164	33.894*	11.642**	23.061**	7.364	11.364
	(10.268)	(10.629)	(12.242)	(19.948)	(5.795)	(11.096)	(7.519)	(10.173)
$\bar{T}_i$								
Mean MV		15.204		-2.853		-13.590		9.703
		(24.807)		(31.148)		(17.032)		(16.716)
Mean new MV (not STRV)		2.983		-7.531		-20.299		12.354
		(22.088)		(31.175)		(17.899)		(15.440)
Mean STRV		-12.516		-30.654		-26.699		-3.624
		(20.542)		(29.975)		(16.941)		(14.994)
Mean hybrid		11.633		-27.413		-19.850		-7.711
		(21.627)		(28.413)		(16.135)		(14.403)
P_{ij}								
Slope (1 = yes)	7.121	2.837	21.300**	-31.612*	12.857***	-11.810	9.028*	-18.698*
	(6.742)	(20.739)	(9.117)	(18.634)	(4.950)	(10.892)	(4.970)	(9.663)
Irrigated (1 = yes)	11.204	26.529	-24.081*	-7.940	-9.212	-4.514	-15.772*	-4.935
	(11.464)	(18.988)	(13.503)	(16.955)	(7.193)	(10.744)	(8.185)	(8.997)
Prone to drought (1 = yes)	17.026**	9.084	-5.886	4.901	-3.774	-2.594	-2.941	5.852
	(6.933)	(11.094)	(9.209)	(17.699)	(4.994)	(11.184)	(5.628)	(11.186)
Plot size (ha)	-63.559***	-86.305***	-154.357***	-232.552***	-75.115***	-112.649***	-78.576***	-119.285***
	(14.625)	(33.314)	(38.526)	(71.986)	(19.957)	(37.297)	(20.408)	(44.750)
$\bar{P}_i$								
Mean slope (1 = yes)		5.206		63.870***		29.491**		33.368***
		(21.889)		(20.482)		(11.908)		(11.214)
Mean		-32.333		-28.538		-7.783		-20.084

irrigated (1 = yes)		(24.995)		(25.644)		(14.049)		(15.982)
Mean prone to drought (1 = yes)		12.708		-14.306		-1.855		-11.458
		(13.963)		(20.352)		(12.744)		(12.651)
Mean plot size (ha)		31.266		95.675		45.131		49.926
		(34.875)		(80.026)		(40.921)		(48.146)
H_i								
Elevation (masl)	-0.018	-0.020	0.028	0.020	0.022*	0.017	0.004	0.002
	(0.027)	(0.026)	(0.024)	(0.025)	(0.012)	(0.013)	(0.013)	(0.014)
Sex (1 = female)	13.788*	15.042*	-28.555**	-25.600**	-18.684***	-17.567***	-10.068	-8.384
	(8.000)	(7.945)	(11.145)	(11.090)	(5.492)	(5.381)	(6.365)	(6.378)
Literate (1 = yes)	9.923	10.947	2.769	4.744	8.817	10.008*	-5.845	-5.172
	(7.210)	(7.237)	(10.897)	(10.863)	(5.478)	(5.508)	(6.687)	(6.578)
SPG village (1 = yes)	-9.319	-8.357	10.261	11.611	3.917	4.245	6.474	7.467
	(8.119)	(8.303)	(14.136)	(14.352)	(7.809)	(7.806)	(7.530)	(7.721)
Constant	38.619*	44.216*	131.619***	144.179***	48.177***	56.447***	85.135***	88.848***
	(22.951)	(25.583)	(29.810)	(37.172)	(15.547)	(19.244)	(17.819)	(22.731)
Number of observations	419	419	420	420	420	420	420	420
Number of households	308	308	308	308	308	308	308	308

Note: */**/*** denotes statistical significance at 10, 5 and 1 per cent, respectively. Standard errors are given in parentheses. All standard errors are robust to heteroscedasticity. The number of observations differs due to missing observations.

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