Why some inferior technologies succeed? Examining the diffusion and impacts of rotavator tillage in Nepal Terai

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Abstract:

We analyze the effects of rotavator tillage adoption on yield and profitability of wheat in the Nepalese small farm sector, using recent survey data and propensity score matching. Rotavator is a tractor-operated cultivating implement for shallow tillage, which operates by pulverizing soil with the help of rotating 'L' or 'J'-shaped blades. Rotavator tillage has been spreading rapidly in many parts of South Asia, despite having a large body of evidence on its negative consequences on soil quality and crop yield from the experimental research trials. A rigorous assessment of impacts of rotavator adoption on farmers' fields has been impending. When we compared the mean yield and profit levels between rotavator adopters and non-adopters using propensity score matching algorithms, we found that the technology adoption clearly leads to inferior outcomes. Due to rotavator adoption, farmers lost about 284–309 kg of wheat grain yield and US$93-101 of profits per hectare on average, and the penalties were more pronounced for large farmers. Adoption of rotavator was driven by the cost-savings (US$11–15; 15–20% per hectare) at the time of land preparation, and the farmers with time and labor constraints adopt the technology. Against this backdrop, we suggest dissemination of zero-tillage as a sustainable alternative.

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Abstract

We analyze the effects of rotavator tillage adoption on yield and profitability of wheat in the Nepalese small farm sector, using recent survey data and propensity score matching. Rotavator is a tractor-operated cultivating implement for shallow tillage, which operates by pulverizing soil with the help of rotating 'L' or 'J'-shaped blades. Rotavator tillage has been spreading rapidly in many parts of South Asia, despite having a large body of evidence on its negative consequences on soil quality and crop yield from the experimental research trials. A rigorous assessment of impacts of rotavator adoption on farmers' fields has been impending. When we compared the mean yield and profit levels between rotavator adopters and non-adopters using propensity score matching algorithms, we found that the technology adoption clearly leads to inferior outcomes. Due to rotavator adoption, farmers lost about 284–309 kg of wheat grain yield and US$93-101 of profits per hectare on average, and the penalties were more pronounced for large farmers. Adoption of rotavator was driven by the cost-savings (US$11–15; 15–20% per hectare) at the time of land preparation, and the farmers with time and labor constraints adopt the technology. Against this backdrop, we suggest dissemination of zero-tillage as a sustainable alternative.

1. Introduction

The development of farming technologies that are environmentally sustainable and financially beneficial to farmers has become a key topic of agronomic research in the last two decades. One of the most prominent technologies emerged is zero tillage (El-Shater et al., 2016; Derpsch et al., 2010). Identified as one of the transformative innovations in conservation agriculture, the technology has potential to enhance the adaptive capacity of farming communities to mitigate the challenges posed by climate change in the tropics (Arslan et al., 2015; Sapkota et al., 2015; Harvey et al., 2014). However, the rate of diffusion of zero tillage has remained slow in many parts of South Asia (Krishna et al., 2016; Kassam et al., 2014). The age-old belief of farming community that tillage is essential for crop production is identified as one of the major challenges for the rapid diffusion (Bhan and Behera, 2014). Easy access to machineries for intensive tillage, ranging from cultivator to power tiller, augments this belief. In recent years, spread of rotavators or rotary tillers – a tractor operated cultivating implement that break the soil with the help of rotating blades – has been rapid in many parts of South Asia (Erenstein, 2010). Not only that this impediments the spread of more sustainable conservation tillage technologies, but adoption of rotavator tillage is also shown to have several negative consequences on soil quality and crop yield in a number of experimental research trials (Guan et al., 2015; Ahmad et al., 2010; Tripathi et al. 2007).

Given the insights from research trials holds true in the farmers' field, the diffusion of rotavator adoption in South Asia becomes a unique case of adoption-impact literature, according to which financial viability is the single most important determinant of adoption (Knowler and Bradshaw, 2015). While the research trials predicts yield and financial loss associated with rotavator adoption, farmers are found adopting the technology quickly and increasingly. There could be two plausible explanations for this. One, unlike in the research plots, the negative effects of rotavator tillage could be less pronounced in farmers' field, especially at the short-run. Researcher-managed plots differ from farmer-managed ones with respect to production conditions and managerial efficiency. Two, adoption decisions could be made under resource constraints and not solely based on the criteria of land productivity. In order to design technology interventions to promote resource-conserving technologies like zero tillage, the effects of technology alternatives on yield and profits are to be documented. To the best of our knowledge, no study is conducted so far to examine on the on-farm effects of rotavator tillage.

In general, the adoption-impact literature is biased toward documenting success stories of promising technologies (El-Shater et al., 2016; Mishra et al., 2016; Shiferaw et al., 2014; Gitonga et al., 2013; Teklewold et al., 2013; Kassie et al., 2011; Ali and Abdulai, 2010). While there exists some evidence on why some promising technologies fail (Douthwaite et al., 2001), the reasons behind farmer acceptance of inferior technologies are hardly understood. We here argue that documentation of the agronomic and financial effects of available (less-sustainable) alternatives of promising technologies also has significant policy relevance. We will; (i) verify whether the effects of rotavators are indeed negative in farmers' fields in terms of both yield and profitability, and if so, (ii) identify the rationale behind acceptance of such "inferior" technology. Farm household data collected from the wheat-based farming systems of Nepal is used for the empirical analysis. Nepal is one of the least developed countries in Asia with a quarter of its population living below the absolute poverty line (NPC, 2017) and about one-third of children under five facing acute nutritional deficiency (FAO, 2013). Food security is a major challenge with more than half of Nepalese districts facing food deficit every year (Joshi et al., 2012). Since two-third of population is engaged in agriculture, technological interventions towards increasing yield and profit are having potential to erode rural poverty. Being a staple crop grown on an area of 25% of cultivated land with stagnated productivity (MoAD, 2016), wheat is a crop of strategic importance. Any technological intervention in wheat that affect the yield and profit can have substantial effect on food security of millions of poor. This study is expected to lead toward strategies for scaling out sustainable intensification practices in the country. The insights would also have wider geographical applications, as diffusion of rotavator tillage is rapid in other countries of South Asia (Krishna et al., 2012).

The paper is organized as follows. In the next section, the background details of rotavator technology and scope of the present study are provided. The database used for the empirical analysis is described in Section 3, and the analytical framework in Section 4. The empirical findings are shown in Section 5, while the last section discusses these findings and concludes the study.

2. Background and scope

The present study aims to estimate the impacts of one of the emerging tillage practices, rotavator tillage, and to identify the reasons for its farmer acceptance in Nepal. In this section, we provide a description on the evolution of mechanized tillage for wheat production in Nepal. Conventionally, tillage has been perceived as one of the most important cultivation practices that determines soil quality (Singh et al., 2013; Mosaddeghi et al., 2009; Mohanty et al., 2007; Tripathi et al., 2005), crop growth (Mosaddeghi et al., 2009), and short-term and long-term sustainability of crop production systems (Bhatt et al., 2016). In wheat production, tillage is found affecting physical, chemical and hydrological requirements for crop growth (Bazaya et al., 2009; Mohanty et al., 2007; Osunbitan et al., 2005). However, these effects vary depending on the type of tillage practices as soil quality, water percolation, and land productivity are affected differently by different tillage practices in different agro-ecosystems (Das et al., 2014; Kumar et al., 2013; Saharawat et al., 2010; Erenstein and Laxmi, 2008).

The history of mechanized tillage in Nepalese agriculture dates back to early 1970s with the advent of two- and four-wheel tractors (Biggs et al., 2011). However, the diffusion was rapid only in the last two decades. The number of farms using mechanized tillage has increased from 5% in 1995 (Takeshima et al., 2015) to 23% in 2016 (Takeshima, 2017a). The area under mechanized tillage has significantly increased in the recent years albeit having only a small share of farmers (<1%) owning tractors and other tillage machinery (Takeshima, 2017b). The custom hiring services became prevalent.

Diffusion of mechanized tillage shows a spatial heterogeneity in Nepal. While only less than 8 percent of farms use mechanized tillage in mountains and hills, about 46 percent use it in Terai regions (Takeshima, 2017a). Terai region has been considered as of higher potential for crop intensification due to plain topography, better input access, and larger landholding size (Takeshima et al., 2017; Takeshima, 2017b). The higher concentration of four-wheel tractors facilitated the use of different types of tillage machineries, including tine cultivator, disc harrows, zero tillage and conventional seed drills, and rotavators (Gauchan and Shrestha, 2017; Biggs and Justice, 2015). On the other hand, conservation tillage practices has been less prevalent even in Terai. Technologies like direct seeded rice and zero- or reduced-tillage wheat have been introduced recently and these technologies are spreading only slowly among farmers (Ghimire et al., 2013).

The history of rotavator tillage is relatively recent in Nepal. Krishna et al. (2012) reported that the technology was introduced in many Nepal Terai villages only after 2005, although it was prevalent in the northwestern Indo-Gangetic Plains from mid-1990s. Private sector in Nepal played major role in disseminating agricultural machineries including rotavators primarily manufactured in neighboring countries India and China (Gauchan and Shrestha, 2017). During the last two decades, a number of studies have been carried out to address the agronomic effects of this new tillage option. Tripathi et al. (2007) reported an inferior performance of rotavator tillage in the rice-wheat systems in India. The negative effects are generated through increasing sub-soil compaction or creation of a hard-pan due to continued use of shallow tillage (Guan et al., 2015; Głab, 2014; Khan et al., 2012; Nawaz et al., 2013; Singh et al., 2013; Ahmad et al., 2010). Increase in soil compaction and hard-pan formation have many detrimental consequences, including lower rate of incorporation of fresh organic matter, reduced nutrient recycling and mineralization, reduced activities of micro-organisms, increased weed pressure, increased lodging problems, increased wear and tear on cultivation machinery (Hamza and Anderson, 2005). Increased soil compaction also increase the bulk density, reduces pore space, impedes root growth, and necessitates more energy for tillage. A reduction in pore space hinders water and air movement in soil, thereby reduces water holding capacity and restricts root penetration in soil (Ahmad et al., 2010). These factors ultimately lead to increased cost of production and reduced yield and profitability.

While there exist a number of studies on negative effects of rotavators, all of them are based on data from researcher-managed field trials. While some of the socio-economic studies had questioned the increased adoption of rotavator tillage (Erenstein, 2010; 2009), no systematic analysis has ever been carried out on the agronomic and economic effects of this technology in farmers' field. Against this backdrop, we formulate our research objective as to assess the on-farm economic impacts of rotavator adoption in Nepal Terai, across districts with diverse socioeconomic and agro-ecological conditions. Understanding the economic effects of rotavators is the first step toward understanding the rationale behind farmer adoption of the technology in Nepal Terai.

3. Data

The empirical analysis is based on farm household data collected from wheat farmers in Nepal Terai. The data were collected through a face-to-face interview with structured questionnaire, conducted during April-June 2016. The questionnaire included sections to elicit information on household demographics, cropping patterns, income sources, as well as wheat production technologies, inputs, and practices (including tillage), and outputs obtained and marketing channels.[1] The survey was conducted immediately after completion of wheat harvest in the

[1] The sample households managing more than one wheat plot were asked to provide inputs and output from their main plot. These households may use different levels of inputs in different plots, and these plots may differ with

region.[2] The sampling strategy consists of purposive selection of 10 districts from Terai region and 5 sub-districts (Village Development Committees or VDCs) from each of the selected districts. All districts and VDCs were selected purposively, based on the wheat acreage and prevalence of mechanized tillage adoption. One ward from each VDC, and 10 wheat farmers from each ward were selected randomly. This procedure yields a sample size of 500 farm-households (from 50 wards of 50 VDCs from 10 districts). Excluding the 15 questionnaires which couldn't fit for current study purposes, a sample of 485 households was analyzed for the present study. Figure 1 shows the location of sampled districts, and extent of wheat area as well as rotavator adoption in the study area.

In this study, treatment group includes farm household adopting rotavator tillage in the main wheat plot during the previous season of survey (winter 2015-16). The control group includes farm households that employed other tillage methods for wheat production in the same season in their main plot.[3] Since the plot-level tillage decisions are more or less homogeneous within a farm household, there will not be significant overlap of control and treatment groups even if other plots were also considered for the analysis. To increase precision, the effects of adoption are estimated at the plot level, and not at the household level. Similar approach has been used in earlier studies (Mishra et al., 2017b; Kassie et al., 2015; Krishna and Qaim, 2012) on technology adoption.

respect to soil type and topography. Eliciting details of different attributes of all plots managed by the household would have increased the survey time and cost, and reduce the data quality.

[2] A total 20 districts lies in Nepal Terai out of total 75 districts in the country (MoAD, 2016). The selected 10 districts were Kanchanpur, Kailali, Bardyia, Banke, Rupendhai, Nawalparsi, Bara, Dhanusa, Saptari and Sunsari.

[3] The other tillage methods in this study includes mainly conventional tillage practices.

4. Empirical framework

Simple and straightforward comparison of average values of outcome variables between rotavator adopters with non-adopters, without considering symmetric differences in attributes among these categories, may provide misleading and biased information. The traditional approach to evaluate the effects of technology adoption is regressing the outcome variables over adoption dummy along with a vector of farm household and plot attributes as explanatory variables. The underlying assumption of this approach is that adoption of technology is exogenously determined. In reality, technology adoption at farmers' field is not a random process. There could be a number of unobserved farm household attributes (e.g., farmer's perception, soil fertility, and managerial skills etc.) that may be correlated with both adoption and outcome variables, making farmer adoption an endogenous process. Therefore, ordinary least squares regression analysis to estimate technology impacts in farmers' field could result in biased estimates (Kabunga et al., 2012).

Different researchers have proposed different estimation techniques in order to resolve the issue of endogeneity (Mason et al., 2017). One of the way to resolve the issue of selection bias is random assignment of the treatment (de Janvry et al., 2010), although this method is inapplicable for impact assessment where data are collected only after technology adoption. Wooldridge (2002) indicated that the application of panel estimators with household-level fixed effects could control for time-invariant heterogeneity. However, development of panel dataset are not always feasible due to time and financial constraints. Also the household-level fixed effects cannot control for time-variant heterogeneity. Selection bias can also be addressed using Heckman two-step method and instrumental variables approach (Heckman et al., 1997). However, suitable instrumental variables are not always readily available (Mendola, 2007; Jalan and Ravallion, 2001).

For this study, we obtained the data through a cross-sectional survey. At the time of data collection, a significant share of households were adopting rotavator tillage in their farms. Impact assessment through randomized control trials is hence not feasible. Instrumental variables are also not available. Hence, we use a matching algorithm to partly correct endogeneity, following Dehejia and Wahba (2002). In this method, we match the outcome indicators between adopters and non-adopters within groups that are made based on the estimated propensity to adopt the technology. These similarity scores are derived from observed attributes of rotavator adopters and non-adopters, and the methodology is called propensity score matching (PSM). The causal effect of rotavator tillage on outcome indicators using PSM is based on balancing the distribution of observed attributes of rotavator adopter and non-adopters and comparing differences after matching based on the similarity in their observed attributes. In order to measure the casual effects of rotavator adoption using PSM, we need not to specify the functional form of dependent variables unlike the classical regression models. PSM is therefore a non-parametric method, and has been increasingly employed to study the effects of technology adoption in agriculture (Mason et al., 2017; Mishra et al., 2017a, 2016; Khanal et al., 2015; Gitonga et al., 2013; Uematsu and Mishra, 2012; Kassie et al., 2011; Rejesus et al., 2011; Diagne and Demont, 2007; Mendola, 2007; Jalan and Ravallion, 2001).

To estimate the effects of rotavator tillage with PSM, we first specified the conditional probability of rotavator adoption. A logit model is used to derive the propensity scores. In the second step, we matched the adopting farm households with the non-adopters based on similarity in the propensity scores. In order to match technology adopters with non-adopters based on their distribution of observed attributes, several algorithms have been proposed in the literature (Caliendo and Kopeinig, 2005). Following the popular practice, we employed three different matching algorithms – kernel-based matching (KBM), nearest neighbor matching (NNM), and caliper matching or radius-based matching (RBM). Each of these matching algorithms has their unique features, although robustness of estimates can be confirmed when all of them provide comparable estimates. In KBM, weighted averages of outcomes of all households in the non-adopter group are used to construct the counterfactual. These weights are inversely associated with the distance between propensity score (Caliendo and Kopeinig, 2005). While NNM involves choosing farms adopting rotavator and non-adopting rotavator that are closest in terms of propensity score as a matching pair (Ali and Abdulai, 2010). This is usually applied with replacement so that the control sample can be the best match pair for more than one treated sample (Becker and Ichino, 2002). In RBM approach, a tolerance level on maximum propensity score distance between subjects in the adopter group is estimated, which is then employed to derive subjects in the counterfactual non-adopter group (Andam et al., 2008).

The main purpose of PSM method is to balance the observed distribution of covariates across the treatment and control groups. The procedure requires a covariate balancing test after matching to ensure that there are no symmetric differences in the distributions and there is an overlap of the covariates among adopters and non-adopters (Lee, 2013; Sianesi, 2004). The results from the post-matching two-sample t-test should not be significantly different across adoption categories for any of the covariates for meaningful comparison. The matching quality is tested by comparing pseudo R^2 and p-values of the likelihood ratio of the joint insignificance obtained from the logit model before and after matching the covariates. Lower pseudo R^2 and insignificant p-value of the likelihood ratio after matching would denote that the balancing property is satisfied (Sianesi, 2004). The balancing property can also be tested with mean absolute standard bias (MASB) between rotavator adopters and non-adopters as suggested by Rosenbaum and Rubin (1985). An MASB value greater than 20% is considered too large to qualify the matching process.

A general weakness of PSM as an impact evaluation method is that the matching is based entirely on the observed characteristics. If there are certain unobserved variables that affect both the adoption decision and outcome variables (hidden biases), the resulting PSM estimates might be biased (Andam et al., 2008). We conducted the sensitivity analysis to identify whether the magnitude of hidden bias could alter the conclusions of the study. According to Rosenbaum (2002), the unobserved heterogeneity or hidden bias may leave visible traces in the observed data, which can be distinguished by a variety of tactics involving pattern specificity.

5. Results

The dataset contains 158 farm households (33%) adopting rotavator tillage and 327 households (67%) following other tillage practices.[4] The descriptive statistics are presented in Appendix I. The

[4] However, since we have purposively sampled the districts and VDCs based on wheat acreage and prevalence of mechanized tillage, these adoption rates may not be considered as representative of the region.

average farm size for the rotavator adopters was 33 percent smaller than that of non-adopters, although there is no significant difference in the mean household size. Adopters and non-adopters do not differ with respect to mean age, education, or group membership status of the household head. However, the share of households belonging to socially forward castes is found significantly higher among the adopters. Share of household heads with agriculture as main occupation was significantly lower in the adopter group, although this has not reflected in the mean off-farm income. A higher share of adopters were having mobile phones. The spatial patterns of technology diffusion was clear with rotavator more popular in western Terai.

The difference between the rotavator adopters and non-adopters was also noticeable in the main plot characteristics (Appendix I). Farmers were adopting rotavator tillage mostly in plots with silty soil, but rarely in plots with sandy soil. Adoption rate was significantly high in the lowlands and in plots with irrigation facilities. Furthermore, farms with delayed harvesting activities (for the previous crop) were the ones mainly adopting rotavator tillage. These symmetric differences in the means of observed attributes of rotavator adopters and non-adopters potentially affect the adoption decision as well as wheat yield and profit, and hence necessitates matching and a test for selection bias.

Rotavator technology is appears to be spreading rapidly in the villages where labor scarcity is relatively high, as adopters are found paying significantly higher wages for agricultural laborers (Table 1). While comparing the costs and returns from wheat farming, the tillage cost is found significantly lower in plots prepared using rotavator tillage, and this could be one of the major reasons for adoption. The fertilizer application rates were also higher after rotavator tillage. As a result, the total variable costs were significantly higher for adopters. Surprisingly, the increased fertilizer use and the cost of cultivation did not enhance wheat productivity. In fact, the per hectare wheat grain yield was 15 percent lower for rotavator adopters compared to the non-adopters. Due to the increased cost and reduced yield, it comes to a natural conclusion that rotavator adoption is not financially beneficial to farmers. The gross margin of wheat in plots where rotavator tillage was adopted was negative (a loss of NPR 2,800 or US$26 per hectare). In comparison, the rotavator non-adopters were making positive returns from wheat (NPR 12,200 or US$114 per hectare). There could be a number of factors other than tillage determining the wheat productivity and profitability, which are delineated in the next sub-section.

5.1. Delineating the effects of rotavator tillage

The first step toward calculation of the plot-level effects of rotavator tillage is estimating farm households' propensity to adopt rotavator tillage. We run binary logit models using farm household and plot attributes affecting adoption decision. Two different specifications were used, and both are presented in Table 2. Model 1 accounts for household attributes alone, while model 2 additionally includes plot-level attributes and regional dummies. The results are more or less consistent across the specifications. Farmers having opportunities for non-farm income activities, belonging to one of the socially forward castes, participating in group activities, having access to mobile phones, and living in villages with high wage rates for agricultural labor form the majority of the adopters. The logit models denote that time- and labor-constraints for farm households could be the major factor determining rotavator adoption. The second model indicates that the adoption is higher in low lands and in plots with irrigation facilities. Delay in harvesting the previous crop is another important factor determining the adoption, as there could be some time-saving associated with rotavator tillage. Since Model 2 explains a greater share of variation in the data, we use it to generate propensity scores, based on which each of rotavator adopting plots is matched with non-adopting plots to derive the treatment effects of rotavator technology.

For matching, we used three different matching algorithms to derive the treatment effect – NNM, KBM, and RBM – as described in the methodology section. The matching procedure for each of the matching algorithms were checked in order to balance the distribution of observed attributes for rotavator adopters and non-adopters. In Appendix 2, we present the covariates status before and after matching, and the result showed a substantial reduction in the percentage bias after matching. The statistical insignificance of difference in the observed attributes of adopters and non-adopters indicates the absent of any symmetric difference among adopters and non-adopters. The distribution of propensity score for the rotavator adopters and non-adopters is presented in Figure 3. The overlapping of distribution of propensity scores indicates a common support for the adopter and non-adopter sub-samples (Rubin, 2008). The pseudo R^2 as well as the p-value of the likelihood ratio became significantly lower and statistically insignificant after matching, indicating absence of any differences in observed attributes for these sub-samples (Table 3). Furthermore, the mean and median bias after matching is significantly below the threshold of 20% for all the matching algorithms considered in this study. The low bias values indicate that the balancing property is satisfied.

The results for the average treatment effect for the treated (ATT), as estimated by NNM, KBM and RBM algorithms, are presented in Table 4. Adoption of rotavator tillage significantly reduced the tillage cost for wheat farming. The results were similar across different matching algorithms, and the cost saved ranged between NPR 1,229 (US$11.5; 15.4%) and 1,586 (US$14.8; 20.1%) per hectare. There are no significant differences across the adoption categories with respect to the total variable cost; the significance of differences in the descriptive statistics vanished after matching. However, rotavator tillage is found resulting in significantly lower wheat yield, and the reduction is in the range of 284–309 kg/ha (13.6 – 14.9%). As a result, the gross revenue and gross margin for wheat farming were also lower in the plots prepared with rotavators. The reduction in gross margin from wheat was NPR 9,916–10,811 (US$93-101; 397 – 445%) per hectare for rotavator tillage over the other tillage options.

Table 4 also includes the sensitivity analysis to detect the presence of hidden bias in the model, based on Rosenbaum bounds.[5] The critical value of Γ ranged between $\Gamma = 1.80 - 1.85$ and $\Gamma = 2.30 - 2.35$. The value of $\Gamma = 1.80$, for example, suggests that only if a farm household with same attributes differ in their odds of rotavator adoption by a factor of 80 percent, the significance of adoption effects on yield could be questioned. We can, hence, conclude that the inference on the estimated effects will not be changed even in the presence of large amount of unobserved heterogeneity.

[5] Since sensitivity analysis of insignificant variables is meaningless Hujer et al. (2004), Rosenbaum bounds were derived only for the variables that are significantly different from zero.

Smith and Todd (2005) demonstrated that the treatment effects derived from matching can be sensitive to specifications of propensity scores. Following Dehejia (2005), two diagnostic test were performed with re-estimation of treatment effect by altering the model specification. Higher order covariates such as quadratic forms of farm size, household head's age, and wage rate were additionally included. The model estimates and sensitivity analysis of treatment effects are presented in the Supplementary Materials S1. The treatment effects are similar to those shown in Table 4, indicating that our estimates are not affected by changes in the model specification.

5.2. Heterogeneous effects of rotavator tillage

A farming practice or technology may have differential impacts across various agro-ecological systems and socio-economic strata of farming community. Realizing this fact, we estimated the effects for different categories of farm households with respect to farm size, soil type, and rate of fertilizer application. The results are shown in Table 5.

To study the impact of rotavator tillage across different farm size categories, the sample data were stratified into large and small farms around the median value (0.8 ha). The treatment effects of rotavator tillage on wheat yield and gross margin (profit) are found significantly negative for larger farmers, while the effect magnitudes were small and statistically insignificant for smaller farmers. For the former, the critical value gamma ranges from $\Gamma = 2.75 - 2.80$ for wheat yield indicating that even in presence of substantial amount of unobserved heterogeneity these results will not alter. The long-term adverse effects of rotavators could be more striking among large farmer, who could have adopted the technology much earlier than small farmers. The continued use of rotavators is found affecting the nutrient uptake and causing lodging problem (Singh et al., 2013).

Do the rotavator effects vary across different soil types? To answer the question, treatment effects were calculated separately for silty and clayey soils. The results show that the effects on wheat yield and gross margin were significantly lower in both silty and clayey soils. Farms adopting rotavator in silty soil tends to lose 198 kg wheat grains equivalent to a gross margin of NPR 8,684 (US$ 81) per hectare, while farms adopting rotavator in clayey soils tends to lose wheat yield of 268 kg and gross margin of NPR 9,086 (US$ 85) per hectare. There is not significant impact heterogeneity with respect to the soil type.

Finally, we estimated the differential impacts of rotavator tillage with respect to the rate of fertilizer application. We have seen in Table 1 that the adopters of rotavator tillage apply more fertilizers compared to non-adopters. Our analysis revealed that, among the plots where nitrogen (N) and phosphorous (P_2O_5) applications are high, rotavator adoption leads to a greater loss both in terms of grain yield and profit. More strikingly, when only one of the nutrients was higher, the yield and profit loss from rotavator tillage were even higher. Among the plots where both nutrients are limiting, the loss of grain yield was not significant and the reduction in gross margins was less pronounced. These results suggest that the effects of rotavators depend heavily on the level of fertilizers applied. A review of related literature suggests that higher level of fertilizer application in plots with rotavator tillage worsens the lodging problem due to shallow tillage and soil compaction by impeding root growth, nitrogen leaching and volatilization (Majeed et al., 2015; Guan et al., 2015; Głab, 2014; Izumi et al., 2004; Bennie and Botha, 1986).

6. Discussion and conclusion

The present study examined the adoption and impacts of high-speed rotavator tillage on wheat yield, cost of cultivation, and gross margin. To the best of our knowledge, this would be the first study examining this technology in farmers' field. The empirical analysis using PSM has shown that adoption of rotavator tillage reduced not only the tillage cost, but also wheat yield, gross revenue and farm profit. We have observed that the rotavator tillage adoption has significant cost saving effects in the beginning of the crop season. Naturally, farm households that face time and financial constraints to engage in tillage operations forms majority of the adopters. In the literature, there are sufficient evidence for adoption driven by potential cost savings (Chuchird et al., 2017; Gitonga et al., 2013; Pierpaoli et al., 2013). Notwithstanding, the present study is unique in the sense that the technology adoption leads to financially inferior outcomes overall. The analysis showed that farmers, especially those facing time constraints, adopt rotavator tillage by observing only the short-term benefits. We have seen that the farmers who harvest the previous crop with delay and those depending mainly on off-farm income tends to adopt rotavator. The adoption of rotavator tillage allows preparation of the wheat field in a single pass that pulverizes the shallow layers of the soil and mixing previous crop stubbles thereby allowing saves time between tillage time and sowing time (Coventry et al., 2015; Erenstein, 2010, 2009). Early seeding of wheat has considerable yield benefits in South Asia (Lobell et al., 2013).

Although our study uses cross-sectional data, it hints on the possible long-term effects of rotavators. The adoption literature suggests that large farms tends to adopt technology at an early stage of technology adoption phase (Sunding and Zilberman, 2001; Rogers, 1995; Feder et al., 1985; Feder and O'Mara, 1981) and the reason for a greater yield and financial loss in large farms due to rotavator adoption could be the soil degradation from continued use of rotavators. Realization of these negative impacts could be leading to dis-adoption of rotavator tillage among large farmers: the farm size of non-adopters are bigger than that of adopters. Our analysis also showed that the small farmers who adopted rotavator also have lower wheat yield, revenue and profit than non-adopters, although the difference is statistically insignificant. These small farmers might also suffer significant yield and profit penalty in the long-run with continued use of rotavator tillage. Panel data are required to establish the changes in impact magnitude over time.

Zero tillage could be a sustainable alternative to rotavator tillage, especially in areas where human labor is scarce and interval between two crops is short. Similar to rotavator tillage, zero tillage requires only a single pass of machine. In addition, significant yield and profit effects are reported for zero tillage adoption. However, the technology dissemination warrants development of information and service provision networks in many parts of South Asia. Furthermore, anecdotal evidences indicate that farmers prefer fine pulverized "clean" (without crop stubbles from the previous crop) soil, which can be attained easily by rotavator technology. Significant promotion programs are required to change farmer perceptions of to make them realize the importance of mulching and prepare them to adopt more sustainable tillage practices.

Agrarian development and poverty reduction are two goals that can be achieved through a congenial policy frame. Policies could signal and persuade farmers and service providers to move towards more sustainable technology options and away from others. The government of Nepal promulgated an agriculture mechanization policy in 2014 (Gauchan and Shrestha, 2017). Since then a number of promotion policies on agriculture mechanization have been formulated, which largely involves provision of subsidies on agricultural machinery (Takeshima, 2017a). Among different types of machines that has been subsidized by the government includes different types of tillage-attachments (Gauchan and Shrestha, 2017) including rotavators. Such encouragement is reflected in the increased interest of farmers to adopt rotary tillage practices and discourage more sustainable technologies of conservation agriculture.

Figure 1. Map of Nepal showing overall wheat areas by districts, survey locations and sampled districts and the spread of rotavators

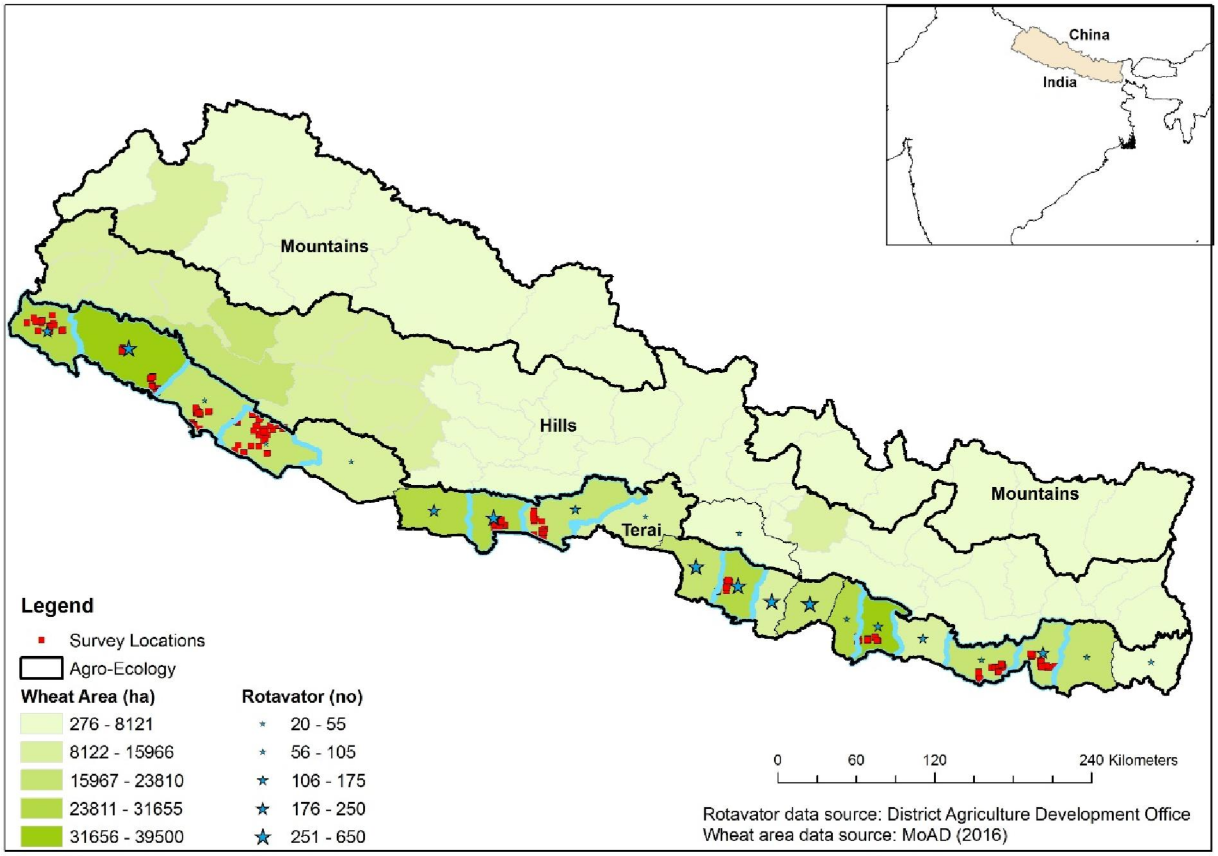
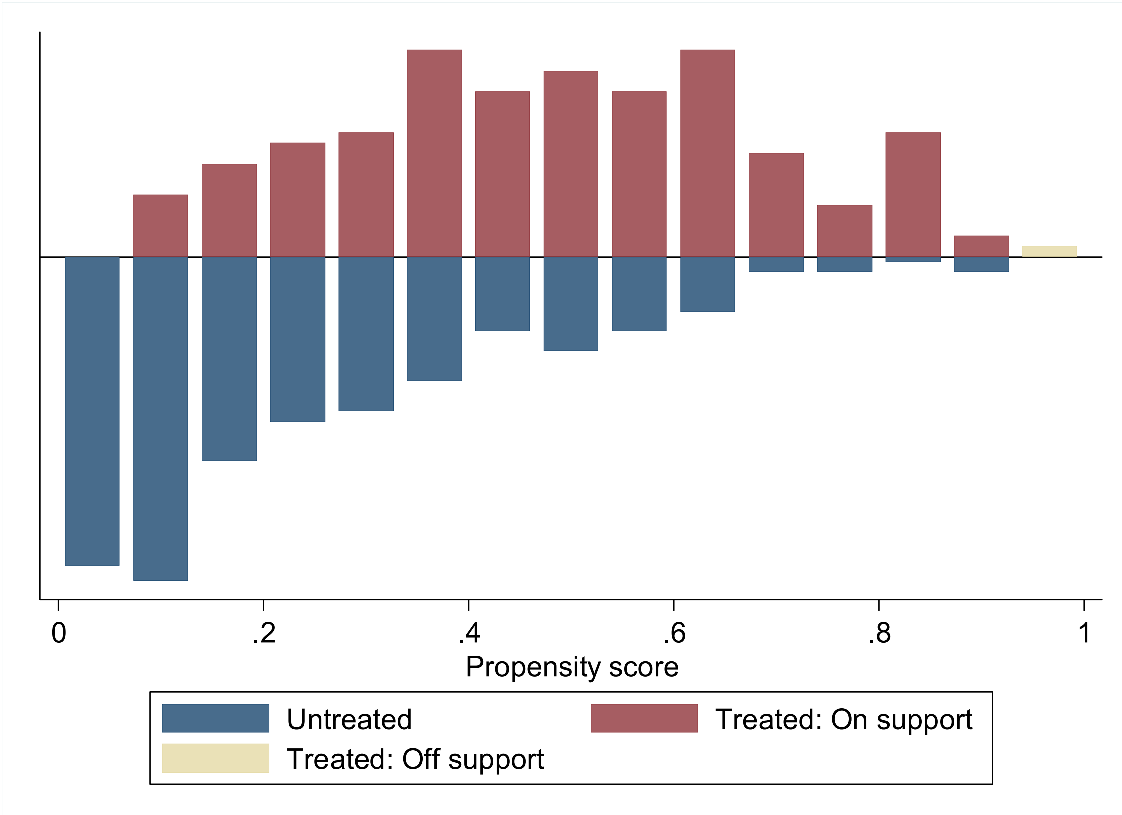


Figure 2. Distribution and common support for propensity score



Note: Treated on support means rotavator adopters who finds suitable matching pairs. Treated off support means rotavator adopters those didn't find matching pairs.

Table 1. Input-output relationship in wheat with and without rotavator adoption in Nepal Terai

Variables	(a) Full sample (N=485)		(b) Adopters (N=158)		(c) Non-adopters (N=327)		Difference (%) (c)-(b)
	Mean	SE	Mean	SE	Mean	SE	
Labor wage rate (‘000 NPR/day)	0.353	0.003	0.381	0.005	0.339	0.003	-10.833***
Nitrogen (N) application rate (kg/ha)	68.438	1.446	74.298	2.270	65.591	1.824	-11.719***
Phosphorus (P_2O_5) application rate (kg/ha)	41.827	0.837	47.299	1.380	39.183	1.017	-17.159***
Tillage cost (‘000 NPR/ha)	9.151	0.162	7.976	0.243	9.720	0.203	21.867***
Total input cost [a] (‘000 NPR/ha)	17.630	0.372	19.769	0.760	16.596	0.401	-16.052***
Total operational cost [b] (‘000 NPR/ha)	18.656	0.331	17.719	0.612	19.109	0.389	7.845***
Total labor cost [c] (‘000 NPR/ha)	19.314	0.372	23.165	0.650	17.453	0.416	-24.659***
Total variable cost (‘000 NPR/ha)	55.600	0.717	60.653	1.364	53.158	0.802	-12.358***
Grain yield (tons/ha)	2.291	0.032	2.079	0.046	2.393	0.040	15.095***
Gross revenue [d] (‘000 NPR/ha)	62.907	0.928	57.833	1.364	65.359	1.186	13.014***
Gross margin (‘000 NPR/ha)	7.308	1.015	-2.820	1.504	12.201	1.231	532.605***

*** Significant at 1% level. NPR stands for Nepalese Rupee (1 US$ = 107 NPR during the survey year (NRB, 2017)). SE stands for standard error of sample mean.

[a] Material input costs include the cost of seeds, fertilizer (urea, potash, DAP, other fertilizers), manure, herbicide, pesticides etc., but not depreciation cost and interest rates.

[b] Operational cost includes tillage (bullock, cultivator, rotavator), irrigation, harvesters, threshing, transport and other expenses.

[c] Labor costs include total family labor (valuated with market labor wage rate) and total hired labor. Household labor cost were valuated with opportunity cost of labor wage rate prevalence in villages. Household members who worked for 8 hours for wheat production related work were considered as one labor day.

[d] Gross revenue indicates total grain yield multiplied by grain price, while gross margin indicates gross revenue minus total variable cost (indicator of profit in this study).

Table 2. Factors affecting rotavator adoption: Logit model estimates

Variables	Model 1		Model 2	
	Coefficient	SE	Coefficient	SE
Natural logarithm of farm size of the household (ha)	-0.584***	0.143	-0.510***	0.147
Household size (number)	0.038	0.032	0.012	0.029
Household belongs to socially forward caste (1=yes, 0=no)	0.603***	0.224	0.730***	0.235
Age of household head (years)	0.003	0.012	0.003	0.012
Education of household head (year)	0.003	0.033	0.011	0.035
Sex of household head (1=male, 0=female)	0.077	0.364	-0.107	0.377
Natural logarithm of off-farm income (NPR/year)	-0.019	0.019	-0.019	0.020
Household members migrated (number)	-0.009	0.253	0.187	0.268
Groups/ cooperative membership (1=yes, 0=no)	0.337	0.230	0.451*	0.271
Household with mobile phones (1=yes, 0=no)	0.899***	0.240	0.933***	0.294
Occupation of household head (1=farming, 0=others)	-1.176**	0.469	-1.279***	0.478
Labor wage rate (NPR/day)	0.013***	0.002	0.009***	0.002
Land tenure (1=if leased-in, 0=otherwise)	-0.657**	0.309	-0.504	0.325
Fertilizer availability in time (1=yes, 0=no)	-0.075	0.239	0.063	0.258
Silty soil (1=silty, 0=others)			0.543	0.376
Clayey soil (1=clayey, 0=others)			0.252	0.415
Low land (1=lowland, 0=others)			0.593**	0.309
Access with irrigation (1=yes, 0=no)			1.607**	0.836
Delay in harvesting previous crop (1=yes, 0=no)			0.698*	0.368
West (1=if farms located in western Terai districts, 0=others)			1.297***	0.427
Mid and far-west (1=if farms located in mid and far-west Terai districts, 0=others)			0.311	0.393
Model intercept	-5.537***	1.135	-6.710***	1.482
Pseudo-R^2	0.17		0.21	
LR-X^2	102.80		127.51	
Log likelihood	-254.7		-242.3	
Non-adopters correctly predicted (%)	72.9		78.0	
Adopters correctly predicted (%)	63.0		63.0	
Model correctly predicted adopters and non-adopters (%)	72.9		74.0	

*** Significant at 1% level; ** Significant at 5% level; * Significant at 10% level. SE stands for standard error.
Number of observations: 485.

Table 3. Statistical test to evaluate matching

Matching method	Pseudo R^2	Likelihood ratio Chi^2	$p>Chi^2$	Mean bias	Median bias
Before matching	0.208	127.50	0.000	20.7	21.9
Nearest neighbor matching (NNM)	0.018	7.68	0.996	5.5	6.0
Kernel based matching (KBM)	0.018	7.28	0.998	5.9	5.1
Radius based matching (RBM)	0.016	6.52	0.999	5.4	5.3

Table 4. Average treatment effect on outcome variables

Matching algorithm	Outcome (per hectare)	Treatment effect for the treated		T-stat	Γ (Critical level of hidden bias)	Number of treated households	Number of control households
		mean	SE				
Nearest neighbor matching (NNM)	Tillage cost (‘000 NPR)	-1.229***	0.447	-2.75	1.80 – 1.85	157	327
	Total variable cost (‘000 NPR)	1.004	2.061	0.49	–		
	Wheat yield (tons)	-0.286***	0.094	-3.03	1.85 – 1.90		
	Gross revenue (‘000 NPR)	-9.807***	2.768	-3.54	2.25 – 2.30		
	Gross margin (‘000 NPR)	-10.811***	2.922	-3.70	2.25 – 2.30		
Kernel based matching (KBM)	Tillage cost (‘000 NPR)	-1.586***	0.436	-3.64	2.30 – 2.35	143	327
	Total variable cost (‘000 NPR)	1.221	2.039	0.60	–		
	Wheat yield (tons)	-0.284***	0.086	-3.29	1.90 – 1.95		
	Gross revenue (‘000 NPR)	-8.695***	2.565	-3.39	2.05 – 2.10		
	Gross margin (‘000 NPR)	-9.916***	2.712	-3.66	2.05 – 2.10		
Radius based matching (RBM)	Tillage cost (‘000 NPR)	-1.482***	0.432	-3.43	2.25 – 2.30	143	327
	Total variable cost (‘000 NPR)	1.294	2.026	0.64	–		
	Wheat yield (tons)	-0.309***	0.085	-3.62	2.20 – 2.25		
	Gross revenue (‘000 NPR)	-9.313***	2.542	-3.66	2.30 – 2.35		
	Gross margin (‘000 NPR)	-10.607***	2.689	-3.94	2.30 – 2.35		

*** Significant at 1% level. Exchange rate: 1 US$ = NPR 107 (NRB, 2017).

Table 5. Heterogeneous effects of rotavator adoption

Farm type	Outcome variable (per hectare)	ATT	SE	T-stat	Γ (Critical level of hidden bias)	No of treated households	No of control households
With respect to farm size							
Large farms (≥ 0.8 ha)	Wheat yield (tons)	-0.551***	0.136	-4.04	2.75 – 2.80	67	204
	Gross margin (‘000 NPR)	-18.423***	4.255	-4.33	3.05 – 3.10	67	204
Small farms (< 0.8 ha)	Wheat yield (tons)	-0.114	0.115	-0.99	–	90	121
	Gross margin (‘000 NPR)	-4.628	3.288	-1.41	–	90	121
With respect to soil type#							
Silty	Wheat yield (tons)	-0.198*	0.126	-1.68	1.25 – 1.30	102	174
	Gross margin (‘000 NPR)	-8.684**	3.797	-2.29	1.70 – 1.75	102	174
Clayey	Wheat yield (tons)	-0.268**	0.132	-2.03	2.20 – 2.25	41	73
	Gross margin (‘000 NPR)	-9.086*	5.099	-1.78	1.75 – 1.80	41	73
With respect to fertilizer application							
Limited dose N and P_2O_5	Wheat yield (tons)	-0.184	0.120	-1.54	–	63	203
	Gross margin (‘000 NPR)	-7.760**	3.819	-2.03	1.60 – 1.65	63	203
High P_2O_5 and limited N	Wheat yield (tons)	-0.553***	0.193	-2.87	3.90 – 3.95	26	33
	Gross margin (‘000 NPR)	-17.483***	4.838	-3.61	4.80 – 4.75	26	33
High N and limited P_2O_5	Wheat yield (tons)	-0.657**	0.329	-1.99	3.80 – 3.85	16	37
	Gross margin (‘000 NPR)	-22.223*	11.434	-1.94	3.80 – 3.85	16	37
Both N and P_2O_5 not limited	Wheat yield (tons)	-0.304*	0.156	-1.95	2.20 – 2.25	39	61
	Gross margin (‘000 NPR)	-9.019*	4.733	-1.91	2.10 – 2.15	39	61

*** Significant at 1% level. ** Significant at 5% level. ATT: Average treatment effect for the treated. SE: Standard error. 1 US$ = 107 Nepalese Rupees: NPR (NRB, 2017). Matching algorithm used is NNM, in which three nearest neighbor matching with replacement and common support.

Estimation was not carried out for sandy soils as adoption rate was marginal.

Appendix I. Socio-economic characteristics of rotavator adopters and non-adopters in Nepal Terai

	(a) Full sample (N=485)		(b) Adopters (N=158)		(c) Non-adopters (N=327)		Difference (%) (c)-(b)
	Mean	SE	Mean	SE	Mean	SE	
Household characteristics							
Farm size of the household (ha)	1.268	0.108	0.950	0.092	1.421	0.153	33.140***
Household size (number)	7.175	0.197	7.570	0.451	6.985	0.196	-7.727
Household belongs to socially forward caste (1=yes, 0=no)	0.460		0.557		0.413		-25.899***
Age of household head (years)	47.181	0.472	47.373	0.833	47.089	0.573	-0.601
Education of household head (years in school)	5.990	0.179	6.215	0.324	5.881	0.214	-5.381
Sex of household head (1=male, 0=female)	0.885		0.880		0.887		0.807
Off farm income ('000 NPR/year)	154.412	6.939	151.677	10.877	155.734	8.858	2.675
Household members migrated (number)	0.328	0.021	0.316	0.037	0.333	0.026	5.333
Groups/ cooperative membership (1=yes, 0=no)	0.532		0.582		0.508		-12.817
Household with mobile phones (1=yes, 0=no)	0.423		0.525		0.373		-28.978***
Occupation of household head (1=farming, 0=others)	0.942		0.892		0.966		8.287***
Land tenure (1=if leased-in, 0=otherwise)	0.225		0.184		0.245		33.291
West (1= if farms located in western Terai districts, 0=others)	0.206		0.310		0.156		-49.710***
Mid and far-west (1= if farms located in mid and far-west Terai districts, 0=others)	0.406		0.335		0.440		31.297**
Plot characteristics							
Fertilizer availability in time (1=yes, 0=no)	0.658		0.646		0.664		2.794
Silty soil (1=silty, 0=others)	0.571		0.652		0.532		-18.375***
Clayey soil (1=clayey, 0=others)	0.235		0.259		0.223		-13.970
Low land (1=lowland, 0=others)	0.202		0.266		0.171		-35.576***
Access with irrigation (1=yes, 0=no)	0.953		0.987		0.936		-5.222***
Delay in harvesting previous crop (1=yes, 0=no)	0.192		0.285		0.147		-48.461***

*** Significant at 1% level. ** Significant at 5% level. SE stands for standard error of sample mean. NPR stands for Nepalese Rupee (1 US$ = 107 NPR during 2016, the survey year (NRB, 2017)).

Appendix 2. Test for selection bias after matching

Variable	Matched samples		% Bias	% Bias reduction	p-value from t-test
	Treated	Control			
Farm size of the household (ha)	0.95	1.09	-6.30	71.70	0.36
Household size (number)	7.49	7.65	-3.30	73.10	0.77
Household belongs to socially forward caste (1= yes, 0=no)	0.55	0.51	8.10	72.00	0.48
Age of household head (years)	47.54	48.43	-8.60	-213.20	0.45
Education of household head (years in school)	6.20	6.18	0.50	93.70	0.96
Sex of household head (1=male, 0=female)	0.88	0.90	-5.90	-169.00	0.59
Off farm income ('000 NPR/year)	150.00	160.00	-8.90	-226.80	0.43
Household members migrated (number)	0.32	0.33	-3.20	11.90	0.78
Groups/ cooperative membership (1=yes, 0=no)	0.59	0.58	0.90	94.30	0.94
Household with mobile phones (1=yes, 0=no)	0.52	0.59	-14.20	54.00	0.21
Occupation of household head (1=farming, 0=others)	0.89	0.88	8.40	71.30	0.55
Labor wage rate ('000 NPR/day)	379.90	378.10	3.00	95.70	0.80
Land tenure (1=if leased-in, 0=otherwise)	0.18	0.14	9.80	34.00	0.33
Fertilizer availability in time (1=yes, 0=no)	0.64	0.65	-2.20	41.20	0.84
Silty soil (1=silty, 0=others)	0.65	0.61	8.30	66.30	0.46
Clayey soil (1=clayey, 0=others)	0.26	0.29	-6.90	18.00	0.56
Low land (1=lowland, 0=others)	0.26	0.27	-1.00	95.50	0.93
Access with irrigation (1=yes, 0=no)	0.99	0.98	5.60	79.40	0.48
Delay in harvesting previous crop (1=yes, 0=no)	0.28	0.32	-8.90	73.80	0.49
Western (1= if farms located in western Terai districts, 0=others)	0.34	0.37	-6.10	71.70	0.58
Mid and far-west (1= if farms located in mid and far-west Terai districts, 0=others)	0.31	0.28	6.60	82.1	0.59

Supplementary Materials S1

Table S1:A. Logit model estimates for sensitivity analysis

Variables	Specification-1		Specification-2	
	Coefficient	SE	Coefficient	SE
Natural logarithm of farm size of the household (ha)	-0.502***	0.155	-0.477***	0.157
Household size (number)	-0.001	0.012	0.014	0.030
Household belongs to socially forward caste (1=yes, 0=no)	0.012***	0.093	0.728***	0.235
Age of household head (years)	-0.014	0.373	0.014	0.073
Education of household head (year)	0.670	0.230	0.012	0.035
Sex of household head (1=male, 0=female)	0.026	0.034	-0.091	0.378
Natural logarithm of off-farm income (NPR/year)	-0.018	0.020	-0.021	0.020
Household members migrated (number)	0.053	0.262	0.221	0.274
Groups/ cooperative membership (1=yes, 0=no)	0.490**	0.244	0.452*	0.273
Household with mobile phones (1=yes, 0=no)	0.664***	0.274	0.940***	0.296
Occupation of household head (1=farming, 0=others)	-1.258**	0.494	-1.340***	0.486
Labor wage rate (NPR/day)	0.005	0.018	0.023	0.019
Land tenure (1=if leased-in, 0=otherwise)	-0.616*	0.322	-0.476	0.326
Fertilizer availability in time (1=yes, 0=no)	-0.063	0.251	0.068	0.258
Silty soil (1=silty, 0=others)	0.714*	0.360	0.545	0.377
Clayey soil (1=clayey, 0=others)	0.311	0.407	0.244	0.416
Low land (1=lowland, 0=others)	0.505*	0.307	0.583*	0.309
Access with irrigation (1=yes, 0=no)	1.592*	0.820	1.583*	0.835
Delay in harvesting previous crop (1=yes, 0=no)	0.435	0.322	0.707*	0.371
West (1= if farms located in western Terai districts, 0=others)	–	–	1.394***	0.446
Mid and far-west (1= if farms located in mid and far-west Terai districts, 0=others)	–	–	0.341	0.401
Farm size × farm size	-0.003	0.008	-0.003	0.008
Age × age	-0.001	0.007	-1E-04	8E-04
Wage rate × wage rate	9E-06	2E-05	-2E-05*	3E-05
Model intercept	-5.748*	3.436	-9.379**	3.921
Pseudo-R^2	0.192		0.209	
LR-X^2	117.61		128.37	
Log likelihood	-247.298		-241.918	
Non-adopters correctly predicted (%)	77.84		77.41	
Adopters correctly predicted (%)	66.09		62.30	
Model correctly predicted adopters and non-adopters (%)	75.05		73.61	

*** Significant at 1% level; ** Significant at 5% level; * Significant at 10% level. SE stands for standard error.
Number of observations: 485.

Table S1:B. ATT for rotavator adopters on outcome variables for different specification of propensity score

Specification	Matching algorithm	Outcome variable (per hectare)	ATT (SE)	Pseudo-R^2		Likelihood ratio Chi^2		Mean standardized bias		% bias reduction	Γ (Critical level of hidden bias)
				before matching	after matching	before matching	after matching	before matching	after matching		
First specification	NNM	Tillage cost ('000 NPR)	-1.398*** (0.415)	0.218	0.045	133.61*** (p=0.000)	19.65 (p=0.663)	22.3	5.6	74.89	2.30 – 2.35
		Gross revenue ('000 NPR)	-8.314*** (2.384)	0.234	0.053	143.48*** (p=0.000)	23.09 (p=0.456)	21.8	5.7	73.85	2.35 – 2.40
		Gross margin ('000 NPR)	-11.129*** (2.526)	0.244	0.070	149.17*** (p=0.000)	30.10 (p=0.147)	23.3	6.2	73.39	2.85 – 2.90
		Wheat yield (tons)	-0.267*** (0.080)	0.229	0.046	140.40*** (p=0.000)	19.87 (p=0.650)	22.2	5.6	74.77	2.10 – 2.15
		Total variable cost ('000 NPR)	2.815 (1.909)	0.195	0.016	119.430*** (p=0.000)	7.00 (p=0.998)	22.2	4.6	79.28	–
Second specification	NNM	Tillage cost ('000 NPR)	-1.212*** (0.416)	0.236	0.037	144.53*** (p=0.000)	15.97 (p=0.916)	22.9	5.7	75.11	1.95 – 2.00
		Gross revenue ('000 NPR)	-9.142*** (2.434)	0.254	0.060	155.44*** (p=0.000)	26.26 (p=0.394)	22.4	6.1	72.77	2.45 – 2.50
		Gross margin ('000 NPR)	-10.653*** (2.581)	0.263	0.070	161.05*** (p=0.000)	30.38 (p=0.210)	23.7	6.3	73.42	2.65 – 2.70
		Wheat yield (tons)	-0.270*** (0.082)	0.252	0.054	154.55*** (p=0.000)	23.65 (p=0.539)	22.8	5.9	74.12	2.10 – 2.15
		Total variable cost ('000 NPR)	1. 511 (1.942)	0.214	0.011	130.79*** (p=0.000)	4.70 (p=0.999)	22.7	4.6	79.74	–

*** Significant at 1% level. ATT: Average treatment effect for the treated. SE: Standard error. NPR stands for Nepalese Rupee (1 US$ = 107 NPR during 2016, the survey year (NRB, 2017)). Matching algorithm used is NNM, in which three nearest neighbor matching with replacement and common support.

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