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Contextual realities and poverty traps: why South Asian smallholder farmers negatively evaluate conservation agriculture

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Abstract

Conservation agriculture-based sustainable intensification (CASI) is gaining prominence as an agricultural pathway to poverty reduction and enhancement of sustainable food systems among government and development actors in the Eastern Gangetic Plains (EGP) of South Asia. Despite substantial investment in research and extension programs and a growing understanding of the agronomic, economic and labor-saving benefits of CASI, uptake remains limited. This study explores farmer experiences and perspectives to establish why farmers choose not to implement CASI systems despite a strong body of recent scientific evidence establishing the benefits of them doing so. Through thematic coding of semi-structured interviews, key constraints are identified, which establishes a narrative that current households' resources are insufficient to enable practice change, alongside limited supporting structures for resource supplementation. Such issues create a dependency on subsidies and outside support, a situation that is likely to impact any farming system change given the low-risk profiles of farmers and their limited resource base. This paper hence sets out broad implications for creating change in smallholder farming systems in order to promote the adoption of sustainable agricultural technologies in resource-poor smallholder contexts, especially with regard to breaking the profound poverty cycles that smallholder farmers find themselves in and which are unlikely to be broken by the current set of technologies promoted to them.

Introduction

The Eastern Gangetic Plains (EGP) of South Asia are populated mostly by resource-poor small-scale farmers who heavily rely on agriculture for their livelihoods. These agricultural systems tend to be limited by the dominant traditional management practices which are labor intensive and uneconomical with limited productivity, high vulnerability to shocks such as climate variations, and limited household and communal resources (especially for water, energy and human labor) (Gathala *et al.*, 2020*a*, 2020*b*). Rural production systems are primarily rice-based, with 'double-rice' systems (both monsoon and winter) dominant in rainfed systems, while winter crops such as maize, lentils and wheat are more abundant where irrigation facilities are available (Islam *et al.*, 2019).

More recently, a significant amount of research has demonstrated the advantages of sustainable intensification practices like conservation agriculture-based sustainable intensification (CASI) in the EGP, in terms of cost savings, yield gains, decreased irrigation requirements, increased profit and significant savings (Alam *et al.*, 2018; Bell *et al.*, 2019; Brown *et al.*, 2021*a*). CASI, commonly known by its main component as zero tillage (ZT) in South Asia, has been defined by FAO (n.d.) via three broad principles—minimum mechanical soil disturbance, permanent soil organic cover and species diversification. Globally, CASI has been shown to not only maintain the health of soil that is already productive, but also regenerate soils that have degraded in quality over time due to intensive tillage (Derpsch *et al.*, 2010). CASI has been promoted in the rural districts of Indo-Gangetic plains of South Asia for more than a decade via various research and development initiatives (Gathala *et al.*, 2021). The majority of this work has indicated positive outcomes for rural farmers willing to transition their production system to CASI (Erenstein *et al.*, 2012; Chaudhary *et al.*, 2022). There are now evidences that these benefits should enable sustained CASI uptake by smallholder farmers across the region (Lalani *et al.*, 2016).

The uptake of CASI has been rapidly expanding in the comparatively prosperous Western Indo-Gangetic plains, supported by adequate irrigation facilities and abundant machinery, as well as comparatively large land holdings (approximately average of 3–4 ha). Additionally, the green revolution and farm mechanization have been concentrated in this region (Hasan, 2014), with influences on Bangladesh and Eastern India at a much later stage. For instance, in Eastern

India, only one of the states has supplied metered electricity for ground water use for irrigation (Sidhu *et al.*, 2020). Mechanization pathways and policies in Nepal Terai have been historically informed by mechanization in India and Bangladesh (Karki *et al.*, 2021). Therefore, emerging research highlights a lack of CASI uptake in the EGP, characterized by both low rates of adoption and comparatively high rates of dis-use for early users of CASI production systems. Brown *et al.* (2021*a*) found that only 16% of the population used the ZT seed drill, while 25% had negatively evaluated the drill in the 14 districts of the Terai region in Nepal. Moreover, one-third of individuals who had ever used the drill had dis-adopted. This highlights that despite the heavy literature focus on the benefits of CASI in the region, adoption has remained limited. Low or limited CASI adoption in the EGP is often linked to smaller farm sizes, thus complicating agricultural mechanization initiatives (Friedrich *et al.*, 2012). Agricultural investment costs ranging from herbicide purchase, labor for weed control with limited perceived benefits of CASI and its implications to their livelihoods hinder adoption (Ngoma, 2018; Senyolo *et al.*, 2018; Brown *et al.*, 2020). In addition to the above, trade-offs associated with CASI use including limited access to machinery, competing uses for crop residues and a lack of skilled manpower further limit adoption (Hellin *et al.*, 2013; Bhan and Behera, 2014; Rodenburg *et al.*, 2020; Brown *et al.*, 2021*a*, 2021*b*, 2021*c*).

While there is an expanding body of literature that explores the negative evaluation of CASI globally with a focus on Africa (Brown *et al.*, 2017*a*, 2018; Ngoma, 2018), literature exploring the reasons for limited uptake in the EGP remains scarce. In the EGP, literature related to CASI is dominated by agronomic and economic analysis that tend to focus on production system rather than farmer experience and perspectives. The majority of these studies apply quantitative approaches to analyze profitability and yield benefits (Gathala *et al.*, 2015; Islam *et al.*, 2019), and evaluate project farmers or trial farms, given the limited time for autonomous adoption to occur (Gathala *et al.*, 2021). Previous research has shown that agricultural technology can reduce poverty through both direct and indirect effects, where direct effects are gains for the adopters, while indirect effects are gains resulting from adoption by others, which reduce food prices, create jobs and have growth-linking effects (de Janvry and Sadoulet, 2002). Furthermore, results from past research in Bangladesh indicate that small- and medium-scale farmers stand to gain more from agricultural technology than those who are nearly landless (Mendola, 2007). The commonality in the research body is that it largely ignored farmers lived experiences, while relying on economic analysis of technical performance and corresponding household characteristics.

More recently, studies have attempted to explore farmer decision-making through qualitative methods. This has origins in the work undertaken across the African continent to understand low CASI uptake from various farmer and actor perspectives, such as from current users (Brown *et al.*, 2017*b*) and negative evaluators (Brown *et al.*, 2017*a*). Such work has recently been expanded to understand the context of the EGP in terms of service provision by CASI service providers (Brown *et al.*, 2021*a*), and farmers who currently use CASI (Chaudhary *et al.*, 2022). However, these techniques are yet to be applied to understand decision-making associated with negative evaluation of CASI in the EGP.

This study contributes to this growing body of research that applies structured qualitative research to better understand farmer decision-making within population subsets. This study particularly focuses on the experiences of farmers in communities where adoption of CASI has occurred, yet they choose to negatively evaluate it through either pre-use non-interest to post-use dis-use. The aim of this study is to explore their evaluation processes and why their experiences differ from both farmers in the same communities positively who positively evaluate CASI, and broadly the most positive literature body related to CASI in the region. Hence, this study is farmer-centric, emphasizing on experiences and opinions rather than measurable agronomic or economic performances, thus giving novel insights into the factors that limit sustainable intensification in the EGP.

Methods

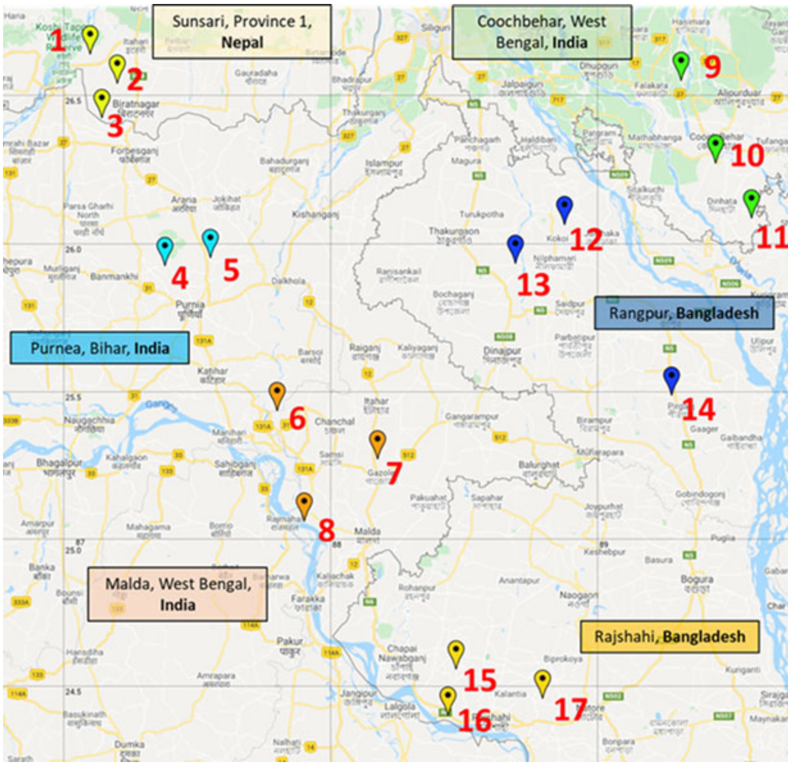
Technological focus

While respondents in this paper tend to identify ZT in their responses, it is important to note that the practices they are referring to occur as part of a wider CASI system. Indeed, multiple studies highlight the nature of ZT and the need for it to be packaged with additional elements to be successful (e.g., Guto *et al.*, 2011; Erenstein *et al.*, 2012). We specifically target the Rabi (winter) season as it provides the easiest entry point into CASI (as compared to Kharif where there are additional complications and considerations—see Brown *et al.*, 2021*b*). Farmers in Bangladesh apply ZT through a two-wheel attached planter box, while farmers in India and Nepal apply ZT using a four-wheel attached multi-crop planter. The unifying concept behind both machinery types is the reduction in tillage cycles before planting crops, as well as the associated benefits that accrue to farmers by doing this (Gathala *et al.*, 2015; Islam *et al.*, 2019).

Location selection

This study was carried out in six different locations in South Asia's EGP. Locations were selected in 2013 based on a thorough pre-screening process to ensure appropriate agro-ecological and climatic conditions for CASI, as well as representative characteristics to enable comparable results and later wider scaling of CASI across the region. A comprehensive agronomic analysis of chosen areas is provided in Gathala *et al.* (2021). Following this and since 2014, there has been a significant amount of research and extension activity in all investigated areas, which has been supported by both international and local actors.

The selection of communities to be investigated was undertaken purposively within each of the six locations to capture a diverse range of ZT equipment user typologies during the 2019 Rabi season. In each of the six locations of interest, three communities were chosen: one with a high adoption rate, one with a low adoption rate and one with recent adoption (Fig. 1). This was done in order to collect a variety of respondent typologies across the farmer adoption pathway. The typologies explored and the number of respondents for each typology in brackets were as follows: experimenters (44), interested non-users (38), implementing farmers (57), the negative evaluators were divided into the disinterested non-users (19) and the dis-users (54), service providers who provided machinery services again categorized into unsupported (14) and supported (15) (see Fig. 2: Chaudhary *et al.*, 2022). In addition, there was a dataset of spouses (47) which came from the households either implementing or had experimented with CASI.



ID	Map ID	Node	Community Type	Farmer Typologies	
				Not Interested	Dis-User
S	1	Bhokhara	High	4	3
	2	Chitaha	Recent	1	0
	3	Kaptangunj	Low	1	2
Sunsari, Province 1, Nepal				6	5
B	4	Udayanagar	Low	6	7
	5	Kathaily	High	1	12
Purnea, Bihar, India				7	19
M	6	Gorangapur	Low	0	3
	7	Ugritola	High	0	1
	8	Sadilchak	Recent	0	0
Malda, West Bengal, India				0	4
C	9	Alipurduar	Recent	0	0
	10	Ghugumari	High	1	8
	11	Dinhata	Low	0	2
Cooch Behar, West Bengal, India				1	10
R	12	Nilfamari	Recent	2	0
	13	Dinajpur	Low	0	3
	14	Pirganj	High	0	4
Rangpur, Bangladesh				2	7
J	15	Nobin Nagar	Low	0	3
	16	Premtoli	High	2	2
	17	Dharampur	Recent	1	4
Rajshahi, Bangladesh				3	9
Total				19	54

Fig. 1. Study locations in Eastern Gangetic Plains, covering six locations and 17 communities.

Respondent selection

This work builds on the same methodology as presented in Chaudhary *et al.* (2022) which outlines a total dataset of 288 semi-structured interviews. While that study focused on a subset of 57 implementing farmers, this work focusses on 73 'negative evaluators' (see Fig. 2). The various typologies of this methodological framing are based on the 'Stepwise Process of Mechanization framework' (Brown *et al.*, 2021*a*, p. 263) with the broader study attempted to capture the various farmer typologies along the adoption process ('PAUF': Brown *et al.*, 2017*b*, p. 15). This approach was chosen to ensure that the experiences and limitations of various phases of an adoption process were recorded in order to inform future CASI scaling initiatives. It should be noted that the methodology is not designed to be representative of the communities investigated; rather, it is meant to represent a spectrum of experiences that have occurred in the communities researched.

To capture these various farmer typologies, a snowball sampling approach was used. Brown *et al.* (2017*a*) conducted a regionally comparative study using a similar approach to investigate the experiences of CASI negative evaluators in Eastern and Southern Africa. The snowball sampling frame begins with a local promotional officer who is requested to identify the initial interview respondents but is not present throughout the interview procedure in effort to reduce bias in the responses provided. Respondents had to be the decision-making members of the household except for the 'Spousal set', who were interviewed as female spouses in men-headed households (Fig. 2). Initial respondents were asked to identify others in the community who fit within other typology types, with this manuscript focusing on those identified as negative evaluators. The objective was to sample each typology sufficiently, which resulted in 15–20 respondents per community (at least two of each typology). In total, 288 interviews were recorded, with a total interview time of 171 h and 34 min (an average of 35 min per interview). In each of the six locations, the intention was to conduct 50–60 interviews.

Questionnaire development

The 'Decision-making Dartboard' (DmD) framework (Brown *et al.*, 2021*a*, p. 257) was used as the basic schedule preparation and analysis approach in this study. The DmD divides critical decision-making processes into six stages spanning four asset categories, which are then merged to analyze the various components that respondents considered before arriving at their final typology conclusion. This DmD is based on the 'Livelihood Platforms Approach' (LPA) (Brown *et al.*, 2018, p. 333).

The DmD framework was used as the basis for both questionnaire development and thematic coding. While module 1 used Kobo Collect software to gather pre-screening and demographic data to classify the respondent typology, the DmD framework informed the subsequent six modules, which were digitally recorded for subsequent transcription. Modules were designed to be adaptive to the respondent typology, with the overarching goal of determining why they were the typology they were and what might be done to move them toward 100% ZT usage. Module 2 explored their agriculture narrative identity and aspiration, while module 3 evaluated how they learn about new technology and how ZT could be taught about. Module 4 focused on their livelihood constraints, whereas module 5 examined how they chose to analyze and respond to ZT. Module 6 explored the context for ZT adoption in the community, whereas module 7 focused at the effects and implications of ZT adoption, as well as what else was needed to ensure success. Each module was

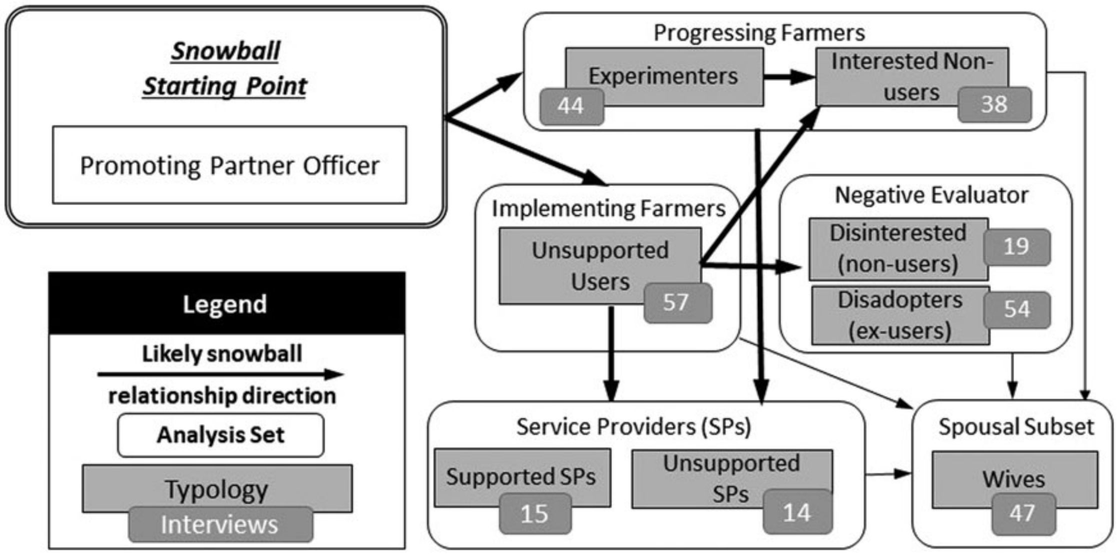


Fig. 2. Snowball sampling methodology employed in this study, with overall interviews shown across the total dataset.

structured in a way to elicit the key resource categories and levels that influence decision-making processes. This methodology has been applied widely in both Africa (e.g., with the precursor LPA framework; Brown *et al*., 2018, p. 333) and Asia (e.g., Brown *et al*., 2021*c*; Chaudhary *et al*., 2022).

Survey implementation

Five enumerators received comprehensive training in qualitative semi-structured data gathering before being assigned to different areas based on their language ability. All received the same training and were guided by a lead enumerator who provided guidance and help as needed during the data collection procedure to maintain the study's consistency. To decrease recall bias, implementation took place from August 2019 to December 2019, following Rabi planting but before Rabi harvest. All interviews were conducted entirely in native languages, with no English being used.

Subset analysis

The focus of this article is on the experiences of farmers who were either not interested in CASI without ever using the technology or dis-users who discontinued using CASI (i.e., the 'negative evaluators' subset in Fig. 2). As a result, people who have discontinued using ZT on their own farms since the 2019 Rabi season (dis-users) or have no interest to use ZT in their own farms without ever using ZT (not interested) are eligible to participate in this sub-study. There were 73 responders who fit with this typology (54 dis-users and 19 disinterested): nine from Cooch Behar, nine from Rangpur, six from Malda, 26 from Bihar, 12 from Rajshahi and 11 from Sunsari. The subset consists of 44 h and 26 min of recorded interview (an average of 36 min per interview).

Analysis process

Microsoft Excel was used to summarize the pre-screening data. All cleaned English transcripts were analyzed in Dedoose qualitative software (Dedoose.com) and thematically coded using the DmD framework. The coding themes included the DmD's 24 codes (6 levels by 4 resource kinds), as well as an additional 20 child-themes relating to frequently raised themes (e.g., communal human resources and issues of gender, social structure and caste, communal informational resources, business strategies and weed management). In total, 4324 extracts were categorized into the 44 themes listed above. These themes were then analyzed in accordance with the DmD to get the findings shown. Using the locations presented in Figure 1, the presentation of results includes a unique identity to correlate the quotation with the location and gender (e.g., S1 refers to Sunsari interview one). In addition, interviews with respondents falling under disinterested typology are denoted by [d] following the transcript ID. Summary demographic information is given in Table 1.

Results

Is negative evaluation of CASI a response to poor performance?

The perception of the performance of CASI by both negative evaluating typologies was often mixed, identifying various cost benefits whilst questioning yield implications. For example, farmers identified reduced input requirements (e.g., '*Everything from labour and water cost reduced up to half. We also reduced our costs associated to ploughing*' B7), yet yield was often estimated to be lower (e.g., '*The crop looked good but did not yield well with ZT*' B41) with associated financial implications (e.g., '*I didn't get a good return the first time I used it, so I don't see why I should lose my land income. The following time, I didn't use it*' B33). ZT's unsatisfactory performance was typically seen to be caused by two major technological problems. First, weed management and growth patterns were adapted from traditional methods (e.g., '*I determined the weeds were to blame for the loss…less money will be profited from the crops in ZT. There will also be less produce.*' J28). Second, issues were perceived with the machinery reliability in terms of seed drop (e.g., '*Deeply buried seed decomposed, and the seed that remained above the ground was picked up and consumed by birds. The result is a lower yield because the seed did not germinate well.*' B36[d]). Additionally, some farmers identified that the initial adoption was sometimes

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Table 1. Summary demographic information of respondents

Typology definition	Dis-users Previously used but have since ceased use of ZT	Not interested Never used, but hold negative perceptions of ZT
Respondents		
Total	54	19
Men	37	18
Women	17	1
Average age	42	36
Education level		
No formal education—illiterate	10	2
No formal education—literate	3	0
Primary	12	1
Higher secondary	24	13
Graduate	4	3
Postgraduate	1	0
Provided support for initial use	7	0
Zero tillage trained	25	3
Sole agricultural decision-makers		
Men	30	14
Women	8	1
Joint agricultural decision-makers		
Men	7	4
Women	9	0

associated with incentives and not necessarily technological performance, complicating their evaluations (e.g., '*The benefit of this technology is that it lowers cultivation costs because the agriculture department gives farmers some things for free. Whatever is harvested is entirely their income*' B36[d]).

Is negative evaluation of CASI a response to limited household resources?

CASI specific constraints

Respondents identified mostly physical and financial constraints as key resource limitations specific to ZT that influenced their decision to negatively evaluate CASI, and many of these appeared to be the primary determinants of dis-use (Table 2).

Generic constraints

Apart from constraints related to the technology, there were often household-level resource constraints that limited the adoption of CASI. These spanned all four resource types of the DmD framework.

Financial resources. Overall, regardless of production systems, respondents tended to experience limited financial viability from farming (e.g., '*I am involved in farming, but I do not earn much from agriculture. In agriculture, we get an income every six months and reinvest the same amount in the next crop without substantial profits*' B19). Multiple respondents also identified a hesitancy in changing to a production system that would require any input intensification (e.g., '*Farmers are disappointed in farming because the price of crops are lower in the market … We need to spend more on seeds and fertilizers, but this will increase our expenses*' R38).

Physical resources. Farmers were mostly small landowners (e.g., '*We have a very small piece of land. Our family cannot manage with just 2 bighas*[1] *of land for income, but we must do it anyway as it's our own land*' J23). This was often associated with difficulties in accepting a new technique that differed from prevalent current practices (e.g., '*The biggest challenge is that farmers don't want to accept anything new easily. We are accustomed to whatever we have been practicing for a long time*' R33).

Labor resources. Respondents tended to be engaged in off farm opportunities alongside farm work, given their financial limitations (e.g., '*I weave fishnets for a living, earning between 700 and 800 taka each day. These are all temporary jobs that I undertake from my home.*'[2] J30), and some farmers also projected that they would be unable to continue farming in the future and desired to focus their efforts on more lucrative sources of income (e.g., '*I barely manage to run the mill with my time … I don't have time and don't intend to farm anymore. I will only plant crops in small area to fulfill personal needs*' R31).

Informational resources. To ensure that they could implement the new production systems required for ZT adoption, respondents emphasized the need for more hands-on trainings as opposed to theoretical lessons (e.g., '*There are many trainings being conducted but those are not very practical. We need trainings for learning the measurements of fertilizers used in different methods of cultivation*' J9). This was particularly evident for sowing and weed management, which contradicted with existing knowledge (e.g., '*If the land is prepared well before sowing, then it gives a good yield*' B12[d]), which often again conflicted with existing knowledge (e.g., '*When the soil is dry and not tilled, the plants in the field die. I must therefore till the fields.*' S28[d]).

Is negative evaluation of CASI a response to an inability to supplement required resources?

Several constraints were raised by respondents that highlight a breadth of issues in accessing supplementary resources.

Rental land

Further adding additional complexity related to land resources were situations where land was leased for cultivation (e.g., '*We don't have land but cultivate in a leased land*' M12). In such situations, payment for leased land was based often on yield, and poor yield through changed practices may lead to landowners ceasing leasing arrangements if ZT yielded poorly (e.g., '*I will not grow crops using ZT … if the yield is not good, there will be loss then the landowner will take away the land and I have to sit idle without any work*' C27). This further reduced the risk profile for respondents who leased land and were considering CASI implementation.

[1] 1 Bigha=0.2508382079 Hectare
[2] 1 Taka=0.0098 US$

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Table 2. Zero tillage specific resource limitations as identified by respondents

Resource limitation	Representative quotation	ID
Irrigation access	'*A lot of people are doing ZT, we are not doing it because we have issues related to irrigation, we do not have any facility for irrigation*'	C44
Alternative uses of crop residues	'*Although Agriculture Officers suggested that it would be better if we keep taller stover residues, I kept it a little shorter as it is the stover residues we use to feed the cows*'	R20
Crop preferences	'*If we do paddy instead, it will help provide for our own family as well and also as cattle feed as we have cattle in the house*'	R7
Upfront investment	'*ZT requires more investment. The price of a maize seed packet is expensive. After that, farmer also need fertilizers and irrigation. For a minimum of 1 bigha land, the cost of cultivation of the maize crop is high*'	B26
Finances and hiring labor	'*We are poor people. If we can save some money by any means, we'll try to do that. The rental cost of ZT machinery is Rs. 300 per bigha, but if all of us at home can labour in farming then that money gets saved. That's why we often do farming ourselves without using machinery*'	M35
Suitable land size	'*I told the ones who have a big land that they have a lot of land and can use ZT, but mine is small so if my yield is not there then what will we eat so we did not believe in ZT*'	R36[d]
Suitable land type	'*Land leveling is another major issue in this area. Because of that, we are facing difficulties in using the ZT machinery*'	B17[d]
Limited information	'*They just said that ZT cultivation can be done, so I thought there is no harm in doing so… but to do CASI it has to be learnt because I have never seen it done before*'	R31

Limited machinery access

Given financial implications and limited machinery ownership in the region, all respondents would need to access CASI practices through machinery service providers. While machinery was recognized as necessary, it was often also perceived as inaccessible (e.g., '*If everyone must switch, ZT machinery is required. Why would anyone perform physical labour if ZT machinery is available?…Everyone will engage in ZT if they have access to the machine.*' R31). This was often linked to overall limited machinery access in communities (e.g., '*When I used ZT, there was only one machinery available in the village, and was not available to us on time*' B10). Even when machinery was available, reliability problems frequently occurred, which made respondents' desire to use CASI even more challenging (e.g., '*Every time, they had to call the mechanic, who took time to fix the ZT machinery. People in such circumstances didn't want to wait and lose sowing time. The village had access to no other ZT machinery, so we left and carried out farming using other machinery.*' B19).

Lack of skilled operators

Even if machinery was available, finding skilled operators seemed to present additional challenges (e.g., '*If the tractor driver drives quickly, crop stalks will stick to the machinery and the seed will not sow evenly. The seed then fails to fall evenly.*' B16). Attribution of such issues was often directed at the operators of machinery (e.g., '*The crop was sown unevenly, in my opinion, which was the operator's fault. The fact that the seed was sown in some places but not others indicates that a mistake was made and that he neglected to correct it.*' B33), which inhibited technological success and ultimately led to negative evaluation.

Information gaps

Overall, farmers had limited exposure and information sources for agriculture (e.g., '*If we get agriculture information, we do it and reap the benefits. Otherwise, we wouldn't know and would just keep farming based on what we already knew.*' B36[d]). Moreover, farmer-to-farmer information networks for respondents were ineffective and limited within smaller groups (e.g., '*There is no system in place for small or large farmers to exchange agricultural knowledge. They only contact the 5–7 people connected to the group.*' S12). Farmers also expressed a lack of continuous technical backstopping during CASI implementation (e.g., '*The agricultural officers didn't come here, and they didn't help us to do ZT. If we need information, we must manage it amongst ourselves*' R38). Trainings were deemed to be useful in many cases, but they also felt that it was time consuming, and that not every farmer could attend because of their busy schedule (e.g., '*There were more people initially, then everyone noticed that spending time in trainings and meetings was affecting their farm work. Naturally, we'll go where we can make money rather than where we can lose it.*' J29). Even when the trainings were accessible, often they were perceived to be less useful for farmers (e.g., '*Training only has a theoretical component. I seek clarification, but they offer no demonstration. The theory and its application differ significantly. We don't adhere to their teachings because we are aware of the same things on a practical level.*' S35[d]). This was sometimes also related to the skills of trainers (e.g., '*The operator came from Rajshahi. One person here had been taught how to do it, but he was unable to do it properly… In the end, nobody was able to use this machinery, so no one could perform ZT.*' J23).

Is negative evaluation of CASI a response to prevalent community norms

Accessing non-roadside land

The use of CASI in cultivation on land that was not immediately adjacent to a road was a major concern brought up by respondents (e.g., '*The road exists, but it doesn't lead directly to my farm. Other farmers will allow a tractor to pass through their land if it is fallow, but if they have already sown their crop, they won't let a tractor through their lands.*' B27). This was particularly prevalent among those who identified as poorer farmers which has implications for the economic position and associated social norms within communities (e.g., '*If a poor person has land away from the road, and the rich farmer has land near to the road. The wealthy farmer has everything; he will cultivate earlier.*

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However, the poor farmer won't be able to use ZT machinery in the field because of the lack of facilities, which will cause him to be late with cultivation.' B16). As a result, such farmers found CASI adoption challenging, particularly because it required a collective decision to use ZT machinery (e.g., '*To use ZT, you need everyone's cooperation or support one another. ZT machinery is not available for individual use. Everyone must do it together*' R33).

Expectation of support from projects

Many respondents relied on project support to implement CASI, but when the support ended, their adoption ceased. This was evident in two ways. First, there were issues with machinery access that were likely to lead the farmers to negative evaluation (e.g., '*There will be a problem when project ends. We can't do ZT without the machine*' J19). Many respondents were introduced to the machine via demonstrations and had no ongoing access to the ZT machinery from the ZT service providers and hence they had no long-term adoption potential (e.g., '*If someone buys the ZT machine and keeps it here, then, people will be able to continue using it. If the machine is used for demonstration and is taken from one village to the other for the same, it will not be accessible to anyone for continuous use*' B40). Financial support was also expected by many respondents and was the determining factor for their decision to adopt CASI (e.g., '*We didn't have to pay for anything before for the ZT machinery use. If we are required to pay for this later then we will not use this method*' J27). Moreover, resource-poor farmers could only continue using the new technology with continuous financial and physical support (e.g., '*Previously, we were provided with seeds and the facilities required for doing ZT, and they taught us the technology, so we did it. We are poor people; if they provide us with such incentives, we will start using ZT again*' M5).

Is negative evaluation of CASI related to ineffective policy support?

Machinery procurement subsidies

Farmers primarily expected the government to provide assistance through machinery subsidies for CASI (e.g., '*The availability of ZT machinery is the most important concern since it is owned by the Government, and not by any of us. If the Government distributes some at reduced prices to the people, many farmers will benefit*' J29), which also highlighted the perception of technology ownership as being owned by the government rather than the community. Due to their financial circumstance, most respondents had no desire to purchase machinery even with a subsidy (e.g., '*I will not purchase ZT machinery at this time due to a lack of funds. Yes, there is a subsidy, but we must pay the entire amount upfront before applying for the subsidy.*' B10). Because small farmers were disproportionately affected by such challenges, it frequently resulted in negative perceptions of government assistance programs (e.g., '*There is no benefit to small farmers. The wealthy farmers receive all the benefits, although they do not work on farms. They get benefits such as diesel and subsidies. They buy agriculture machinery at agricultural fairs and resell it to others at a higher price*' B7).

General government intervention programs

Farmers frequently expressed a desire for more government intervention in their agricultural activities, and a lack of programs and interventions was sometimes associated with a negative evaluation of CASI. Sometimes these expectations were far reaching (e.g., '*If the government provides seed, fertilizer, electricity, and irrigation facilities, farmers will not face any problems in farming*' B17[d]), also often, however, it was focused on issues like current market fluctuations in both the input markets (e.g., '*Fertilizer and insecticides are necessary, and the farmers do not have access to good quality inputs. The government needs to take appropriate action in this regard*' R36[d]) and output markets (e.g., '*We do not have any marketing or storage facilities. If any farmer harvest crops, there is no place to store it*' B17[d]). Where programs had been accessed but discontinued, dis-use was common (e.g., '*I am not getting the seed now from the Agriculture Development office. Every year, they rotate the seed distribution initiative among different farmers… thus, I could not do ZT*' C24). Some farmers also identified the government's role in reducing the risk of practice change (e.g., '*If the farmer has lost due to the use of the CASI technology, then the government should pay compensation to the farmer, so that the farmer's family is not affected. If the government does not do this, it will be difficult to adopt ZT machinery.*' B17[d]).

Discussion

While respondents generally agreed that ZT would reduce production costs, several other constraints appeared to be driving their negative evaluation of CASI. Primarily among them were perceived technological issues such as competitive uses for stover, limited access to machinery, inconsistent seed drop and physical resource requirements (especially land availability with access to irrigation). Such challenges are also mentioned by current ZT users in the same areas in a study by Chaudhary *et al.* (2022), who argue that current ZT users are inventive in the ways in which these problems could be resolved. However, the respondents in this study appeared to be less able to seek adaptation and instead negatively evaluate the technology. For instance, while stover prioritization for livestock is a common issue with CASI globally (Kassie *et al.*, 2015; Brown *et al.*, 2017*a*; Brown *et al.*, 2018), Chaudhary *et al.* (2022) suggest that some farmers were willing to trade off stover for improved soils while others were not. Likewise, machinery access remains a challenge for all ZT users in the EGP (Karki *et al.*, 2021; Brown *et al.*, 2021*c*), and a shortfall of skilled operators is widespread throughout the EGP. This often results in poor technological performance, which impedes technological success (Brown *et al.*, 2021*c*) and ultimately results in negative evaluation for dis-users. On the other hand, the disinterested farmers had concerning perceptions regarding the technology's profitability and showed less willingness to adopt due to their risk profiles, pre-assuming they couldn't take responsibility if the season ended in failure. Overall, respondents here did not appear to be as capable of seeking solutions to resolve these issues, which may be influenced by their lack of access to more reliable sources of information. Furthermore, a lack of access to resources and agricultural inputs, a lack of information and support, and pressure to make trade-offs and decisions all contribute to the poverty trap for small farmers as also suggested by Jumare *et al.* (2019, Ch. 8).

Our findings also show that, while farmers demanded and valued trainings, they were often perceived to be time consuming, with a low perceived usefulness compared to allocating time to more profitable alternative livelihood activities. Although local information networks were proven to be helpful in building trust in communities and stakeholders in Brown *et al.* (2021*a*); respondents here perceived that farmer-to-farmer information networks were inefficient which contradicts the findings of Chaudhary *et al.* (2022) in the same communities. The divergence between Chaudhary *et al.* (2022) and this study may be explained in the resource status of households in this study. Respondents in this study appeared to stress their weak financial position and limited risk profile unlike implementers who overcame similar socioeconomic constraints. Similar to our findings, Kurkalova *et al.* (2006) illustrated that the benefit anticipated by dis-users does not fully compensate them for the increased risk they may face, as well as the possibility of irreversible loss of earnings associated with traditional tillage techniques. This meant that they had limited tolerance for crop failure and were more hesitant to embrace and consider change. Therefore, it is crucial that the decision-makers, policymakers and other development-oriented organizations design agricultural interventions such that farm households in the implementation areas have access to credit as also mentioned by Challa and Tilahun (2014), and farmers should also be trained to understand the advantages of implementing new technologies.

With respect to constraints limiting continued use of CASI, early plantation in adjacent fields has resulted in obstructed land, which adds to the already existing financial limitations for investment in agricultural inputs, leading to CASI dis-use. This has strong implications for not only ZT interventions, but more broadly implementation of any such technology across the EGP in general; particularly given the generic constraints raised by respondents are an indication that ZT (and practices like ZT that imply input intensification and changed practices) is unlikely to enable resource-poor smallholder farmers to exit their agriculture-based poverty trap.

Due to these limited resource contexts, respondents were often found to be deeply reliant on project assistance. The adoption of CASI was perceived to be profitable only when agricultural inputs were subsidized, but not when they had to invest their own resources. The findings also revealed a lack of community ownership of technology as a result of such challenges which deterred further adoption. As Banks and Marsden (2000) point out, maximizing the broader rural development impacts of agricultural conservation schemes is a critical component in the EGP, especially in areas where many farmer businesses are likely to be heavily reliant on subsidies. A sustainable farmer business and desirable rural development can be achieved with properly planned and embedded regional policies, lowering reliance on aid-based subsidies and boosting sustainability based on such farmer enterprises. Given that some of the respondents in this study initially received financial assistance to experiment with ZT but ultimately stopped, it is clear that the current subsidy support is insufficient to help farmers with limited resources escape poverty. In addition, small and marginal farmers remain vulnerable as they rely mostly on non-formal credit sources and lack timely and adequate access to institutional sources of finance (Yadav and Sharma, 2015). Furthermore, we also know that procurement subsidies usually are not effective, given most subsidies are targeted at machinery owners (Rehfuess *et al.*, 2014) and are more likely to benefit larger farmers (Keil *et al.*, 2016), emphasizing the need to target and support smallholder farmers rather than machinery owners as suggested by Brown *et al.* (2021*a*).

It is evident from our findings that decisions related to technology adoption made by small-scale farmers consider the deeply rooted poverty trap that they are bound in. This poverty trap, as highlighted for African smallholder farmers in Rodriguez *et al.* (2009), proposes that resource-poor smallholder farmers can become trapped in a cycle of low input, low output production systems which are perceived to require input intensification and are not able to break that cycle. This is particularly so when subsidy and support mechanisms do not directly catalyze financial resources in a meaningful way to enable reinvestment. This is also consistent with Mendola's (2007) study in Bangladesh, which argues that while technology adoption appears to raise the income of poorer near-landless farmers in rural regions, it does not assist them transcend poverty, unless further equity-enhancing policy measures are implemented. Similarly, through their research, Osabohien *et al.* (2019) concluded that effective policies should be formulated in agricultural development plans that prioritize sustainable land and water management, access to markets and food security in order to reduce poverty rates and ultimately to increase government revenue in the long run. In addition, previous studies also illustrate that policies such as insurance payouts have been proven to alleviate poverty and have welfare-enhancing effects by pushing policyholders to adjust their investment and risk-management decisions or by dampening weather-related shocks through payouts (Noritomo and Takahashi, 2020).

Radosavljevic *et al.* (2021) have also explored fractal poverty traps in similar agro-ecological systems and stress that cross-level interactions, farmer behavioral changes and the effectiveness of development interventions are crucial in alleviating poverty traps. Therefore, it is crucial to consider the findings from such studies that directly focus on farmers experiences for evidence-based program planning and designing, meanwhile also recognizing, and utilizing the already available local resources. However, it is equally important that the basic facilities required for agriculture are in place for better adoption of agricultural technology like CASI. Policies aimed at achieving food self-sufficiency, on the other hand, tend to undervalue non-traded items, particularly land and labor resources, warranting appropriate policy reform, both at the macro and sectoral levels (Pingali, 2012). This also has strong implications for inclusiveness of current promotional strategies and technologies, as well as changes required to current programmatic and governmental subsidy and promotional support activities. One of the most critical aspects is the need for a change in mindset, not just of farmers, but also of policy and programmatic actors. While most policies and programs condemn farmers for failures to take up and scale new technologies, there is a need for a shift in perspective among policymakers and practitioners, with an eye on how policies and interventions can help farmers escape the cycle of poverty.

Conclusions

This work aimed to identify why farmers negatively evaluate CASI, a common government and development priority in the region. Findings suggest that while CASI has some technology-specific issues, overarching issues with the financial viability of farming are more likely to drive negative evaluation of CASI. More importantly, these are likely to constrain any attempts to sustainably intensify agricultural systems in the region more generally. This means that the recent intensification of production in the comparatively wealthy Western Gangetic Plains is unlikely to work in the EGP and a tailored region-specific programming design will be required.

The findings demonstrate that, despite CASI's established benefits in terms of cost savings through reduced tillage and labor needs, farmers were unwilling to experiment owing to several other constraints, demonstrating that many variables influence the decision-making process. However, based on the experiences of farmers who have used CASI at some point, we can conclude that poor finances, machinery unavailability, expectations of sustained assistance from information sources and extension services and a lack of a strong farmer network lead to premature dis-use. As a result, it is critical to create an enabling environment to assist farmers in adopting CASI and enabling continued use. Adoption of agricultural technology such as CASI is directly affected by its ability to provide a relative advantage (particularly financially) and its applicability within the farmers capacity. Furthermore, expanding agricultural programs is difficult in regions where there are smallholder farmers with limited resources, and they are likely to rely substantially on subsidies. This manuscript also highlights that a transformation in mindset is needed, not just among farmers, but also among policymakers and program stakeholders. Therefore, policies for smallholder farmers must be appropriately designed, localized and regionally integrated to achieve sustainable technological adoption and expansion. This study demonstrates why farmers choose not to embrace sustainable agricultural technology such as CASI, and future research should build on these findings to gain a deeper knowledge of tiers of constraints that lead to community dis-use for more effective future interventions.

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