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Experiences With Conservation Agriculture in the Eastern Gangetic Plains: Farmer Benefits, Challenges, and Strategies That Frame the Next Steps for Wider Adoption

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While there are numerous studies that explore the agronomic and the economic benefits of Conservation Agriculture in South Asia, only few studies have explored the farmers' experiences and the drivers of its adoption. This study aims to learn directly from current users through exploration of their decision processes, evaluations, and experiences in extrapolating the concept for the broader scaling of Conservation Agriculture across the Eastern Gangetic Plains (EGPs) of South Asia. We analyzed a total of 57 qualitative and semi-structured individual interviews with the farmers who are currently implementing Conservation Agriculture practices across six locations. These farmers faced a variety of hurdles including hesitation in accepting and adopting the technology, technical performance challenges, information gaps, and subsidy/project dependence. To overcome these, respondents adopted various strategic approaches such as assuming the role of an educator by sharing their knowledge with other farmers in the community, changing mindsets for stover retention, adoption through self-investment, and opting for communal purchase of machinery to reduce project dependence. This led farmers to identify a range of benefits including improved socio-economic condition, increased respect in the community, and increased free time to pursue diverse interests and opportunities. Additionally, strengthened information networks such as improved interpersonal connection with agricultural universities, government extension systems, and local farmers groups have positively enhanced the uptake, allowing them to overcome further limitations. These findings provide novel learnings on how farmers overcome nine key friction points, and what this means for increasing the farmer uptake of new practices across the region, which are crucial for successful future interventions as implemented by the government and development organizations.

Keywords: zero tillage, technology adoption, Conservation Agriculture, farmer decision making, scaling, farmer experiences, Eastern Gangetic Plains

INTRODUCTION

The Eastern Gangetic Plains (EGPs) are spread across three countries, namely, southern Nepal, north-eastern India, and northern Bangladesh. These areas are densely populated, with a high rural population, high levels of poverty, low agricultural productivity, small average land holdings, and limited mechanization (Kassam et al., 2018; Brown et al., 2021b; Gathala et al., 2021). This region is home to 450 million people who depend on agriculture to achieve household food security (Gathala et al., 2020). Agriculture also continues to be a major employer for people in this region (Ojha et al., 2014), being the main source of income and the economic backbone for the majority of people in the EGPs. Given this, improving productivity and resilience of the farming systems in the EGPs is crucial in sustaining food security, alleviating poverty, and improving socio-economic standards amidst a changing climate and resultant threats to the environment (Harvey et al., 2013).

Ongoing intensive tillage as part of traditional planting practices in the region is leading to decreasing water levels, reduced yields, increasing production costs, and declining farm earnings (Jat et al., 2014). In response, Conservation Agriculture-based Sustainable Intensification (CASI) has emerged as an alternative to tillage-based challenges. The CASI has the potential to manage biotic and abiotic stresses, contribute to climate mitigation and adaptation, save labor and energy, and improve yield, food security, and profits among other benefits for smallholder farmers across the region (Erenstein et al., 2012; Gathala et al., 2020; Jat et al., 2020).

According to Kassam et al. (2018), the area under CASI has increased by 69% globally over the 7-year period between 2008–2009 and 2015–2016. This is driven primarily in developed countries through public policies and government incentives (Fuglie and Kascak, 2001; and Llewellyn et al., 2012). In the Global South, uptake has shown a more variable trend. In Eastern and Southern Africa, CASI has been included in national policies (Giller et al., 2015), and Brazil has witnessed widespread adoption of no-till agriculture over the years but often without the implementation of the complete CASI (Bolliger et al., 2006). Some studies have articulated that CASI is more suited to large farms (Giller et al., 2015), while arguing that the multi-year lag, before farmers started experiencing yield gains, adds to the lack of economic incentive for smallholder farmers to adopt CASI (Stevenson et al., 2014). Studies highlighting the efforts to promote CASI, specifically among smallholder farmers in South Asia, are ongoing and have witnessed progress over the last few decades, though, mostly concentrated in regions of the Western Indo-Gangetic plains (Bhan and Behera, 2014; Giller et al., 2015), while it remains more limited in the Eastern Indo-Gangetic Plains (Brown et al., 2021b).

While there are substantial studies to highlight the agronomic and economic benefits of CASI worldwide (Kassam et al., 2018; Dixon et al., 2020), there have been minimal investigations of farmer perspectives and experiences in the EGPs when it comes to CASI adoption. Their drivers and motivations, or lack thereof, are imperative in building an understanding of why some farmers adopt CASI more easily than others. Understanding this will help enlighten the requirements for scaling out CASI technology across the EGPs. Studies on effective scaling of CASI are often focused on econometric analysis of agronomic benefits that establishes the technology's potential for success (Mitra et al., 2020; Wortmann and Dang, 2020). Few studies explore farmers' experiences, perceptions, and evaluation processes as a pathway to understanding how to scale, particularly from the view of current users. For example, Derpsch et al. (2016) focused on the variables that lead to dis-adoption rather than the analysis of experiences and aspects of successful adoption based on farmers' experiences and effective CASI scaling.

More recently, a body of work has emerged in Eastern and Southern Africa that uses an in-depth, structured, and qualitative explorations of farmer evaluation and decision-making processes to understand the context of CASI adoption by smallholder farmers. This work was framed within a "Livelihood Platform Approach" to explore a spectrum from those completely unaware of CASI (Brown et al., 2017a), to positive and interested (Brown et al., 2020), negative and not interested, or dis-adopting (Brown et al., 2017a) and current users (Brown et al., 2020). Such an approach provides new and novel insights into how to scale CASI in Eastern and Southern Africa, and the application of such methodologies is warranted to explore similar issues of limited adoption of CASI in the EGPs.

Previous literature has largely focused on establishing the agronomic benefits of CASI technology, with little attention paid to learning about farmers' experiences and perceptions of the technology. The absence of relevant data (as opposed to a lack of empirical techniques) is often a barrier to better understanding of adoption and thereby, acknowledging this gap will help such studies to have proper insights into how farmers adopt new technologies (Doss, 2006). Given the emerging qualitative frameworks used above, there is an opportunity to extend this and to address a void in qualitative exploratory studies of farmers' decision-making in the EGPs. This research aims to bridge this gap by answering two research questions: (1) What are the experiences and the challenges of the smallholder farmers in the EGPs, who are also implementing CASI? and (2) How can those experiences be utilized in the successful scaling strategies for wider adoption of CASI for smallholder farmers in the EGP? The objective of this study is to provide an insight into the farmers' experiences of CASI adoption to highlight the regional and the location-specific opportunities, as well as the challenges in scaling up CASI uptake. Based on the findings, a set of recommendations is provided to address the current challenges limiting wide-scale CASI adoption in the EGP.

MATERIALS AND METHODS

Technological Focus

As part of a broader investigation of CASI, this paper especially focuses on Zero Tillage (ZT) planting systems used in the Rabi (winter) season. The ZT systems have been locally tailored to the

Abbreviations: CASI, Conservation Agriculture-based Sustainable Intensification; DmD, Decision-making Dartboard; EGP, Eastern Gangetic Plains; ZT, Zero Tillage.

needs of the region, with farmers in Bangladesh using a two-wheel planter box attachment and farmers in India and Nepal using a four-wheel multi-crop planter attachment. The unifying principle is the same in both methods, reducing the number of tillage events before planting crops.

Location Selection

This research was carried out at six different places in the EGPs of South Asia. The six areas were chosen after a thorough pre-screening process prior to the start of promotional activities in 2013 and were chosen based on suitable agro-ecological and climatic conditions for CASI to ensure its use would be beneficial for farmers in those areas, as well as the representative conditions to allow for wider scaling of CASI across the region. Since 2014, all areas have had significant research and extension activities. A full agronomic overview of selected locations is given in a study (Gathala et al., 2021).

Within each of the six locations, communities were intentionally selected to capture a diversity of user typologies of ZT equipment in a Rabi season. Three communities were selected in each of the six locations of interest: one with a high adoption, one with a low adoption, and one with a recent adoption (**Figure 1**). This was done to capture a diversity of respondent typologies along an adoption pathway (see section Respondent Selection), rather than exclusive representations among survey respondents and communities. All locations of interest followed this structure except in Purnea (Bihar), where no community of recent adoption was located.

Respondent Selection

The overall study aimed to capture a variety of different farmer typologies along the process of adoption, based on the Stepwise Process of Mechanization framework (Brown et al., 2021b) and the Process of Agricultural Utilization Framework (Brown et al., 2017b). This was done to ensure that the experiences and the constraints of various stages within an adoption process were captured in order to inform about the broader implications in increasing and scaling efforts. It should be noted that the methodology, hence, is not intended to be representative of communities; rather, it is meant to reflect a range of experiences that have occurred in the communities studied.

A snowball sampling methodology was employed to capture these diverse farmer typologies. This is similar to that employed by Brown et al. (2020) to explore the experiences of CASI adopters in Eastern and Southern Africa. The sampling frame has a starting point with a local promotional officer, who is asked to identify the first interview respondents, but was not present during the interview procedure to avoid any bias in the given responses. The decision-making members of the household were selected to be the respondents for the survey, except for the "Spousal set," which specifically included women spouses within men-headed households (**Figure 2**). Initial respondents were then asked to identify other typologies of interest. The goal was to adequately sample each typology, which generally resulted in 15 to 20 respondents per community (at minimum two of each typology), depending on the type of community and the availability of different types of respondents. In total, 288 interviews were collected, which totaled 171 h and 34 min of interview duration (an average of 35 min per interview). The objective was to capture between 50 and 60 interviews in each of the six locations.

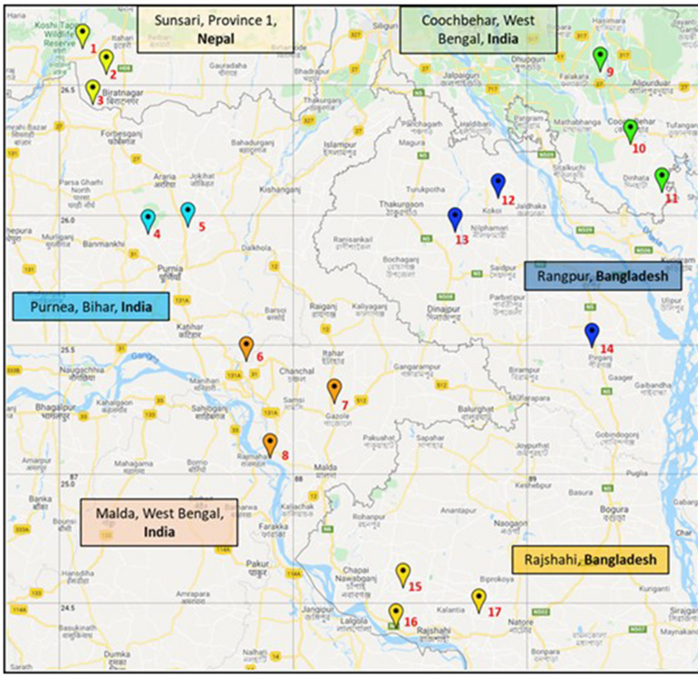
Subset Analysis

This study aims to create novel and unique understandings of the action and the experience of implementing ZT in the EGPs. While most studies undertake binary studies of adoption and non-adoption or combine various different types of adoption, this study specifically disaggregates the said approaches to focus directly on the action and experience being explored. As such, only a subset of the above-mentioned data is analyzed in this paper with the emphasis on the experiences of farmers who are currently implementing ZT without the benefit of subsidies or financial inputs from promotional organizations (i.e., the "Implementing Farmers" subset in **Figure 2**). The criteria for participation in this sub-study include those respondents who are currently using ZT on their own farms during the 2019 Rabi Season and those who are not receiving any financial assistance from any promoting organization. The 57 respondents were identified that fit within this typology: 11 From Cooch Behar, 10 from Rangpur, 13 from Malda, eight from Rajshahi, and 15 from Sunsari. In Bihar, no respondents were found because all the currently implementing farmers are receiving subsidy support from promoting organizations. The subset consists of 29 h and 24 min of recorded interview (an average of 36 min per interview).

Respondents consisted of 48 men and nine women farmers. The respondents had an average age of 43 years. Two women and 10 men were illiterate, while the other respondents had completed a minimum of primary education. Respondents had first heard of ZT between 2006 and 2018 and began the implementation of ZT between 2010 and 2019. Approximately half of the respondents had undertaken training in ZT practices. A total of 26 respondents practiced ZT in crops such as mustard, lentil, jute, chickpeas, in addition to wheat, maize, and/or paddy. None of the respondents have bought ZT drill themselves indicating that they relied on fee-for-hire services.

Questionnaire Development

The Decision-making Dartboard (DmD) framework (Brown et al., 2021c) was applied in this research as the underlying schedule development and analysis framework. The DmD breaks down important decision-making processes into six levels across four asset categories, which are then combined to examine the many factors that people evaluated in order to arrive at their final typology conclusion (Brown et al., 2021c). This led to the development of a semi-structured question schedule which consisted of seven distinct modules. Module 1 collected limited pre-screening and demographic data to categorize respondent typologies, which were collected using KoboCollect software. Modules 2 to 12 were open-ended and digitally recorded for later transcription. Modules were set to be adaptable to the respondent typology with the overall focus to explore why they were the chosen typology, and what could be done to progress them to the total use of ZT. Module 2 focused on the story of



ID	Community	Type	Total	Implementor
1	Bhokhara	High Adoption	21	5
2	Chitaha	Recent Adoption	12	7
3	Kaptangunj	Low Adoption	16	3
S set - Sunsari, Province 1, Nepal			49	15
4	Udayanagar	Low Adoption	24	0
5	Kathaily	High Adoption	24	0
B set - Purnea, Bihar, India			48	0
6	Sadilchak	Recent Adoption	14	0
7	Gorangapur	Low Adoption	20	9
8	Ugritola	High Adoption	15	4
M set - Malda, West Bengal, India			35	13
9	Alipurduar	Recent Adoption	14	3
10	Ghugumari	High Adoption	22	5
11	Dinhata	Low Adoption	13	3
C set - Coochbehar, West Bengal, India			49	11
12	Nilfamari	Recent Adoption	14	3
13	Dinajpur	Low Adoption	10	1
14	Pirganj	High Adoption	63	13
R set - Rangpur, Bangladesh			87	17
15	Nobin Nagar	Low Adoption	15	2
16	Premtoli	High Adoption	18	5
17	Dharampur	Recent Adoption	15	1
J set - Rajshahi, Bangaldesh			15	1
Total			288	57

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

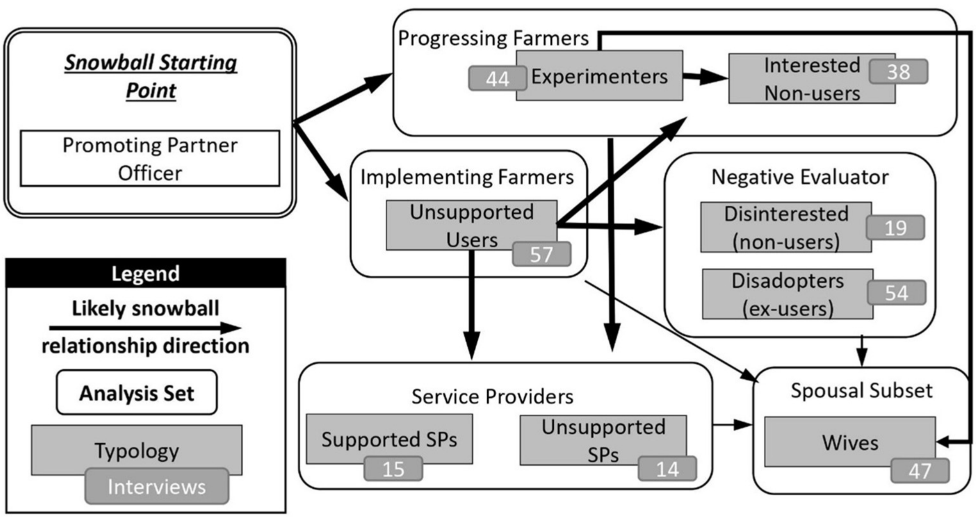


FIGURE 2 | Snowball sampling methodology employed in this study, with overall interviews shown across the total dataset.

their agricultural identity and ambition, while module 3 explored how they learn about new technologies and also, the ways on how ZT could be learned. Module 4 explored their livelihood constraints while module 5 explored how they chose to evaluate the actions of ZT. Module 6 explored the community context of adoption ZT, while module 7 looked at the outcomes and implications of ZT implementation, and what else was needed to ensure success.

Survey Implementation

Five enumerators undertook extensive training in qualitative semi-structured data collection and were allocated to various locations based on their language skills. All received the same training and were led by a lead enumerator, who offered advice and assistance as needed during the data collection process, to ensure standardization of implementation of the study. Implementation occurred from August 2019 to December 2019, after the Rabi planting but before the Rabi harvest to reduce any recall bias. All interviews were conducted in local languages without any use of English.

Analysis Process

Demographic information was summarized using Microsoft Excel, while all cleaned English transcripts were analyzed in Dedoose qualitative software (Dedoose.com), and was thematically coded using the DmD framework. The themes used for coding consisted of the 24 codes related to the DmD (6 levels by 4 resource types), with an additional 20 child themes related to commonly raised topics (for example, communal human resources and issues of gender, social structure and caste, communal informational resources, business strategies, and weed management). In total, 4,324 excerpts were coded into the above 44 themes. These themes were then analyzed in line with the DmD to produce the given results. Presentation of results includes a unique identifier to associate quotation with location and gender, using the sets in **Figure 1** (e.g., S1 refers to Sunsari interview one). Additionally, interviews with women farmers are represented as [f] after the transcript ID.

RESULTS

To understand the past and present narratives of CASI users, the results section is structured around the experienced benefits of CASI and the challenges that farmers overcame to implement CASI by using various mitigation strategies. The relationship with the DmD framework across all resources levels and types is provided in subheadings throughout the results. The requirements for use of CASI, which is categorized in level 1 of the DmD framework, are dispersed throughout the "challenges overcome for successful implementation" sub-section of the Results section and hence have not been sectioned separately in the results.

Experienced Benefits of CASI Use (DmD Level 2)

Direct Benefits

Respondents identified a variety of benefits that they had experienced because of CASI implementation, as well as drivers of a likely continued use (**Table 1**). These benefits were experienced by farmers across the study locations suggesting CASI has various consistent advantages.

Indirect Benefits

Beyond the direct and immediate benefits of the CASI use, respondents also identified implications of CASI use that have a broader impact on their livelihoods, which are described here below.

Reduced Reliance on Daily Laborers in the Context of Labor Scarcity

Farmers were dependent on hired labor for diverse farming activities, and out-migration was a common trend in all locations, given the better earning opportunities that exist outside of agriculture (e.g., "*Most farmers prefer working in off-farm activities because they can earn more money there*" C21). As a result, there were limited laborers available for agricultural tasks, which increased farmers' production costs (e.g., "*The daily wage of laborers is high, and since labor is in short supply, the labor wage continues to rise*" M29). Farmers have been addressing this labor shortage using ZT machinery (e.g., "*If I don't get laborers, then I will have to use the ZT machinery.*" M36) while also predicting its use in the future of farming by the younger generation (e.g., "*The children now and in the future will not toil in the farm, and laborers will not be available. Therefore, we have to automatically switch to ZT machinery*" C33).

Implications of Saved Time

While respondents directly identified time savings as a CASI benefit, they also identified the indirect benefits of this time savings. Respondents utilized saved time in two ways. First, the extra time was used to take care of a variety of other household activities (e.g., "*Earlier, it used to take the entire day to finish the farm work. Now much time is not required, the work can be done in less time, so in the time saved, I can do household chores and take care of my kids. Since I have time in my hand, I can do other things*" R25[f]). Secondly, respondents highlighted an increased opportunity to engage in other income-generating activities (e.g., "*This time saved via ZT use can be used in different activities,… I have two cows I can cut the grass for them. I can do many activities now*" C4).

Application of Additional Financial Resources

Respondents highlighted savings from reduced production cost due to CASI, and acknowledged the compounding financial benefits (**Table 2**), such as improvements in the household's socio-economic condition and changes in lifestyle.

Enabling of Crop Diversification

Farmers stated that conventional rice-rice farming systems were being replaced by rice-wheat and rice-maize systems, alongside other income generating crops facilitated via ZT machinery. Farmers expressed that they were growing multiple crops in a year and had been changing the cropping cycle that was previously dominated by paddy (e.g., *"Earlier, we did not cultivate any crop other than paddy. Now, we are getting wheat in between. This is a new profit that we are generating*" [C25]). Farmers also expressed that CASI provided them with options to cultivate crops that yielded higher profits (e.g., *"I grow maize the most… The income in the maize is better. We don't earn that much from other crops*" [S19]). In addition, some farmers also practiced intercropping in their CASI plots and opted for crops with a high market value (e.g., "*Sometimes we grow some coriander or spinach or other leafy vegetables with maize in some area to sell it in the market*" M4).

Improved Social Status

Other farmers also learned from respondents who were early adopters of CASI and were in touch with institutions delivering agricultural information (e.g., "*They take advice from me quite frequently. That is because I go to the agriculture development office and research farm… After taking information from there, I am able to tell a lot of people about it*"[M34]). This change has led

TABLE 1 | The experienced benefits of Conservation Agriculture-based Sustainable Intensification (CASI) as articulated by respondents.

Benefit	Representative quotation	ID
Stable or increased yield	*"We used to harvest about 8 mons of paddy from a bigha, but now we sometimes get even 22–25 mons [due to CASI]"*	J36
Improved soil quality	*"Soil fertility is increasing. …This soil was not fertile before, but it is so fertile now [due to CASI]"*	J17
Reduced need for inputs	*"CASI required less irrigation and fertilizers. It actually requires half the amount of fertilizer, compared to traditional method of farming"*	M13
Reduced need for irrigation	*"It [using conventional system] requires four times irrigation in the field, where a ZT system will require only two times"*	R17
Reduced tillage cost	*"We had to till the soil three times or maybe four times earlier, then we had to level the land which would be very expensive [using conventional system]. Now costs are saved [due to CASI]"*	J38
Reduced labor requirement and costs	*"Earlier we used to require a lot of laborers [using conventional system], but now [due to CASI] we are free from such labor expenses"*	C42
Intensification opportunities	*"After the coming of ZT machinery, a lot of crops can be cultivated in a short period of time… Now, I do not keep those lands fallow. Automatically, if your land is not fallow then your income will increase"*	C33
Reduce management time	*"Earlier the tractor would plow, and we would wait for a few days, then the laborers would distribute seeds. Thus, ZT has saved us manpower and time"*	S33
Reduced drudgery	*"In ZT, a lot of tasks have been reduced. farming requires hard work, a lot of effort and physical labor is required. You must plow and level, then again plow and level, and you will then have to dry it in the sun. It takes a lot of time and hard work"*	C4
Ease of weed management	*"The weeds would increase [in conventional farming], but in this one [CASI] we use herbicide and kill the weeds, then the weeds do not grow much"*	C38

TABLE 2 | Financial benefits and implications for farmers as experienced through CASI adoption.

Categories of benefits	Representative quotation	ID
Emergency funds	"*Suppose someone gets sick, now I have [money] to spend on it"*	C21
Investment in children's education	"*I am saving some amount for my children's marriages. I have also invested in their studies"*	M13
Re-investment in farming	*"With my savings I can use it during harvest season, and I can also use that to sow again next season"*	S44 [f]
Investment in off farm income opportunities	"*There are so many things to do so I try to rotate the money. The savings from ZT is further invested into another business*"	S42
Investment in livestock	*"The money I am saving from ZT, I have to spend on cattle feed… I couldn't do it this way earlier) … there were many expenses in farming so I could not feed the cows and goats that much, and I couldn't even suffice for myself"*	R17
Purchase of household assets	*"I opened Life Insurance accounts for my home. I have bought some land and also bought a motorcycle with the money saved after doing ZT…It is not the money from my husband's earning, it is savings from agriculture"*	C29 [f]

to an increased status in the community and communal respect for farmers practicing CASI (e.g., "*I am viewed a little differently in the eyes of the people [who learn ZT from me]… there is a change in my status*" R25[f]).

Gendered Implications

The extra time due to the shift to CASI gave some women the opportunity to implement other livelihood activities in the saved time (e.g., *"As an educated person, I teach privately. Also, I'm in the school committee. In the meetings, I go and give suggestions.… this was not possible earlier because, before [in conventional farming], when I went to the field, I didn't return until five in the evening. Now, I can finish the 4 h work in 2 h*" J2[f]). Women's workload and on-farm activities were identified by other respondents as considerably reduced, allowing them to use their leisure time as they liked (e.g., "*There are cows, goats, ducks, and hens, I take care of them and feed them…I did this earlier just as I am doing now, but now it is more comfortable for me. I can relax and take more rest after farming. This relaxation time was not there [before CASI]" R34 [f]).*

Financial independence also enabled women to address the requirements of their families on their own, thereby contributing to economic empowerment (e.g., *"It was difficult before. I could not give money to my sons…But now [after using CASI] whenever they ask, I can take out money they want which wasn't possible earlier*" R10[f]). Women farmers also identified feeling more respected and heard in their communities (e.g., *"My experience [after CASI] is that everyone respects me, even if there are old people they get up and give the chair to me to sit*" C29 [f]).

Challenges That Were Overcome for Successful Implementation

While respondents experienced various benefits of CASI implementation, they also encountered various challenges that they overcame to continue the use of CASI. This section identifies the issues experienced in CASI implementation and how they were overcome by respondents.

Changes to Stover Management (DmD Level 3–Physical)

Farmers mostly used stover for feeding their livestock (e.g., "*Now many people have livestock, and for that, they cut a lot of their stover…I bring stover home to feed the cows*" C21). Although farmers believed that retaining stover saved them time and labor (e.g., "*We need less laborers and less time in ZT, compared to earlier methods for stover management*" C8[f]), they also saw it as a barrier that hampered the operation of ZT machinery (e.g., "*ZT requires keeping stover… but this causes trouble in machinery functionality…That is why it is best if we cut most of the stover, otherwise stover will get stuck in the ZT machinery*" J16).

Notwithstanding, farmers were still willing to consider stover retention, given their understanding of the benefits to soil quality (e.g., "*Stover works as manure. This is the reason why the condition of our field is still good. It is in better condition than the field of people who burn stover… This also helps to retain soil moisture of the field. It's highly beneficial*" M13) and have been able to redirect stover use from its other competitive uses (e.g., "*Earlier, we used to bring the stover for cattle feed in larger amounts, and we used to keep less stover, but now, after we receive the suggestions, we keep most of the stover in the field* " [C33]). Field owners even declined to let the others take away the stover from their fields, which was common in the past (e.g., "*This is why we keep the stover now. If someone wants to pick it up, we don't let them*" J4). Some farmers also described instructing their field laborers how to manage stover following the CASI principles (e.g., "*We ask laborers to keep the stover in the fields while harvesting and cut above 8 inches. If you use the traditional method of farming, then you would have to cut them out and throw them out before planting. But in ZT you do not have to remove them*" M4).

Determining Land Compatibility for CASI (DmD Level 3—Physical)

Based on their experience of practicing CASI, farmers perceived that the selection of appropriate land was essential for implementation. One of the requirements considered by the farmers while selecting land for practicing CASI was a leveled land (e.g., *"The field should be leveled for ZT. Some of my land is not leveled, so I haven't done it on that land" S17).* The reasons cited for this were requirement of the suitable land with an adequate water holding capacity (e.g., "*I have to select land that is able to hold water. If I do it on in the upland, there will be no water held and the crop will not grow well. That's why, selection of land is very important in these matters" [J4]),* to avoid machinery breakdown *(e.g., "In general, in the ZT machinery, there is no big problem, but sometimes when land is uneven, the chain breaks. Then there is a problem" [C33]),* and to avoid balancing issues with the machinery *(e.g., "On uneven land the machinery becomes unbalanced. It is not easy to take the machinery to the field. If you understand this, then ZT will work" [C23]).*

Overcoming Limited Machinery Availability (DmD Level 3—Physical/Financial)

Lack of access to machinery appeared to have been the most important hindrance for respondents (e.g., "Machinery *is not available. This is where the biggest problem lies, machinery, delivery and the supply*" [R15]). High demand for limited machinery also affected reliability, often resulting in long waiting hours, and untimely planting (e.g., "*I got the ZT machine 2–4 days later than expected. The service provider said he had to service many farmers.*" [S17]), so, some farmers occasionally returned to the traditional methods in the absence of machinery (e.g., "*If ZT machine not available or I don't get my turn, then I will look for alternatives. I will continue farming whether using traditional method or by ZT*" [S1]).

Similarly, respondents were largely in agreement regarding their inability to personally purchase ZT machinery due to a limited landholding and insufficient financial resources (e.g., "*It requires a lot of money… I have limited land. If you buy a ZT Drill as an individual, it is impossible*" [C23]). In particular, respondents noted that the perceived utility of ZT machinery is limited for individual ownership, hence it was perceived as a low viability investment (e.g., "*ZT can be used only twice a year, and our land size is not big enough to cover the investment cost of purchasing ZT machinery*" [M34]). Respondents identified two pathways to overcome this, firstly, they were willing to pay for hire services by using service providers (e.g., "*No one will be able to buy the machinery. However, we can use it by paying the rent for it*" [M1]). Secondly, some farmers indicated a willingness to purchase ZT machinery, with the intention to provide rental services, communally through farmer groups (e.g., "*farmers of our area don't have that much money. We have thought that 7 or 8 persons will save money and buy the ZT machinery with the subsidy [together]*" [M8]). This highlights the willingness to explore alternative access mechanisms and the potential to expand usage.

Manual Modifications of CASI to Overcome Machinery Constraints (DmD Level 3–Physical)

Particularly in Malda, issues with access to individual plots made it difficult to access ZT machinery (e.g., "*You cannot always use the ZT method. Everyone rushes to sow and the access to my field is blocked after the crops are sown in other people's field." [M28]), and* therefore, some farmers have resorted to manual surface-seeding to continue CASI practices *(e.g., "In my case the field is in the middle of other fields and there is no suitable access road for ZT machinery to enter, so I sow the seeds with hand still without tilling the land." [M29]).* Farmers manually replicated ZT technology by adapting machinery spacing and seed drop alignments, to manual planting methods (e.g., "*It has been seen that sometimes the machinery is not available, so what we do is observe how much space the ZT machinery leaves and how it sows in a line, …and then we do it manually.*" R25 [f]).

Addressing Functionality Issues (DmD Level 3—Human)

Farmers noticed that the usage of ZT machinery had several technical challenges, such as uniformity of seed drop (e.g., "*we are* *still facing a difficulty that we aren't able to maintain the sowing lines properly. Reliability of seed drops is low, and seeds fall here and one there, and often there are gaps.*" [M8]), which was mostly crop specific (e.g., "*CASI works best in wheat cultivation. Maize cultivation can be a bit problematic due to uneven distribution of seeds… I observe that there are gaps in some places and sometimes, many seeds drop at one place*" [M13]). According to farmers, this necessitated the hiring of a second operator to oversee the usage of the ZT machinery (e.g., "*When the vehicle moves… for the seed grain that is thick, it gets stuck with the brush of the vehicle. And that's why gaps occur. One needs an operator to stay in the back of the machine to monitor.*" [M26]).

Some of the farmers also invested time themselves for these supervisory roles (e.g., "*I work with the machinery…I stand behind the tractor to check if the fertilizer and seeds are falling as expected.*" [S42]). Respondents also identified that machinery was often not the primary constraint, but instead the operator's skill and capability to effectively operate the ZT machinery (e.g., "*It's because of the driver who operated the ZT machinery. Previously, they did not pay attention and were also untrained. More recently we have had sincere drivers who took their work seriously and did a good job.*" [M34]), and these difficulties were resolved when the operators became skilled (e.g., "*There are a few boys in the village who can operate ZT machinery. They go to the farmers' club and then take the training from them*" C4).

Access to Informational Sources and Training (DmD Level 4—Information)

Farmers were eager to learn about CASI and its applications to maximize their benefits (e.g., "*Whatever I know about CASI is enough but to progress in farming, there is a need to learn.*" [J26]). However, for some farmers, there was a lack of interaction with agriculture extension officers for such information (e.g., "*I don't have contact with Department of Agriculture …We don't know where they come and go*" [R29]). As a result, farmers started to rely on multiple sources of information, mostly *via* mobile phones to access information (e.g., *"I get some of information from the mobile… I also watch some videos regarding agriculture from the internet"* [M3]). They also utilized mobile phones for sharing information within their own networks, using various social media platforms (e.g., *"I use WhatsApp, and I watch the videos. The agricultural officers send the videos. We have a group"* [C37]). In Nepal radio was more popular than social media among farmers (e.g., "*I have a radio. I listen to the news and the programs in that… sometimes agricultural programs… I attempt to compare my knowledge and understand what they mention about the different crops.*" [S8]). In addition, farmers also benefited from consultations with local agricultural universities to expand their knowledge. These agricultural universities and local institutions were identified as reliable sources for agricultural information (e.g., "*I mainly take advice from farmer club members, apart from that also the government extension officers, and the professors of Agricultural college. I do not go to any other person. I take the advice from these people only*" [C24]). This aided farmers in evaluating information and sources of information that they perceived as reliable.

Training and demonstrations were identified as key mediums of learning to overcome the identified knowledge gaps of the farmers, despite already implementing CASI. To overcome challenges in technological information, farmers were keen to learn through practical demonstrations and exposure visits (e.g., *"You can take us to some place where we can get the training and see the ZT machinery, and figure out if we can use it… When we get that training, we can learn about it"* [M6]) and acknowledged that attending training sessions and participating in exposure visits helped address knowledge gaps before adopting CASI (e.g., *"When the people told us to do ZT, I did not start immediately. They took us to different training programs and to different places. I saw what is being done there. Then, after seeing all the results, I started doing it in my field"* C21).

Community Approaches to Change (DmD Level 5)

Commonly, respondents identified that many farmers in the community had a tendency to adhere to conventional agricultural practices followed by previous generations (e.g., *"Our father and grandfather have done conventional tillage for 14 generations, now ZT has come here, people will obviously call me mad."* [C29]), and often remained unaware of ZT machinery (e.g., "*Some people from the community are bewildered by how crops can grow without tilling the land, without the help of cows and oxen… They don't know about it so they can't believe ZT can be done*" [J26]). Farmers also experienced ridicule and criticism from other farmers in the community during the initial stage (e.g., "*When I started doing ZT, a lot of people would pass through the road and call me a mad person.*" [C33]), including initial resistance from the family members (e.g., "*People in your neighborhood will criticize ZT, and people in your house will say things as well, whether ZT works or not. But once it worked…people have started to trust it" [C4]*). To overcome this, some farmers chose to become promoters to their peers to help them adopt ZT and to minimize their knowledge gaps (e.g., "*I like my position a lot because they do not know the things, but I know. They come to me because I know. I never give them bad advice. And they are benefitting from depending on my words*" R25 [f]). Furthermore, family support was also evident once there was a realization of better income and profits from ZT (e.g., "*They are happy about me doing agriculture because, as of now, there is no shortage of money for fulfilling our daily needs*" [M28]).

Aid-Dependence (DmD Level 6)

Agricultural inputs were mostly paid for by farmers, while some were subsidized by the project in the beginning, resulting in project dependence. However, some farmers were unconcerned about such incentives upon realizing the benefits of using CASI and were keen to invest their own resources and continue practicing CASI (e.g., "*This project came to my knowledge… I cultivated one bigha with risks in my mind. After farming, I saw, it's more effective than our old conventional system. After that, we continued farming using ZT without assistance*" J2 [f]). This created a mindset that may lead to continued expectancy for inputs, where farmers appeared to be dependent on projects for accessing ZT machinery, which was present in all locations (e.g., *"If government helps a bit, I'd obviously do it… If I don't get any*

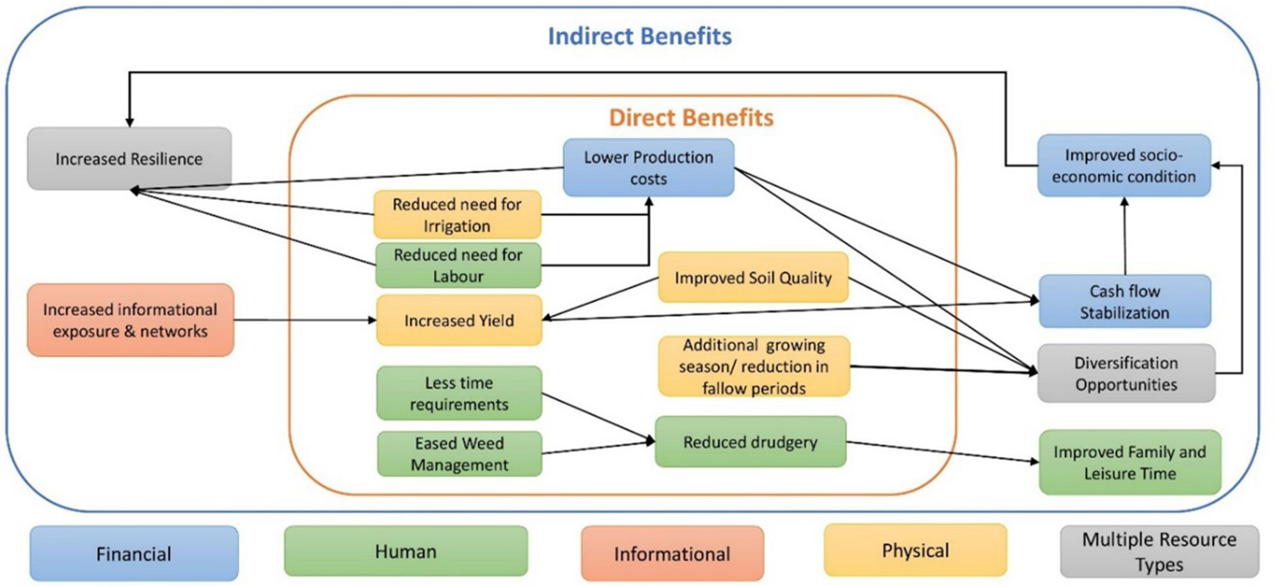


FIGURE 3 | The direct and indirect benefits of CASI use as identified by respondents.

ZT machinery, how would I be able to do it then" [J16]), and farmers who have weaker financial conditions also expected to receive some form of continued support from projects or for the government to continue CASI use (e.g., "*Why will I not do it? I will definitely do ZT. For example, any project gives us these things [machinery, seeds, inputs, or fertilizers], and asks us to use them to cultivate, I will definitely do it"* [C38]).

DISCUSSION

Respondents in this study highlighted a variety of direct and indirect benefits of CASI (**Figure 3**). These benefits existed across all resource types within the DmD framework. The most common direct benefit was related to human resources through saved time and drudgery requirements, alongside the physical benefits of increased crop yield, improved soil fertility, and reduced input and irrigation requirements. This is consistent with the vast literature on the attributable benefits of CASI, ranging from improved yield for both wheat and maize (Pokhrel and Soni, 2018), improved soil quality (Reeves et al., 2016, p. 76; Pal et al., 2018), ease of weed management (Soni et al., 2020), time savings (Brown et al., 2021a), to the reduced irrigation requirements (Erenstein et al., 2008). Because CASI is relatively new in the region, most studies have focused on project-aligned participants. This study provides a novel point of view in the analysis of non-supported farmers, and as such confirms the benefits of CASI outside of the normal project-oriented evaluations, thus, providing a new level of confirmation that CASI can be beneficial to the financially unsupported farmers in the EGPs.

Respondents also confirmed the existence of indirect benefits through CASI implementations. These indirect benefits link to both improved economic conditions through cash flow stabilization and increased resilience, a common finding with the increased economic opportunities and benefits that come from CASI implementation (Brown et al., 2021a) and improved lifestyles and financial stability (Keil et al., 2020). This may then be linked with an overall increased resilience in production systems. Alongside this, respondents expressed increased satisfaction with their livelihoods, primarily linked to the improved time for family and the leisure achieved through CASI, consistent with the findings of Brown et al. (2021a) that highlight substantial time savings experienced in CASI systems by farmers in the region. This study is unique because it links these benefits (e.g., reduced labor needs) to how such benefits impact livelihoods (e.g., new economic opportunities). These indirect consequences of technological progress are frequently less explored, and so another novel outcome is derived through the qualitative methodology used.

The challenges to implementation can be summarized into nine key points of friction in the implementation of CASI by smallholder farmers in the EGPs (**Figure 4**). Despite the diversity of resource types that relate to these challenges, a narrative emerges around the importance of the closure of informational gaps in addressing these friction points. Brown et al. (2021c) highlight that this information is generally a major barrier to mechanization for farmers in Nepal, and it is expected to be the same across the EGPs. Similarly, the findings from this study highlight that if farmers have access to adequate information, most of the technological constraints related to CASI can be overcome. The constraints faced by respondents were mostly overcome by strengthening immediate existing information systems and closing their knowledge gaps. For example, most of the physical challenges related to the machinery's functionality and technology were typically addressed by ensuring that machinery operators were well-trained or worked in teams of

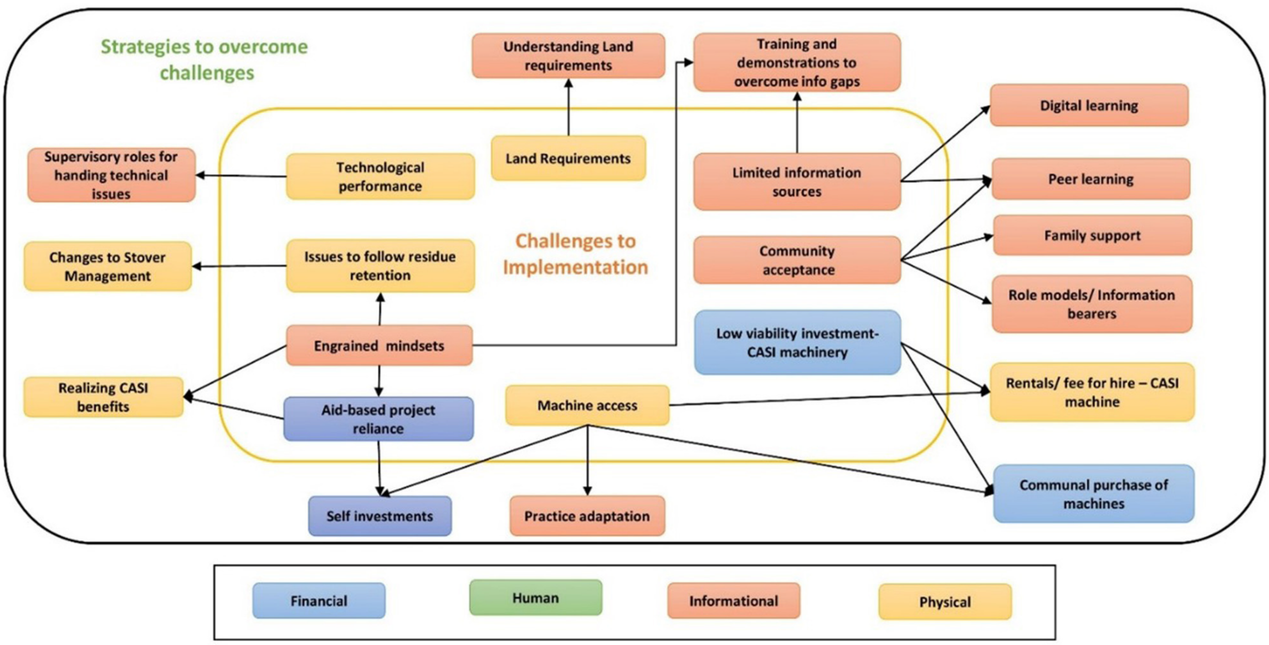


FIGURE 4 | Various challenges to implementation as identified by respondents and strategies employed to overcome them.

two to ensure correct and reliable implementation. Furthermore, farmers also observed that appropriate land selection was important for the successful implementation of CASI technology and hence, were able to avoid issues with the poor performance of CASI systems on unsuitable land. This indicates that operators' training should be prioritized, and two-person operation teams will be encouraged to address operational issues. Therefore, greater effort must be placed into incorporating CASI service providers and operators into government training programs, so that they may receive training and be connected to extension services, as opposed to the farmer awareness creation campaigns that currently dominate the extension sector.

The other linking factor in the identified friction points is that of the mindset and the willingness for change and adaptability. Respondents in this study appeared to identify themselves as more open-minded to the change than their farming peers. They highlighted a willingness to consider change, adapt practices to local conditions, and remained open-minded to further adaptations. Stover is one example, where the farmers raised maintaining soil health as an equal priority to animal feed. While other studies have also highlighted this trade-off (e.g., Derpsch et al., 2016), this study highlights that the benefits of stover retention need to be seen as an opportunity rather than a limitation in promotional activities. Respondents also seemed willing to consider co-investment through groups to access machinery. This demonstrates both open-mindedness as well as the possibility that the respondents were financially better off than their peers because of CASI implementation. Hence, whether the financial status and open-mindedness of respondents are linked to investment decisions needs to be further explored through quantitative studies. Furthermore, Kiptot et al. (2007) in their study about the dynamics of improved tree fallow use by farmers in Kenya, found that the process of adoption is highly dynamic and variable with farmers, ranging from consistent use to discontinuation or re-adoption due to a variety of factors, which is significant compared to some of the pseudo-adoption patterns that we realized in our study. While many of the identified challenges are not novel, the methodology applied enables a new level of understanding of how farmers have developed strategies to overcome these challenges. These strategies highlight two key learnings. First, farmers do maintain an adaptive ability to manage the implementation of modern technologies. Second, such strategies highlight the importance of local adaptation to ensure the feasibility and relevance of CASI.

While access to information regarding the new technology's appropriateness and profitability is likely to be a significant factor, respondents gained knowledge over time from their own experience, from peers through information networks, and/or by observing early adopters. It is also evident that the lead farmers serving as role models was one of the most effective ways in information distribution and community-level support for CASI implementation, because they spoke in basic and local languages and were aware of local idiosyncrasies. Previous research has shown that awareness of ZT has a favorable impact on attitudes about CASI, resulting in adoption (Kumar and Godara, 2017). In addition to overcoming technological challenges directly related to field implementation of the technology and strengthening of service providers, and local agri-businesses were also found to be crucial for scaling, as also seen in Landers's (2001) research. Various mediums of information networks seem to be at play with the implementing farmer networks. The rising use of mobile telephones in almost all states of the EGPs demonstrates the potential of using it as an effective approach for information exchange among farmers, as also studied by Singhal et al. (2011). Getting the correct information also contributes to a change of mindset, thus, enabling farmers to continue using CASI. Therefore, there is a need to diversify information systems to encourage the adoption of sustainable practices such as CASI technology among smallholder farmers.

Furthermore, these findings suggest that projects must consider some wider consequences of their interaction on community dynamics. Specifically, it can be seen from respondents that their direct involvement with projects enabled them to increase their status in communities. Farmers associated with project activities had greater exposure to agricultural information sources, training, and demonstrations, enabling them to understand and close gaps identified during CASI implementation. This enabled farmers, to better understand land requirements, re-allocated the stover and overcome technological challenges with machinery, such as seed drop issues and machinery imbalance, all while adhering to CASI principles, thereby establishing them as CASI knowledge-holders in the community and earning them greater respect from community members. However, dependency on the projects for subsidized agricultural inputs and abandoning CASI practices was observed among some farmers when unable to access ZT machinery due to various reasons. Such dependencies are common in systems where CASI has been strongly led through top-down extension approaches (Brown et al., 2020). However, this also has implications on how projects approached farmer-to-farmer methodologies, in the knowledge that they are potentially changing inter-community dynamics based on who they select for involvement, which is especially relevant in South Asia within the already complex social hierarchies. It is known from previous research, which aligns with our findings, that social, capital, training, and perceived usefulness play important roles in the decision to embrace new agricultural practices (Cofré-Bravo et al., 2019); as a result, "socio-psychological" factors should be addressed in order to promote smallholder farmers' acceptance of sustainable farming techniques (Zeweld et al., 2017), such as CASI. Along the same lines, another study conducted in Africa by Brown et al. (2018) implied that extended participatory adaptation is necessary for community leaders to embrace Conservation Agriculture. Therefore, our findings stress on community-level social learning as a coping strategy against the formal extension system's current constraints that does not resolve social disparities existing in the information networks which is comparable to Leta et al's (2018) work in Ethiopia.

CONCLUSION

Previous research tends to focus on econometric relationships *via* a binary classification of adoption, leading to a narrow understanding of the actual experiences of farmer adoption of CASI. This in-depth qualitative study has enabled a new level of understanding of what CASI implementation entails, alongside suggestions for what this means for the wider up-scaling of CASI in the region.

Firstly, our findings demonstrate that CASI is seen as profitable by users outside of supported and project-aligned farmers. Only a subset of our whole dataset was chosen for this study to isolate the typology to contextualize our findings for current adopters, thus enabling future comparisons with a wider range of CASI adoptive typologies in the future. Secondly, we identify nine key friction points for CASI implementation, alongside a set of strategies employed by farmers to address them. This shows not just the new possibilities for CASI adoption, but also the significance of closing knowledge gaps to achieve a successful long-term sustained individual and community adoption. Future research in CASI should focus on building these nine critical friction points *via* broad quantitative studies. The findings also highlight the importance of adaptation as a crucial component of CA promotion initiatives, because complete adoption of all the principles of CASI by smallholder farmers may not always be attainable. In conclusion, the successful scaling of CASI in the region would need more concerted efforts to incorporate CASI into functional extension projects, as well as the readiness to adapt CASI to local farmer conditions. We suggest future research work to quantify the scope of the nine identified challenges so that future policy and program strategies may be statistically informed. In addition, an analysis of other typologies that will support these strategies is warranted.

LIMITATIONS OF THE STUDY

We examined one subset of our entire dataset for this analysis; future work should focus on contextualizing our findings with a larger collection of CASI adoptee typologies. The interview could not include a number of women interviewees for this subset since women actively pursuing CASI farming were difficult to find in the EGPs, and an equal ratio of men and women respondents could not be achieved.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Gideon Kruseman, Head of CIMMYT Internal Review Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

BB was in charge of the study's conceptualization and design. AC, PT, BS, RS, and EK were in charge of material preparation and data collection with the oversight of BB. AC led the analysis for this study with support from PT and BB in refining and finalizing the manuscript which included contributions from all authors in the review process.

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