

Gendered impacts of climate-smart agriculture on household food security and labor migration: insights from Bihar, India

Household
food security
and labor
migration

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Tripti Agarwal, Prarthna Agarwal Goel, Hom Gartaula,
Munmum Rai, Deepak Bijarniya, Dil Bahadur Rahut and M.L. Jat
(*Author affiliations can be found at the end of the article*)

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Abstract

Purpose – Increasing trends of climatic risk pose challenges to the food security and livelihoods of smallholders in vulnerable regions, where farmers often face loss of the entire crop, pushing farmers (mostly men) out of agriculture in destitution, creating a situation of agricultural making agriculture highly feminization and compelling male farmers to out-migrate. Climate-smart agricultural practices (CSAPs) are promoted to cope with climatic risks. This study aims to assess how knowledge related to CSAPs, male out-migration, education and income contribute to the determinants of male out-migration and CSAPs adoption and how they respond to household food security.

Design/methodology/approach – Sex-disaggregated primary data were collected from adopter and non-adopter farm families. STATA 13.1 was used to perform principle component analysis to construct knowledge, yield and income indices.

Findings – Yield and income index of adopters was higher for men than women. The probability of out-migration reduced by 21% with adoption of CSAPs. An increase in female literacy by 1 unit reduces log of odds to migrate by 0.37. With every unit increase in knowledge index, increase in log-odds of CSAPs adoption was 1.57. Male:female knowledge gap was less among adopters. Non-adopters tended to reduce food consumption when faced with climatic risks significantly, and the probability of migration increased by 50% with a one-unit fall in the nutrition level, thus compelling women to work more in agriculture. Gender-equitable enhancement of CSAP knowledge is, therefore, key to safeguarding sustainable farming systems and improving livelihoods.

Social implications – The enhancement of gender equitable knowledge on CSAPs is key to safeguard sustainable farming systems and improved livelihoods.

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Originality/value – This study is based on the robust data sets of 100 each of male and female from 100 households ($n = 200$) using well-designed and validated survey instrument. From 10 randomly selected climate-smart villages in Samastipur and Vaishali districts of Bihar, India, together with focus group discussions, the primary data were collected by interviewing both men and women from the same household.

Keywords Migration, Climate-smart agriculture, Food and nutrition security, Knowledge index

Paper type Research paper

Introduction

Climatic risk because of extreme weather events variability is one of the most critical factors affecting agricultural production. Indian agriculture is largely weather-dependent; over 60% of crops are rainfed, making them highly vulnerable to climate-induced changes in precipitation patterns. Weather-related risks in India such as heat waves, cold snaps, droughts and floods have become the norm because of their increasing occurrence during the recent past. This is evident from the extreme weather data; the number of extreme temperatures (minimum and maximum) and rainfall events have increased significantly from 30 in 1930 to about 358 in 2010 (Mahdi *et al.*, 2015). It is estimated that by the 2050s, with a temperature increase of 2–2.5°C compared to pre-industrial levels, water for agricultural production will reduce further, and this may impact food adequacy for some 63 million people (The World Bank, 2013).

In India, the state of Bihar is highly vulnerable to hydro-meteorological natural disasters, with North Bihar, in general, being flood-prone and South Bihar being drought-prone. In the (relative) absence of state-level climate models and/or vulnerability studies, and with low community awareness, the state is potentially more sensitive to climate change (Bihar state action plan on climate change, 2015). A unique paradox is witnessed in Bihar wherein flood and drought events occur in the same year and sometimes in the same district. Out of 38 districts, 28 are flood-prone, with major flood events occurring in 2004, 2007, 2011, 2013 and breach-induced flooding in 2008. Both North and South Bihar have experienced drought, as evidenced by drought being declared in 26 districts in 2009, all 38 districts in 2010 and 33 districts in 2013. Further, the years 2012, 2014 and 2015 were no better than the drought years because Bihar experienced irregular and erratic rainfall. In March 2015, there was extensive crop damage because of unseasonal rainfall and hailstorms (Roadmap for Disaster Reduction, 2016).

Because of these unpredicted and extreme climatic stresses, farmers often face the loss of their crops, livelihoods and food security are threatened and already-stressed areas are pushed further into poverty and destitution. To cope with this vulnerability and marginalization, farmers look for alternatives, and labor out-migration is an important and often-adopted strategy to diversify household livelihood portfolios (Choithani, 2017; Kim *et al.*, 2019). Although the extreme weather conditions may hit the male and female farmers somewhat equally, the implications for coping and recovering from the shock may differ because of social and gender inequalities prevalent in the society. The Indian sociocultural contexts offer more freedom to men than to women to migrate out of their home area and explore opportunities for additional income. A survey from the Institute for Human Development, New Delhi, says that 70% of households where women are engaged in cultivation to have witnessed male labor out-migration. This leaves the women left behind obliged to

perform agricultural activities on top of the household responsibilities that already overburden them (Times of India, 2014). This may already limit their performance, but even worse, their limited access to knowledge and resources may lead to deteriorating agricultural production and also impact the overall well-being of the women involved, as is highlighted by many prior studies (Gartaula *et al.*, 2012; Tamang *et al.*, 2014; Patel *et al.*, 2015).

With the extent of these human and economic concerns of increased extreme climatic situations, and to safeguard farmers' well-being, there is a need to manage climate risks better and find a way forward. In an attempt to address the problem, the International Maize and Wheat Improvement Center and consultative group for international agricultural research (CGIAR) Research Program on Climate Change, Agriculture and Food Security (CIMMYT–CCAFS), in collaboration with stakeholders at national and international levels, are working on the concept of climate-smart villages (CSVs). The CSV program addresses climatic risks from both technological and social perspectives. It provides gender-inclusive training to farming communities to scale climate-smart agricultural practices (CSAPs) up for sustainable agriculture and better mitigating the risks of climate change. Interventions ensuring economic access to resources need to be targeted and scaled to safeguard climate change mitigation and minimize productivity loss. In CSVs, farmers practice climate-smart agriculture (CSA), which is an approach that integrates the three dimensions of sustainable development (environmental, economic and social) by jointly addressing food security and climatic challenges through CSAPs (Sriram *et al.*, 2019).

The mitigation strategies such as food crops choice mix (or crop diversification), off-farm work, better farming practices, etc. ensure household income and food security and thereby reduces male out-migration. However, adopting the proven beneficial CSAPs requires adequate knowledge for their use, economic viability and broader scalability. Practical training and the provision of services are strategies that can make adoption easier. Given the immense role played by women in agriculture, it is vital to build women's capacities and ensure that they have sufficient knowledge and training to achieve gender equality in agriculture. It is also crucial to overcome the exclusion of women from decision-making processes and labor markets so that they can better cope with and adapt to the impacts of climate change (Sriram *et al.*, 2019). However, there remains a gap in knowing to what extent and how the capacity enhancement of women in climate risk mitigation strategies can curtail migration and improve household food security and overall farm livelihoods.

In this context, this paper investigates how CSAPs affect food security and, consequently, male labor out-migration in the state of Bihar, India. Our analysis shows that the adoption of CSAPs can reduce the probability of migrating by 21%, whereas women's literacy also reduces migration. Moreover, a narrowing of the gendered knowledge gap increases the adoption of CSAPs, thus improving food security and decreasing male out-migration. This paper concludes with insights into how the enhancement of gender-equitable knowledge relating to CSAPs is key to safeguarding sustainable farming systems and improving livelihoods.

Literature review

Gender and social differences are dynamic and nuanced within communities. Thus, an understanding of how these differences could affect implementation strategies and the need for climate information is critical in reaching the most vulnerable (Bernier, 2013). The primary form of gendered vulnerability in the context of agrarian distress emerges

from male out-migration, which affects the distribution of labor and resources. Sugden *et al.* (2014) observe that poverty, gender inequality, insecure land rights, heavy reliance on agriculture and less access to education and information are among the principal reasons for climate change vulnerabilities. At the same time, women are not only the passive victims of climate change but are also agents of hope for adapting to and mitigating abrupt climate change shocks. Women are also concerned about environmental issues and are highly supportive of policies aimed at restoring the environment. There are plenty of suggestions for gender-differentiated agricultural strategies aimed at adapting to climate change. Many studies claim that differences in men's and women's responsibilities, priorities and access to resources, training and services at the community and household levels are responsible for the gender gap in agriculture in many developing countries (Khatri-Chhetri *et al.*, 2020). Although hotspots of women in agriculture are discussed to assess CSA interventions relevant for women, their potential to help women mitigate climatic risks in production and consumption is not well addressed. A recent study points out that some CSAPs have the potential to reduce women's labor drudgery, but their adoption depends on several social, economic and political factors. Notably, the prospect of negative implications for a specific group of women should not be ignored but addressed and mitigate challenges accordingly (Gartaula *et al.*, 2020).

India's agricultural labor force is reducing. In 1981, over 66% men and 83% women worked in agriculture, which in 2011 were reduced to about 50% for men and 65% for women (Pattnaik *et al.*, 2018). This shows that although overall labor force engaged in agriculture is declining in India, women's involvement is still more than of men's, indicating women's paramount role in Indian agriculture. Their contributions to household livelihoods vary according to the region and the type of farming and cropping system but broadly include providing labor for crop and livestock production and household management. Of the 98 million women who live in rural areas and practice agriculture in India, about 37% are farmers, whereas 63% are agricultural wage-laborers (Chanana-Nag and Aggarwal, 2018). Statistics show that 48% of India's self-employed farmers are women. About 75 million Indian women are engaged in the dairy industry compared to 15 million men. Likewise, 20 million women practice animal husbandry compared to 1.5 million men (Ghosh and Ghosh, 2014). Women are generally involved in various cultivation and post-harvest operations like storage; these activities are essential for the well-being of farm households but are often not included in the definition of economically beneficial activities. A substantial proportion of rural women who are active in farming are counted merely as unpaid family labor.

Despite their crucial role, women's contributions to agriculture in India tend not to be valued in the same way as men's, and often women are not involved in agricultural decision-making. Men's departure from agriculture to non-agricultural jobs is increasing across South Asia, including Bihar, India. This process of agricultural feminization, sometimes, linked with women's better space in the agricultural decision-making. However, men's exit from this sector does not necessarily leverage the decision-making capacity of the women left-behind in agriculture (Pattnaik *et al.*, 2018). Moreover, women's increased participation to some extent increased their role in the agricultural decision-making, but the "final" decisions should still be approved by men, even if they stay outside, as evident in Karnataka, India (Goudappa *et al.*, 2012) and in Jhapa, Nepal (Gartaula, 2012).

Like in other areas in the region, Bihar's agricultural sector is also feminized, with over 50% of the total farming workforce consisting of women, according to a report on women in the informal economy of Bihar, Asian Development Research Institute. Additionally, women make up 79.5% of the workforce engaged in animal husbandry in the state (The [Times of India](#), 2014). This underscores the significant role of women in contributing to household income and food and nutrition security.

There is a clear understanding of the positive correlation between income and food security. By food security, we refer to not only having enough meals but also meeting the nutritional needs of the men, women and children of the household. The ratio of per-consumer unit calorie intake to the measure of per capita calorie intake may vary widely between individual households because of inter-household differences in age-sex composition. Thus, for a household with no children, the two measures will be much closer than for a household with a large proportion of children and babies. Hence, the per-consumer unit calorie intake analyzed in the study gives a much better idea of the adequacy of calorie intake at the individual household level. For India as a whole, the share taken by cereals in household consumer expenditure is 10.7% for the rural sector. In rural Bihar, total spending on food is calculated as 59.3% of total household expenditure, 15% of which is spent on cereals, contributing 61.6% of calories. Cereals are followed by milk products, oils, pulses, and so on. Thus, any effect of climate change on cereal production or consumption will have a significant impact on the food and nutrition security of the consumer units. In our paper, we emphasize how farmers are practicing CSAPs to safeguard production, ensuring higher yields and income and thereby securing consumer consumption.

With limited access to resources and decision-making, women play a vital role in forming mitigation strategies while adopting CSAPs for improved household food security. To the best of our knowledge, none of the previous studies have investigated the impact of climatic risk in terms of male out-migration, causing feminization of agriculture. The results substantiate how CSAPs can be promoted among women farmers to support them in mitigating climatic risks in agriculture, combating the effects of these on yield and securing household food security. Integrating the structural intersections between climatic risks, gendered knowledge, migration and food security is necessary to make informed policy decisions that will impact at scale ([Sugden et al., 2014](#)).

Materials and methods

Research location

This study was carried out in Samastipur and Vaishali districts of Bihar, India. The study area map (Supplementary [Figure 1](#)) presents the geographic location of the villages surveyed. Both districts are located in central Bihar and have similar geographic conditions and similar literacy averages, thus negating the scope of disparity in CSAPs adoption.

Research design, data collection and sampling

To assess the impact of climatic risk on farmers' mitigation strategies, defined by the awareness and adoption of CSAPs by both men and women, we used a mixed research design that combined qualitative and quantitative methods of data collection and analysis. The qualitative data were collected using focus group discussions (FGDs) conducted separately for men and women. The FGDs were crucial to identify the domains to be included in the survey questionnaire as part of the quantitative data

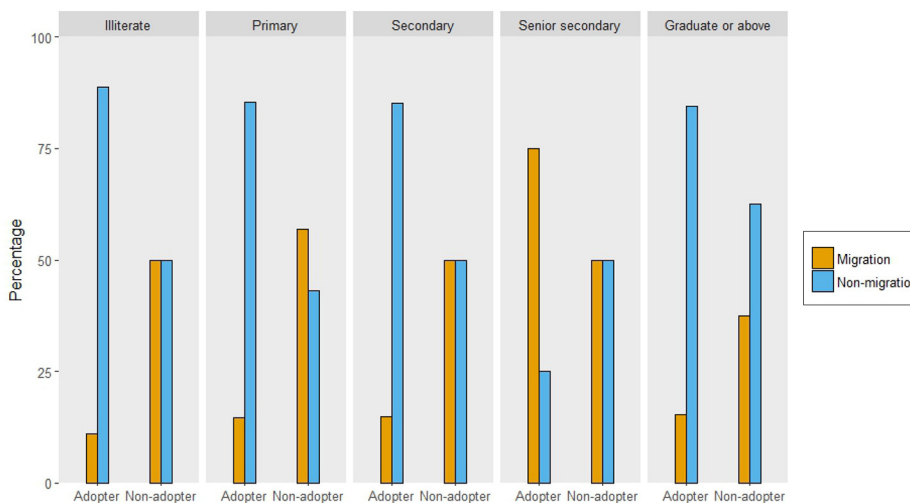


Figure 1.
Data distribution as per literacy, adoption and migration status

collection. The survey was performed by a team of men and women enumerators to ensure capturing the responses of women respondents appropriately. In the survey, we captured the farmers' understanding of how they had experienced climate change and the benefits of project interventions aimed at CSA adoption over time. We also collected comparison data on the impact of climatic risks on household food security among adopters and non-adopters.

The survey was conducted in 100 households where both men and women from the same household were interviewed, making a total sample size of 200. In total, 10 CSVs were selected in Samastipur and Vaishali districts for data collection. From each CSV, 10 households comprising five adopter and five non-adopter households were randomly selected and interviewed. Interviewing both male and female respondents of the same household helped us to capture perspectives of both genders and to map out the gender gap about issues like crop yields, income, migration, food consumption, technology adoption and other demographic variables. We aimed to assess the determinants defining CSAPs adoption among men and women and resulting behavioral changes.

We observed the impact of the CSAP interventions for over 10 years. Before 2007, the farmers carried out their usual agricultural practices, and from then onwards, training in building knowledge about CSA was initiated in the districts as mentioned above of Bihar. Hence, the year 2007 was taken as the base year from which data were collected based on recall, and 2016 was taken as the current year. However, spillovers because of improper record-keeping by farmers and insufficient knowledge of females remained a constraint to the analysis.

Generating indices and data analysis

The average yield and income indices of CSAP adopters were analyzed to estimate the effects of adoption on yield and income and to capture post-adoption percentage changes. The indices generated were derived only from the adopters. Yield and income were not calculated separately for men and women as both reported the household data; however,

because of inefficient farm budgeting and differences in farm information and decision-making, the indices reported by men and women did differ.

A knowledge index (KI) was generated to capture the current knowledge level, which mapped out the farmers' understanding of CSAPs. In our study, the CSAPs included nine technologies: laser land leveler, green seeker, multi-crop planter, harvester and thresher, zero tillage, leaf color chart, nutrient expert tool, relay planter and bed planter. This index ranked different individuals based on their knowledge about the practical usage and adoption of the technologies. The index was developed for men and women separately to assess the difference in technical knowledge about CSAPs; this is discussed in the following subsection.

The indices were generated based on the principal component analysis (PCA) of the variables related to CSAPs knowledge, yield and income. PCA is used to exploit variation in variables to generate weights and corresponding ranks for households and individuals in the large dimensionality of the data (Jolliffe and Cadima, 2016). PCA provides a weighted rank based on the variation across a large dimension of variables as compared to some other measures that are based on means making it less susceptible to biasedness owing to extreme values. Various other studies have used PCA to construct indices with discrete data (Kurbanoglu *et al.*, 2006; Filmer and Pritchett, 2001).

The male and female respondents were asked to respond to a given statement on a five-point Likert scale 1 = very low, 2 = low, 3 = average, 4 = high, 5 = very high. The five-point scales were reconfigured to three-point scales to show a pattern of reduced (for very low and low), unchanged (for average) and improved (for high and very high), and a tabular analysis was performed.

The PCA technique and the derivation of indices is discussed briefly below; we normalize the N indicators as follows:

$$X_{ik} = \frac{X_{ik} - \min(X_i)}{\max(X_i) - \min(X_i)}$$

where X is the responses for i indicators, 1 to N for k th individual.

The above adjustment transforms all the selected variables on the 0–1 scale. The value of 0 is assigned to the individual with the lowest value of the selected knowledge indicator, and a value of 1 is assigned to the individual with the highest value of the selected knowledge indicator.

The results for the eigenvalues ($\lambda_1 \dots \lambda_n$) are presented in Supplementary tables 7, 9 and 11, respectively, for knowledge, income and yield.

Eigenvectors as in Supplementary Tables 8, 10 and 12 are obtained for knowledge, income and yield.

Finally, the index is computed as a weighted sum of N principal components and $\lambda_1 \dots \lambda_n$ eigenvalues, where weights are the variances of successive principle components as follows:

$$KI_k = \frac{\lambda_1 P_{1k} + \lambda_2 P_{2k} + \lambda_3 P_{3k} + \dots + \lambda_n P_{nk}}{\lambda_1 + \lambda_2 + \lambda_3 + \dots + \lambda_n}$$

The index is monotonous, with higher index values indicating higher knowledge levels related to better farming techniques. The index is generated for males and females separately, providing an opportunity to assess the gender gap in technical expertise in farming. A separate analysis at the village level provides important information on

differences across villages in farm knowledge and indicates the direction to follow in policy design. The efficacy of CSA options in terms of their benefits to both men and women stands to lose out if the gender gap in agriculture is not considered (Nelson and Huyer, 2016), and hence, the KI is used to measure the gap and form corrective measures. The KI not only helps compare the information levels on various climate-smart practices across villages and gender gap in information but also enables to study the association and impact of these variations on socio-economic outcomes such as CSAP adoption, migration and consumption.

Impact analysis – To understand the effect of the KI, female literacy, training on CSAPs, household size and alternative livelihood activities on the adoption of CSAPs, migration and nutritional security, we used impact analysis using the following formula. The adoption of CSAPs also depends on landholding, other livelihood options, and the availability of required resources. Quisumbing and Pandolfelli (2010) highlight that other socioeconomic parameters such as age, marital status, education level and landholding size can affect agricultural technology adoption. These are therefore included as controls in the impact analysis for CSAPs adoption to circumvent omitted variable bias as follows:

$$CSAP\ Adoption_{ks} = f(KI_{ks}, X_{ks}) \quad (1)$$

where, k is the individual, s is the state and X_{ks} comprises the other control variables. The model is estimated using logistic regression that estimates the probability of CSAPs adoption as a function of KI and training. The binary values “1” and “0” represent adoption and non-adoption, and if we assume that, this probability follows the logistic curve as denoted by the following logistic function:

$$f(z) = \frac{1}{1 + e^{-z}}$$

The probability of adoption can be modeled as follows:

$$P(M = 1|X_1, X_2, \dots, X_K) = \frac{1}{1 + e^{-\left(\alpha + \sum_{i=1}^k \beta_i X_i\right)}}$$

where $P(M = 1|X_1, X_2, \dots, X_K)$ is the probability that the value of the dependent variable, CSAP adoption, takes the value 1 (Hu and Lo, 2007). X_i represents the vector of independent variables, KI, training and other controls.

Another key was to study the effect of CSAPs adoption, female literacy and age of the migrant men. We hypothesize that CSAPs adoption would raise the productive capacity of farmers and minimize risks and that similarly, a higher degree of female literacy would correspond to better decision-making and farm budgeting, resulting in increased income. Such factors are imperative to higher productivity and improved standards of living, further negating the need for migration. Poor nutrition standards, on the other hand, could be a result of low productivity and income levels, increasing the probability of migrating to find an alternate source of earnings. The analysis also controls for factors that may affect migration and lead to omitted variable bias if excluded from the estimation. The current estimates are derived through logistic regression models similar to those explained in the previous section, with the variable of interest – the dependent variable, migration – being a response variable with the response as either a “yes” or a “no.” Equation (2) below represents the logistic regression model for estimation.

$$Migration_{ks} = f(Adopter_{ks}, Age_{ks}, Female\ Literacy_{ks}, X_{ks}) \quad (2)$$

The control variables include household size, land size, KI, OBC and SC/ST. Model 1 contains only CSAP adoption as the independent variable.

Caste	Acronym	Definition
Other backward classes	OBC	is a collective term used by the Government of India to classify castes that are educationally or socially disadvantaged
Scheduled castes/ scheduled tribes	SC/ST	are officially designated groups of historically disadvantaged people in India

The literature suggests that the risk of food security increases with increased volatility in climatic conditions (Campbell *et al.*, 2016). We hypothesize that when faced with climatic risk, it is more likely that non-adopters will reduce their consumption compared to CSAPs adopters. A farmer who has a large land size would also be less affected by climate risk, as he is able to practice a diversified cropping system giving higher yields and income.

Ordinary least square estimates are derived from studying the impact of CSAPs adoption on nutrition intake as per the equation below. The control variables include female literacy, migration, age, household size, land size, OBC and SC/ST.

$$Reduction\ in\ consumption_{ks} = \delta_0 + \delta_1 CSAP\ adoption_{ks} + \delta_2 X_{ks} + \varphi_{ks} \quad (3)$$

The design of this study was not a systematic observation of transformative changes in terms of gender roles and relations. This snapshot data collected from the areas where some climate risks mitigation strategies are applied, and we wanted to know how male and female farmers respond to that. Therefore, the analysis of this paper should not be viewed as a full scale gender studies that have systematic observation of changes and gendered responses to the interventions. Moreover, it is important to note that this paper is not an independent impact evaluation of the CSV program that is being implemented in Bihar, India, but our attempt is to showcase how the men and women farmers experience the CSAPs in the research areas.

Results and discussion

Yield and income indices

Yield and income indices were 0.799 and 0.671 for men, which are slightly higher values, than 0.686 and 0.571 for women, respectively. Results from more than 15 CSA interventions in Nepal show that women's participation in different agricultural activities were found to potentially reduce women's drudgery in agriculture and improve productivity and farm income (Khatri-Chhetri *et al.*, 2019). Another study conducted in India also observes the potential of CSAPs to reduce women's labor drudgery (Gartaula *et al.*, 2020), indicating that adopters of CSAPs tend to be less affected by climatic risks.

Climate-smart agricultural practices adoption, migration and literacy

Supplementary Figure 2 presents the trend of CSAPs adoption with respect to male out-migration in the period between 2007 and 2016. Data suggest a higher adoption rate between 2012 and 2014. During this period, fewer men migrated; out of a total of 92 adopters

(innovators and early adopters), 83.6% of male farmers did not migrate; of those, 78% adopted CSAPs during that specific period. There has been a considerable change in the nature and causes of migration. Recent years have witnessed greater migration rates among the labor force in search of a livelihood, mainly for a more extended period of time (De Haan, 1999; Rodgers and Rodgers, 2001; Sharma *et al.*, 2000). One of the more significant impacts of labor out-migration is the supply of remittances to the migrants' households, a significant non-farm source of income, depicting the severity of migration in the area. The remitted money increases the small household income of about Rs 6,426 per month; approximately, 60% of this derives from crop and livestock production, and the rest seems to be supplied by wages from local off-farm labor and remittances from migrant workers (The Hindu, 2017).

The migrants' income at their destination largely depends on the type of occupations they are involved in, the duration of the work and the personal endowments of the migrant workers, such as level of education, skill, years of experience, etc. Because most of the migrant workers possess low private endowments, they are generally absorbed by the informal sector in irregular or casual employment that have abysmally low earnings. However, declining employment opportunities in their home area and the expectation of finding remunerative employment at their destination keep migrant workers tied there. Because the nature and patterns of migration in the research areas do not necessarily yield a large supply of remittances, interventions such as CSAPs do have an impact on curtailing migration by providing high-income and low-cost technologies. Our data highlight the fact that adopters are less likely to migrate compared to non-adopters. Among the 94 adopters, 17% were migrants, whereas, among the 92 non-adopters, 52% were migrants. In a situation where there has been an alarming rate of out-migration (from rural Bihar in the recent past), CSAPs can play an important role in curtailing this phenomenon by transferring the monetary paybacks together with delivering environmental benefits.

Supplementary Figure 3 shows that the adoption of CSAPs also differs from farmers' levels of education. We have categorized education as illiterate (no schools), primary, secondary, senior secondary and graduate levels or above. Individuals possessing primary, secondary or higher levels of education tend to adopt CSAPs. We observe that illiterate farmers are more resistant to adopting new technologies, which is the main bottleneck for scaling. This validates the notion that knowledge of and training in CSAPs increase adoption because a literate and well-educated farmer is obviously better able to understand the technologies and related benefits. The resources, knowledge and capacity required to adopt a new CSA practice can be significant.

Data reveal a stronger relationship between education and migration. Illiterate people are not able to perform advanced agricultural operations efficiently, are usually involved in low-paid labor activities and tend to migrate in search of jobs. Highly educated people are seen to migrate more, as they have better earning opportunities in cities. Education is seen as strongly linked to migration (Rajan, 2013).

Supplementary Figure 4 suggests that irrespective of the level of education, adopters are less likely to migrate. Over 85% of adopters with primary education do not migrate, whereas, with the same level of education, 56.8% of non-adopters migrate. This could be attributed to the higher profits realized from CSAPs that encourage adoption. Farmers with higher education are more likely to adopt and not migrate, as they are in a better position to understand the benefits of conservative agriculture. In our study, we observed that 85.2% of farmers with secondary education, and 84.6% of those with a bachelor's degree or above, were adopters and did not migrate.

Irrespective of adoption, approximately, half of the farmers were non-migrants. From the policy perspective, there is a scope and a need for interventions to curtail migration aimed at

a better education, capacity building and scaling of CSAPs with a focus on women. Observing the role of female education on migration, we observed that if women were highly educated, men were less likely to migrate, as shown in Supplementary Figure 5. If a woman in the same household has a bachelor's degree, only 20% of men migrate, whereas 42.1% of men migrate if a woman is illiterate. We also observed that men did not migrate if a woman in the same household had primary or secondary education in 65.1% and 84.2% of cases, respectively. These quantitative estimates are also supported by the qualitative response of one of the male adopters who had migrated and whose wife had secondary education, who stated, "My wife plays a very important role in farm decision-making. As we are aware of the benefits of CSAPs, her education, and my exposure to training help us achieve good profits. Not only her education supports in farming but also to take care of livestock, providing us additional income for children's education." These qualitative and quantitative findings justify the interventions targeting women's capacity building by providing training and knowledge.

From the above statement and other field observations, the role of educated women in reducing low-paid out-migration and concentrating the household labor force on agriculture and allied activities becomes clearer. Although education plays an important role, literacy rates in India are low and witness significant gaps. As per the 2011 census, male and female literacy rates were 73.4% and 53.3%, respectively, in Bihar [1]. In this context, increased women's education may help households in several ways as follows:

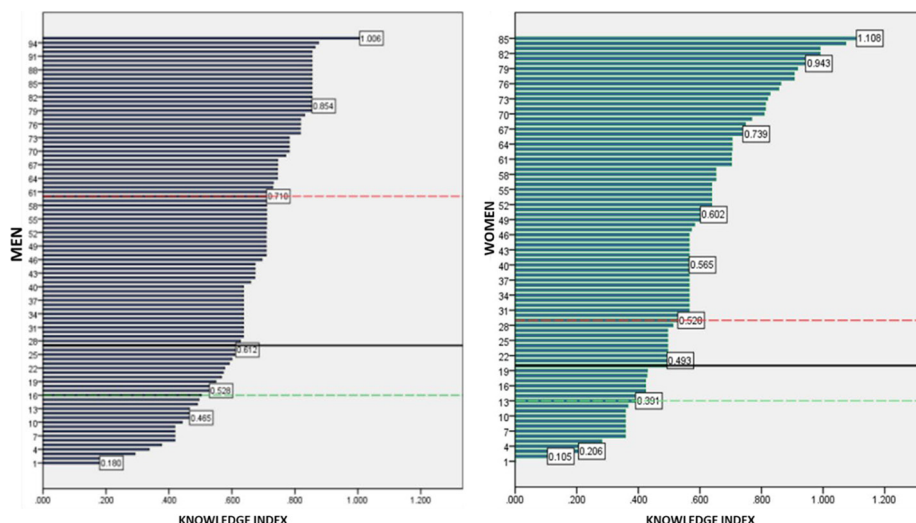
- Women may be better off in terms of managing households and agricultural (through extension education they receive).
- It may reduce men's out-migration, as men also see more opportunities locally and be with the family.
- It may eventually increase adoption of CSAPs.

Knowledge gap

Figure 2 shows that a higher KI is indicative of better knowledge. Among adopters, the KIs for men and women were 0.717 and 0.527, whereas for non-adopters, they were 0.614 and 0.388, respectively. Data suggest that the male adopters are 1.36 times more knowledgeable than their female counterparts. Among non-adopters, men are 1.58 times better informed than women about CSAPs. This reflects a knowledge gap between men and women farmers in terms of adopting CSAPs. This corresponds with the results found in other studies that reflect on women's (as opposed to men's) vulnerability to the adverse impacts of climate change because of greater poverty, less education and training and less access to institutional support (Yadav and Lal, 2018; Goh, 2012). Women, however, play a strategic role in economic activities. Rather than merely supplying labor, they possess detailed knowledge of agriculture and plants and plant products for food, medicine, fish farming and animal feed. Women today are central to the selection, breeding, cultivation, preparation and harvesting of food crops (Weerakoon and Motebennur, 2017). Apart from their pivotal role in the cultivation of staple crops, they are primarily responsible for producing secondary crops, such as pulses and vegetables, which are often the only source of nutrition available to their families. Thus, we require plans for strategic integrated farming interventions to enhance women's participation by increasing their knowledge and endowment of resources.

To gain a better understanding of the gendered nature of KIs across the region, a village-wise analysis was performed as presented in Supplementary Figure 6. Detailed analysis from the set of 10 CSVs suggests a critical piece of information, highlighting the differences

Figure 2.
Average knowledge index (KI)
distribution of
adopters and non-
adopters for men and
women



between men' and women's KI and the factors behind them presented and described in Supplementary Table 1. Besides, we also analyzed CSA technology-specific gendered KI to help design technology-specific interventions, as shown in Supplementary Table 2.

The World Bank considers the KI as an economic indicator to measure a country's ability to generate, adopt and diffuse knowledge. The report shows that India ranks 109th out of 145 countries with a score of 3.1. Of the three pillars of the knowledge economy – education and human resources; innovation systems; and information and communication technology, India ranks highest in the area of innovation with several examples of low-cost innovative techniques that have emerged in rural India (Livemint, 2014). Innovative and cost-effective techniques lead the discussion for the adoption and scaling of CSAPs. They combine both high- and low-cost machinery, but when it comes to the benefit–cost analysis, they lead to significant profit-making technologies. The challenge, therefore, is the widespread diffusion of knowledge about these technologies in rural communities. There have been several initiatives made by CIMMYT and its partners to make farmers climate-smart and to increase yields, income, food security, adaptation and climate-risk mitigation sustainably.

Food and nutrition security: an ultimate outcome

We analyzed the food and nutrition security scenario, where farmers' coping strategy was to alter their consumption pattern for different food groups if they fell short of supplies because of climatic stress. The mean reduction in consumption was calculated as a weighted average of the responses to the percentage reduction in each food category that was experienced with weights and compared between adopting and non-adopting respondents and among males, females and children (Supplementary Table 3). The average consumption of pulses, eggs, meat, vegetables, cereals, legumes and fruits was reduced less by adopters than non-adopters across all social categories – males, females and children. In other words, the impact of climatic risk on nutrition intake is more severe for non-adopters, thus making it necessary for farmers to adopt CSAPs to mitigate risks. Food category-wise, the highest impact on the mean reduction in consumption under climatic risks for both adopters and non-adopters was on the consumption of eggs and meat. Cereals contribute approximately

62% of total calories consumed, equivalent to 1,748 calories/day. The consumption of cereals, which are a major source of energy, was less affected among adopters than among non-adopters. Legumes were majorly affected by climatic risks among non-adopters, despite being a major source of calories. Pulses, vegetables, legumes and fruits were comparatively less affected among adopters; on average, adopters reduced their consumption by 10.53%, whereas non-adopters reduced it by 21.76%. With such a significant reduction in consumption, non-adopters tended to fall below the recommended calorie intake levels. The difference highlights the fact that food security for adopters is ensured as they experience higher yields and income, which allows them to mitigate risk in the case of climatic adversities.

Based on the data obtained from NSSO (REPORT 560, 2014), we estimated the average daily calorie intake in rural Bihar as 2,731 kcal, obtained from different food groups (Supplementary Table 4). The report illustrates that the number of meals consumed by men for 30 days (71.2) is almost the same as the number consumed by women (70.9). It was also observed that children were not discriminated against in any age group and were provided equally well with food at home or school (Supplementary Table 5). Neither did we observe any discrimination in food consumption between men and women across age groups. Thus, under normal conditions, we should assume that nutritional requirements are equally addressed as long as sufficient energy-rich foods are consumed.

Knowledge impact on the climate-smart agricultural practices adoption

Table 1 shows that the KI has a positive impact on the adoption of CSAPs. Model 1 shows an expected increase of 1.57 in the log odds of adoption with every unit increase in the KI. Adoption may be impacted by several other factors such as farmer literacy; availability of training; farmers' characteristics, such as gender, caste, education, social and economic capital; farmland characteristics; access to market and extension services; and climatic risks experienced by the farmers (Aryal *et al.*, 2018). It is imperative to partial out the effects of such variables to obtain consistent estimates for KI. Model 2 includes other impacting variables such as circumventing omitted variable bias. The results are significant and remain robust to the inclusion of other variables. The estimate suggests that adoption of CSAPs increases the log of odds to adoption to 2.36. The inclusion of other variables leads to an increase in the probability of CSAPs adoption with an increase in the KI, indicating a possible underestimation of the estimate in the absence of the control variables [2]. Other similar studies conducted in India (Aryal *et al.*, 2018) and elsewhere (Tran *et al.*, 2019) also observed that farmers' knowledge about CSAPs is vital to address climatic risks and increase adoption of such technologies. It is thus essential to improve farmers' knowledge of CSAPs to increase their adoption.

	(1)	(2)
Knowledge index	1.573***(0.461)	2.365***(0.738)
Includes controls	No	Yes
Observations	156	156
Standard errors in parentheses		

Note: *** $p < 0.01$

Table 1.
Logistic regression
estimates for the
impact of CSAPs
knowledge on
adoption

Impact of labor out-migration on the climate-smart agricultural practices adoption

The result in Table 2, Model 1, contains only CSAPs adoption as the independent variable. Farmers who adopt CSAP technology are less likely to migrate. The results are significant and remain robust to the inclusion of other variables. Model 2 regresses migration on age and female literacy besides CSAPs adoption, and Model 3 also includes the controls. The results suggest that CSAPs adoption has a significant negative impact on male out-migration. This supports the hypothesis that farmers who adopt CSAPs technology are less likely to migrate. The results are significant and remain robust to the inclusion of other variables. The results suggest that adoption by CSVs reduces the log of odds to migrate by 1.3. This could also be interpreted as a reduction in the probability of migrating by 21%. Female literacy is also shown to have a negative and significant effect on male out-migration. The results are again robust across the models. Model 3 suggests that an increase in female literacy by one unit reduces the log of odds to migrate by 0.37. Put differently, the probability of migration reduces by 40% upon adoption of CSA technologies and practices. A rise in the age of an individual is also seen to be negatively associated with migration.

Rural youths leave their residence searching for better employment opportunities elsewhere within and outside the country; the main push factors are less agricultural production, local unemployment and other socioeconomic drivers (Patel et al., 2015; Choithani, 2017; Deshinkar and Start, 2003). Labor out-migration could be a climate-change adaptation strategy, as the supply of remittances contributes to household income and food security (Jha et al., 2018). Our study complements these studies but also demonstrates that adoption of CSAPs could be a strategy to reduce labor out-migration and promote the local economy.

Climate-smart agricultural practices adoption and household food security

Model 1 results in Table 3 suggest that CSAPs adoption leads to a rise in nutrition intake by 5.92 units. The estimate is found to be significant and robust to the inclusion

Table 2.
Logistic regression estimates for the impact of CSAPs adoption on male migration

	(1)	(2)	(3)
Adopter	-1.684*** (0.347)	-1.734*** (0.357)	-1.304*** (0.407)
Age		-0.032** (0.015)	-0.03* (0.016)
Female literacy		-0.252* (0.146)	-0.374* (0.176)
Includes controls	No	No	Yes
Observations	156	156	156
Standard errors in parentheses			
Notes: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$			

Table 3.
Logistic regression estimates for impact of CSAPs adoption, female literacy and migration on reduction in consumption

	(1)	(2)
CSAP adopter	-5.923*** (1.447)	-3.45** (1.593)
Includes controls	No	Yes
Observations	156	156
Standard errors in parentheses		
Notes: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$		

of other controls such as age, household size, etc. Men's migration tends to increase nutrition intake deficiency by almost five units. In the previous results, it is shown that in the case of food deficiency, men migrate. This highlights the vicious cycle of food deficiency among migrating households. To break this cycle, proper emphasis should be placed on addressing climatic risks and harnessing women's potential. An increase in land size also tends to reduce the decline in consumption and is robust at a 5% level of significance. Thus, well-endowed farmers are less impacted by climatic risks. To address the situation of smallholders, CSAPs offer the best interventions to secure household food security. CSAPs adopters can sustain a higher standard of food consumption. These results contradict other studies that look at migration as a household strategy to cope with poverty and food insecurity (Sunam, 2017; Patel *et al.*, 2015; Kim *et al.*, 2019) and as an adaption strategy to cope with climate change (McLeman and Smit, 2006); this may be because of differences in the causes and consequences of migration in Bihar and elsewhere.

Conclusion and policy implications

In this paper, we focused on how the adoption of CSAPs influences farmers' decisions on rural–urban migration and how it impacts the overall household food security in two relatively food insecure Bihar districts. The overall low economic development and gender and social inequalities, especially in rural villages, are the most important reasons for the high incidence of rural out-migration in South Asia. The solution lies in the rapid economic development of rural areas. We observed low, average knowledge indices of the farming community and that women are in a disadvantaged position in the two study areas of Bihar, India. Thus, informed policy decisions are urgently needed. Business models for creating gender-equitable employment opportunities, improved education levels and training packages should be priority targets for investment and benefit from strategic short-, medium- and long-term interventions. A socio economic-environmental benefits portfolio should include focused, improved access and control for women over resources, ensuring enhancement of their decision-making and reducing low-paid workers' migration.

This paper has highlighted the knowledge gaps that exist between men and women farmers in terms of CSAPs. Therefore, a policy intervention for an equitable gender-responsive development action plan is needed. The results suggest that a reduced knowledge gap would increase CSAPs adoption and consequently reduce the likelihood of migration. This is especially important in the research area as the labor migration is mostly a destitute migration, and if it could be reduced by improved social and economic conditions locally, it would benefit the rural youths in the research areas. The subsequent benefits, such as improved household income, proper farm budgeting and enhanced household food and nutrition security, would help improve the productive capacity of the society. Although the role of women in curtailing migration and ensuring household food and nutrition security (through production and consumption) is significant, there persists discrimination in wages and working status for the female workforce in agriculture. This wage inequality needs important consideration in policy so that both male and female farmers would be encouraged. This paper has demonstrated the need to implement policies and initiatives taken by the government to promote CSAPs for mitigating climatic risks; these policies and initiatives should aim to empower women and make women's labor as agricultural workers visible. One strategic intervention could be to enhance the adoption of CSAPs with a gender lens, endowing women with better decision-making. The direction should be toward gender

equity, aiming toward gender equality, targeting improved societal productive capacity and ensuring a sustainable integrated farming system.

Although the adoption of CSAPs helps minimize the impacts of climatic risks significantly and promotes gender equality while relieving the pressure on government expenditure in massive amounts of compensation paid to farmers as relief at times of climatic risks. Its success, after all, relies on political will and commitment to the public.

Notes

1. http://censusindia.gov.in/2011-prov-results/data_files/mp/07Literacy.pdf
2. Included controls are if enough training is available, household size, farmer literacy rate, government policies, financial inclusion and migration.

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Author affiliations

- Tripti Agarwal, Sustainable Intensification Program, International Maize and Wheat Improvement Center (CIMMYT), New Delhi, India
- Prarthna Agarwal Goel, Guru Gobind Singh Indraprastha University, New Delhi, India
- Hom Gartaula, Integrated Development Program, International Maize and Wheat Improvement Center (CIMMYT), NASC Complex, New Delhi, India
- Munnum Rai, International Maize and Wheat Improvement Center (CIMMYT), New Delhi, India
- Deepak Bijarniya, Sustainable Intensification Program, International Maize and Wheat Improvement Center, New Delhi, India
- Dil Bahadur Rahut, Asian Development Bank Institute (ADBI), Tokyo, Japan, and
- M.L. Jat, Sustainable Intensification Program, International Maize and Wheat Improvement Center (CIMMYT), New Delhi, India

About the authors

Tripti Agarwal is Project Administrator for Sustainable Intensifications Program at International Maize and Wheat Improvement Center (CIMMYT), India. She holds experience in project management, communications and social science research with focus on gender and business models. Her research interests involve social inclusion for improved livelihoods of farming community, gender mainstreaming in climate-smart agriculture and business cases for scaling climate-smart agricultural practices supported with coauthored research articles. Tripti received bachelor's degree in Economics (Hons.) and Master in (Rural) Business Administration from Xavier's Institute of Management, India.

Prarthna Agarwal Goel is an economist with areas of interest and specialization in the field of applied economics, development economics and gender studies. Currently, she is engaged in academics, works at GGS Indraprastha University, and prior to this, she has worked with the analytics industry. She holds long experience on credit risk modeling and marketing mix analytics. She holds a patent in the USA and several other countries in "Marketing Investment Optimization

Analysis.” Some of her ongoing research includes work on economics of gender, labour market, and so on. Also, she has submitted her PhD in the Centre for International Trade and Development, Jawaharlal Nehru University, New Delhi, India.

Hom Gartaula is a Social Scientist working as a Theme Leader for the gender and social inclusion research at the International Maize and Wheat Improvement Center (CIMMYT). His research focuses on gender and social inclusion in agriculture and food security, climate change, seed systems, participatory technology development, and rural-urban migration and farmers’ wellbeing. With an undergraduate degree in agriculture obtained from Nepal, Hom holds MSc and Ph.D. in Social Sciences with a disciplinary orientation on Sociology and Anthropology of Development from Wageningen University, the Netherlands.

Munnum Rai is Research Associate at International Maize and Wheat Improvement Center (CIMMYT). She has nine years of experience in conservation agriculture, climate-smart agriculture and gender research. She holds a PhD in plant sciences from Jaipur National University, Rajasthan. Her work focuses on generating knowledge, building capacity and learning on climate smart agriculture practices that can lead to equitable outcomes for women and other marginalized social groups in agriculture. Her particular interest is in finding innovative ways how sustainable shifts toward empowerment, equality, poverty reduction and nutrition security and sustainability can be achieved that leads to income and food security under progressive climate change and variability.

Deepak Bijarniya is Research Scientist at International Maize and Wheat Improvement Center (CIMMYT). He associates in the sustainable intensification research, specially related to gender and social inclusion research portfolio in India. His research covers the issues of gender and social inclusion, youth and agriculture, climate change, food security, labor migration and human wellbeing. Deepak holds a PhD in Plant Sciences with interdisciplinary focus on integrated management of plant diseases from University of Rajasthan, Jaipur, India.

Dil Bahadur Rahut is Senior Research Fellow at Asian Development Bank Institute, Tokyo, Japan. Before joining ADBI, Dil was global program manager for the International Maize and Wheat Improvement Centre’s (CIMMYT) socioeconomics and sustainable intensification programs. He previously worked for the Royal Monetary Authority of Bhutan’s Research and Statistics Department. He also served as a research fellow at the WorldFish Centre; senior fellow and Japan chair at the Indian Council for Research in International Economic Relations; chief of research, planning, and monitoring and Visa/Mastercard director at the Bank of Bhutan Ltd; and assistant professor of development economics at South Asian University. He has a PhD in development economics from the University of Bonn’s Center for Development Research, a master’s degree in economic policy management from the University of Tsukuba, and an MBA specializing in finance and Bachelor of Science degree from India. He has over 100 publications in Scopus indexed journals focusing on development issues across Asia and sub-Saharan Africa.

M.L. Jat is Principal Scientist/Systems Agronomist at International Maize and Wheat Improvement Center (CIMMYT). He has devoted over two decades to intensively work on basic and applied science in agronomy, soils and environment and promote conservation agriculture-based sustainable intensification in smallholder farming systems of Asia. His research on CA has provided scientifically sound basis and directions for promoting sustainable intensification through policy changes and led to impact at scale in smallholder systems of south Asia. Research results of his group have been well documented in over 300 peer reviewed high impact journal articles, book chapters, books, manuals, monographs and proceedings. He has served several reputed international and national scientific bodies and fora. A fellow of National Academy of Agricultural Sciences, Dr Jat has several awards and recognitions to his credit. M.L. Jat is the corresponding author and can be contacted at: M.Jat@cgiar.org

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