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Climate smart agriculture, farm household typologies and food security An *ex-ante* assessment from Eastern India

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A B S T R A C T

One of the great challenges in agricultural development and sustainable intensification is the assurance of social equity in food security oriented interventions. Development practitioners, researchers, and policy makers alike could benefit from prior insight into what interventions or environmental shocks might differentially affect farmers' food security status, in order to move towards more informed and equitable development. We examined the food security status and livelihood activities of 269 smallholder farm households (HHs) in Bihar, India. Proceeding with a four-step analysis, we first applied a multivariate statistical methodology to differentiate five primary farming system types. We next applied an indicator of food security in the form of HH potential food availability (PFA), and examined the contribution of crop, livestock, and on- and off-farm income generation to PFA within each farm HH type. Lastly, we applied scenario analysis to examine the potential impact of the adoption of 'climate smart' agricultural (CSA) practices in the form of conservation agriculture (CA) and improved livestock husbandry, and environmental shocks on HH PFA. Our results indicate that compared to livestock interventions, CA may hold considerable potential to boost HH PFA, though primarily for wealthier and medium-scale cereal farmers. These farm HH types were however considerably more vulnerable to food insecurity risks resulting from simulated drought, while part-time farmers and resource-poor agricultural laborers generating income from off-farm pursuits were comparatively less vulnerable, due in part to their more diversified income sources and potential to migrate in search of work. Our results underscore the importance of prior planning for development initiatives aimed at increasing smallholder food security while maintaining social equity, while providing a robust methodology to vet the implications of agricultural interventions on an *ex ante* basis.

1. Introduction

The global diversity of smallholder farming systems and associated livelihood strategies reflects the intrinsic interaction of social-ecological processes and factors at different organizational levels. Proper characterization of this diversity is therefore an important step towards delineating the appropriate social-ecological niche for different technological and policy options (Descheemaeker et al., 2016; Ojiem et al., 2006). When combined with geographic analysis, recommendation domains for agronomic technologies, management practices, and farming systems can be developed, with the ultimate goal of increasing the efficiency of development efforts by accelerating smallholder farmers' adaptation and adoption of productivity increasing technology products (Sumberg and Reese, 2004).

In intensive cereal based farming systems, the successful development of resource use efficient management practices requires coherence with farmers' resource endowments, ability and interest to invest in diversified crop and livestock species, crop and livestock management

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techniques and livelihood options, as well as with the full range of activities carried out by farming households. Grouping farming systems in terms of their resources and livelihood activities, as well as agricultural management practices, is now common. Farming system typologies have been used for nearly two decades to capture the diversity of farming systems (Landais, 1998), and are increasingly used to provide guidelines for the development of agricultural innovations and to better understand their implications for climate change (Berre et al., 2016; Chopin et al., 2015; Douxchamps et al., 2015; Kuivanen et al., 2016; Pacini et al., 2014; Tittonell, 2014).

Foresight of the possible impact of climatic shocks and technological alternatives is also an indispensable step towards the delimitation of appropriate recommendation domains for 'climate smart' agriculture (CSA). CSA aims to simultaneously increase agricultural productivity, food security, and farmers' adaptive capacity to climate extremes, while also lowering greenhouse gas emissions (Campbell et al., 2014). *Ex-ante* foresight can also aid in the design of technological alternatives (and accompanying delivery pathways and policies) for CSA, and development interventions intended to improve the smallholder livelihoods (cf. Rosenstock et al., 2014). The complexity and diversity of farm household livelihood strategies however necessitates careful focus on key indicators that reflect changes in vulnerability or resilience, with particular emphasis on food security (Frelat et al., 2016).

In South Asia's intensively cropped Indo-Gangetic Plains (IGP), an estimated 640 million people live in extreme poverty and rely on cereals for primary subsistence (Saharawat et al., 2010). The IGP encompasses the Ganges, Indus, and Brahmaputra river basins where rice, wheat and maize are the most commonly rotated cereals. Rice-wheat rotations in particular predominate on > 13 million ha (Chauhan et al., 2012; Jat et al., 2016). The IGP nonetheless has a high degree of spatial variability in terms of poverty, with a clear low-to-high gradient of food insecurity moving from west-to-east (Erenstein and Thorpe, 2011). Farmers tend to have larger herds and farm sizes, more access to irrigation, and higher cropping intensity in the west, all of which influences household food security (Erenstein et al., 2010; Erenstein and Thorpe, 2011). Yield gaps however remain common in the IGP, ranging from 14 to 47%, 18–70%, and 36–77% for wheat, rice, and maize, respectively. These gaps widen in the eastern IGP, broadly correlating with the region's increased poverty, farmers' low investment capability and aversion to risk, and increasing in energy and input costs, in addition to climactic variability (Aravindakshan et al., 2015; Jat et al., 2016). Pulses, oilseeds, and mixed crop-livestock systems are also common, as is farmer engagement in seasonal and semi-permanent migration and off-farm labor (Erenstein and Thorpe, 2011).

Farmers in the IGP are also vulnerable to climate change (Jat et al., 2016; Sapkota et al., 2015). Increasing temperatures reduce the winter season wheat crop's duration which, when combined with terminal heat stress and drought, can substantially lower productivity (Arshad et al., 2016; Krupnik et al., 2015a,b). Eastern India's Bihar State has been identified as one of most vulnerable regions to climate change due to heat, drought and flood risks, in addition to increasingly erratic monsoon precipitation (Sehgal et al., 2013; Chhabra and Haris, 2015). As India's third most populous state, over 90% of Bihar's inhabitants live in rural areas. 81% depend on agriculture, although food insecurity remains common (Krishna and Kumar, 2014). Development planners nonetheless hope to convert Bihar to India's 'future food bowl' by dramatically boosting cereals and livestock production (Singh et al., 2009; Laik et al., 2014). This is a formidable challenge given the state's generally unfavorable biophysical and climactic environment, high degree of farm fragmentation, inadequate infrastructure, and weak institutions and markets (Laik et al., 2014).

Over the last decade, alternative cropping systems employing the principles of CSA have been have been developed in the form of conservation agriculture through on-station and on-farm validation trials across Bihar (Jat et al., 2014; Laik et al., 2014; Sapkota et al., 2015). These innovations include alternatives to intensive tillage for rice establishment that mitigate global warming potential, alongside rotational options for direct seeded maize and wheat establishment with the retention of crop resides as a surface mulch to conserve soil moisture (Singh et al., 2012; Jat et al., 2014; Laik et al., 2014). When carefully implemented, these practices can reduce production costs, energy demand, and greenhouse gas emissions, while also maintaining or augmenting yield (Gathala et al., 2013; Jat et al., 2014, 2016; Gathala et al., 2016). These outcomes qualify these practices under the rubric of CSA (Sapkota et al., 2015). Not all technologies are however likely to generate equal income or food security benefits for all smallholder households. For example, milk production comprises an important source of nutrition and income generation for some farmers' livelihood systems in eastern India (Erenstein et al., 2010; Erenstein and Thorpe, 2011) and therefore, increases in cereal crop productivity may have less impact on their food security or income. The poor fit of many widely-promoted agronomic technologies has been corroborated by their low and differentiated adoption (Erenstein and Laxmi, 2008; Singh et al., 2012), further challenging the goal of increasing Bihar's cereal productivity.

In this paper, we demonstrate how the use of farming systems typologies and an innovative food security model can be used to explore and assess the impact of CSA practices, improved animal husbandry, and climactic shocks on the food security of farm households on an *ex-ante* basis. Using survey data from 269 farmers in six villages and three districts of Bihar, we apply a multivariate statistical methodology for typology construction combined with the calculation a simple yet robust food security indicator. We follow with an analysis of different agronomic intervention and climactic risk scenario analyses, with interpretation of the results differentiated by predominant farming system type. We conclude by discussing the ways in which this methodology can be used to generate insight into the advantages and constraints of alternative agricultural interventions and scenarios, in order to better target interventions for more equitable development among smallholder farmers while reducing their vulnerability to climate change related risks.

2. Methodology

2.1. Study location and survey details

Administered in 2010–2011, the Cereal Systems Initiative for South Asia (CSISA) farm household (HH) survey catalogued farming systems and livelihood pursuits in the IGP (Pede et al., 2013). The survey included intensive sampling in Bihar, selected because of its dependency on agriculture for food security, and because of its ranking as India's poorest state (RBI, 2013). Bihar also hosts a number of long-term agronomic experimental platforms that compare conventional crop management with CSA practices, thereby providing data for simulation analyses (see Section 2.4). Surveys were administered in Bihar's Begusarai, Nawada and Samastipur districts. Within each, three administrative blocks were chosen, after which two villages per block with 18 HHs each were selected (Fig. 1). Each layer of this selection process was randomized, resulting in a dataset of 269 HHs. The survey instrument was organized into five sections, including (i) general farm and HH characteristics, including land use and capital, (ii) farm input and labor use, (iii) experience with and adoption of field crop and horticultural production technologies and practices, (iv) livestock production, with emphasis on dairy, and crop residue management (including use as animal feed), and (v) off-farm HH income sources and financial expenditures.

2.2. Typology construction

2.2.1. Selection of variables

We explored the diversity of Bihar's farming systems using typological analysis (Berre et al., 2016; Cortez-Arriola et al., 2015; Pacini