Global Food Security 17 (2018) 1–8

Contents lists available at ScienceDirect

Global Food Security

journal homepage: www.elsevier.com/locate/gfs

Priorities for wheat intensification in the Eastern Indo-Gangetic Plains

Alex G. Park[a,*], Adam S. Davis[b], Andrew J. McDonald[c]

[a] Department of Crop Sciences, University of Illinois at Urbana-Champaign, S-306 Turner Hall, 1102 South Goodwin Avenue, Urbana, IL 61801, USA
[b] Department of Crop Sciences, University of Illinois at Urbana-Champaign, N-319 Turner Hall, 1102 South Goodwin Avenue, Urbana, IL 61801, USA
[c] CIMMYT-Nepal, Singh Durbar Plaza Marg, Kathmandu, Nepal

1. Introduction

Increasing yields of the rice-wheat cropping system in South Asia is important to the food security of more than a billion people. Two regions in the Eastern Indo-Gangetic Plains (EIGP) of South Asia, the Indian state of Bihar and the Terai of Nepal, are half as productive as the adjacent Indian states of Punjab and Haryana (FAO, 2016; Indian Ministry of Agriculture, 2017). Increasing yields in these two regions to more closely approximate those in Punjab and Haryana will be critical to the regional food security of the EIGP because of rising demand for wheat products from increasing population, changing diets and rising personal income (Paulsen et al., 2012). Nepal and Bihar have wheat yield potential (Y_p) similar to Punjab and Haryana based on soil and climactic properties (Aggarwal et al., 2000), presenting an opportunity to identify agronomic practices that lead to higher productivity.

Understanding the causes of yield loss in farmers' fields, and the capacity of agronomic practices to reduce those losses, can empower farmers to make the right decisions that improve their food security. The concept of yield gaps has emerged as a useful analytical tool in development agriculture because it provides a relativistic measure of yield, allowing researchers to deploy interventions that reduce yield gaps (Lobell et al., 2009) Yield gaps are typically calculated as the difference between the Y_p and average yields of farmers (Y_a) within a spatially explicit area, with the difference being called model-based yield gap (YG_M) (van Ittersum and Rabbinge, 1997). Yield potential has been argued to be most accurately calculated by crop models because they can simulate growing conditions for a given location and crop variety for several years to estimate long-term average potential (van Ittersum et al., 2013). On-farm production practice and crop yield surveys can be used in combination with YG_M to identify which management and site factors contribute to better yield outcomes.

In order to identify technological and management entry points that reduce YG_M in wheat production, the Cereal Systems Initiative for South Asia (CSISA – www.csisa.org) conducted on-farm production practice and crop yield surveys across 1181 farmer's fields within 109 villages in Bihar and the Terai region of Nepal (Fig. 1). CSISA is part of a collaborative effort between CGIAR centers (CIMMYT, IRRI, and IFPRI) and national partners in South Asia (Nepal, India, Bangladesh). Surveys were conducted in April and May of 2012, 2013 and 2016 (limited resources prevented sampling in 2014 and 2015). Sampling occurred in areas where CSISA project interventions were ongoing and included both farmers who were implementing new technologies and those that were not. Although the sampling design was not completely random (e.g. including areas outside of CSISA working domain), we assume the large number of farmers included in the study across significant environmental and socioeconomic boundaries is representative of the diversity of management and environments found in the EIGP. Data from these surveys were used for three purposes: 1) Determine YG_M for the EIGP, Bihar, Terai of Nepal, and environments therein; 2) Identify and prioritize stand out agronomic practices that reduce YG_M across different political and environmental boundaries; 3) Provide context on how agricultural policy and Per Capita Income may influence the adoption of successful agronomic practices that emerge in our study.

2. Methodology

2.1. Study location and cropping system

The study area was located in fourteen districts of the Terai region of Nepal bordering the Indian states of Bihar and Uttar Pradesh, and twelve districts in the Indian state of Bihar. The study area climate is sub-tropical, with a mean annual temperature between 20 and 25 °C and an average annual rainfall of approximately 1400 to 2000 mm which mostly falls during the summer monsoon (WFP, 2010). All fields in the study received at least one irrigation during the wheat growing season. The dominant annual cropping pattern in the survey area is the rice-wheat rotation and covers approximately 33% and 42% of the total rice and wheat area in the EIGP (Mahajan and Gupta, 2009). Wheat is largely sown in November and harvested in March or April.

2.2. Survey data

Data was collected on tillage and crop establishment type (rotovation, cultivation, or zero-till); Nitrogen (N), Phosphate (P), Potassium (K) and seed input rates in kg ha^{-1}; number of irrigations during the growing season; wheat variety and maturity rating; date of sowing; and

---

[*] Corresponding author.

E-mail addresses: Agpark2@illinois.edu (A.G. Park), asdavis1@illinois.edu (A.S. Davis), A.McDonald@cgiar.org (A.J. McDonald).

https://doi.org/10.1016/j.gfs.2018.03.001
Received 9 August 2017; Received in revised form 26 February 2018; Accepted 2 March 2018
2211-9124/ Published by Elsevier B.V.

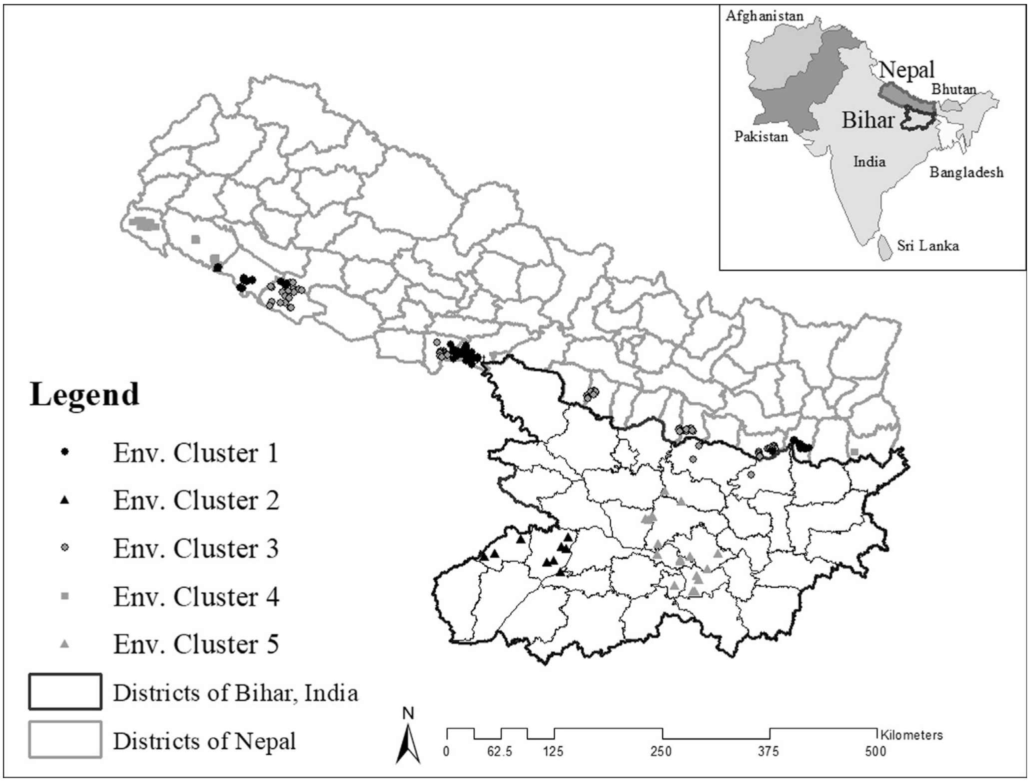

Fig. 1. On-farm production practice and yield estimation surveys taken at 1181 farms in 109 villages in Bihar, India and the Terai Region of Nepal. Surveys taken in 2012, 2013, and 2016, but not universally replicated yearly at all locations. Five environmental clusters created from k-means cluster analysis are shown. Environmental clusters two and five are found in Bihar, while one and three are found in Nepal. Environmental cluster four was predominantly found in Nepal, while three villages in Bihar were classified as environmental cluster four.

wheat grain yield in kg ha^{-1}. Yield samples were corrected for moisture content using a *wile 55* moisture meter or equivalent. District level Per Capita Income for 2014 estimates in USD ($) were determined from each country's Bureau of Statistics (MSPI, 2015; Sharma et al., 2014). Per Capita Income was included in this analysis because there are a host of management decisions associated with wealth for agricultural intensification and risk bearing capacity that are difficult to fully capture in production surveys. Its inclusion was an attempt to include some of these latent variables and their associated effects on management decisions within our analysis.

2.3. Yield potential

A previous study by Aggarwal et al. (2000) used model-based methods to estimate the Y_p of rice and wheat in the Indian States of Punjab, Haryana, West Bengal, Uttar Pradesh and Bihar. In this study, we used wheat Y_p estimates from the simulations conducted Aggarwal et al. (2000) for Bihar that were planted during an optimum sowing window with no water limitations. Varieties of the same lineage commonly found in our study were used by Aggarwal et al. (2000) to estimate Y_p. We used the same Y_p values from Indian districts bordering Nepal as a reasonable proxy for the Nepali farmers in our study because the two regions share very similar agroecological characteristics (Pathak et al., 2003).

2.4. Farmer-based and model-based yield gaps

The large sample collected by CSISA allows for a modification of the farmer-based yield gap (YG_F) which is calculated as the difference between area-averaged Y_a and maximum farm yields (Lobell et al., 2009). Instead we treated YG_F as an individual value per farmer independent of Y_a, and is the difference between their yields and that of the maximum farmer in their respective village (Eq. (1)). In our calculation of YG_F, the maximum yielding farmer in each village has a YG_F value of 0 kg ha^{-1}, while all other farmers within that village had a negative value as a measure of the difference between their yields and that of the maximum yielding farmer. YG_F were calculated for the i^{th} farmer within the j^{th} village as

$$YG_{F_{ij}} = Farmer\,yield_{ij} - Maximum\,yield_{j} \tag{1}$$

We do not consider maximum farmer yield within our calculation of YG_F as an approximation of Y_p. This is because highest yielding farmers are often unable to achieve optimal yields for a given variety with their management practices, and is therefore not an adequate measure of Y_p (Ittersum et al., 2013). However, we treated YG_F as a relative measure of yield performance with the assumption that similar development and environmental conditions exist at the village level, and that differences between the maximum yielding farmer and all other farmers within a village were a result of different agronomic practices (Fischer et al., 2009).

We then determined the YG_M of different political units and/or environments by finding the difference between area-averaged Y_a and Y_p as estimated from Aggarwal et al. (2000). Estimations of YG_M for the EIGP, Bihar, Nepal and their environments were compared against each other to determine if there were agricultural practices that had the potential to improve yields in other parts of the EIGP.

2.5. Elite and low-performing farmers

Once we had identified agronomic practices that were important in predicting YG_F for all the farmers within a political unit or environment, we wanted to identify how the farmers with the lowest and highest YG_F used these selected practices relative to each other, and to average yielding farmers. To determine the differences in implementations of the farmers with the lowest and highest YG_F, we isolated the farmers that were the top 10% of YG_F in each political unit and environment, as well as the lowest 10% YG_F values. These top farmers we identified as “elite farmers”, while those in the bottom 10% were identified as “low-performing farmers”.