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Prioritizing climate-smart agricultural land use options at a regional scale

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ABSTRACT

The promotion of climate-smart agriculture in different parts of the world requires a clear understanding of its relative suitability, costs and benefits, and the environmental implications of various technological interventions in a local context under current and future climates. Such data are generally difficult to obtain from the literature, field surveys and focused group discussions, or from biophysical experiments. This article describes a spreadsheet-based methodology that generates this information based on a region specific production function and 'target yield' approach in current and future climate scenarios. Target yields are identified for homogeneous agroecological spatial units using published crop yield datasets, crop models, expert judgement, biophysical land characterisations, assessment of yield gaps and future development strategies. Validated production/transfer functions are used to establish relationships between inputs (water, seed, fertilizer, machinery, energy, labour, costs) and outputs (crop yields, residues, water and fertiliser use efficiencies, greenhouse gas emissions, financial returns). The process is repeated for all spatial units of the region, identified through detailed mapping of critical biophysical factors, and for all suitable current and potential agronomic production technologies and practices. The application of this approach is illustrated for prioritizing agronomic interventions that can enhance productivity and incomes, help farmers adapt to current risk, and decrease greenhouse gas emissions in current and future climates for the flood- and drought-prone state of Bihar in north-eastern India. In general, climate smartness increases with advanced technologies. Yield is the least limiting while emission is the most limiting factor across the entire crop-technology portfolio for climate smartness. Finally, we present a robust climate smart land use plan at district level in Bihar under current and future climate scenarios.

1. Introduction

South Asia has witnessed robust economic growth over the past 20 years, yet it is home to more than one-fourth of the world's hungry and 40% of the world's malnourished children and women. Persistent climatic variability, which results in frequent droughts and floods, is among the major reasons for this. Climate change, manifested by depleting glaciers, increasing coastal erosion, frequent heat waves, rising sea level, frequent floods and droughts and varying rainfall patterns, is projected to exacerbate the existing pressures on land and water resources. Several global as well as regional studies have indicated that the productivity of food crops, livestock and fish may decline even in the short-term with significant effects later in the century, if corrective actions are not taken now to improve our adaptive capacity (Aggarwal, 2008; Naresh Kumar et al., 2013; Rosenzweig et al., 2014). Since these impacts on agricultural production influence poverty levels, especially in South Asia where >500 million people directly depend on agriculture for a living, it is evident that climate change can worsen poverty in the region. There is, therefore, an urgent need to develop strategies that can incentivise land use that would meet future food demand, increase farmers' income, build resilience, and wherever possible reduce emissions (FAO, 2010; Lipper et al., 2014).

Several technological interventions and policy measures may be able to bring about this transformation. Changes in agronomic practices, adoption of the new technologies and the use of relevant information (e.g. climate information based agro-advisories and weather index based insurance) at the farm level can be key components in improving the adaptation of agriculture to climate change (Byjesh et al., 2010; Naresh Kumar et al., 2014; Naresh Kumar and Aggarwal, 2013; Parihar et al., 2016). These options can significantly improve crop yields, increase input-use efficiencies and net farm incomes, and reduce greenhouse gas emissions (Smith et al., 2007). Many of these interventions

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have been successful in increasing production, income and building resilience among farming communities in many areas such as the Indo-Gangetic plains (Parihar et al., 2016). These interventions, however, come with varying costs and economic impacts, and their implementation requires critical investment decisions in relation to both on-farm capital and wider agricultural outreach programs. Their implementation also requires an understanding of trade-offs and synergies among them. Selecting appropriate interventions for maximizing the synergies and reducing the trade-offs requires decision support tools to facilitate identification of portfolios of appropriate technological interventions. Climate change associated uncertainties add to the complexity of prioritizing technologies. Further, this makes prioritization data hungry and complex. Since developing countries have invariably limited capital and resources to invest, there is a need to choose interventions that can meet multiple goals of development. At the same time, it is important to ensure that our actions today to promote adaptation do not lead to increased maladaptation or inequity in society over the long term.

There are relatively few studies in the literature showcasing work on prioritizing climate-smart agriculture interventions (Brandt et al., 2015; Tendall and Gaillard, 2015; Webber et al., 2014; Claessens et al., 2012). A key reason for limited studies on this subject is difficulty in obtaining data that can facilitate the analysis of changes in local biophysical characterization and production economics with the top-down policy changes and regional land-use. The typical minimum dataset required are economic yields of various commodities and the inputs used, such as irrigation and fertiliser, to produce them in different regions over several crop seasons. At the same time, the data should provide an assessment of costs and benefits, carbon sequestration and GHG emissions in order to understand the mitigation potential of various interventions. Traditional methods of research such as field and stakeholders' surveys, focused group discussions, regular national yield monitoring trials, and agronomic trials are generally inadequate to provide sufficient data to understand the synergies and trade-offs among production, resilience and mitigation in current and future climate conditions.

Several recent studies have shown the application of production functions, crop simulation models, and field experiments to generate such data for a region for food security planning (Shaffer et al., 2000; Aggarwal et al. 2001; Louhichi et al., 2010; Alary et al. 2016; Claessens et al., 2012; Webber et al., 2014; Tendall and Gaillard, 2015; Belhouchette et al., 2011; Rigolot et al., 2016). These bio-economic modelling studies used multiple approaches to generate input-output data for land use prioritisation for food security planning and other developmental goals. None of these studies, however, considered a climate-smart agriculture perspective, in particular GHG emissions. Several tools are now available that are able to provide quick estimates of GHG emissions of various agronomic interventions (Hillier et al., 2011). In this paper, our objective is to provide a spreadsheet based methodology to generate production, economic and environmental databases of agronomic interventions for different regions and for different climate change scenarios. The database developed here integrates from process based models (crop simulation models), weather generators and downscaler, tools and calculators (emission calculators, irrigation requirement calculators etc.). Since the dataset is a result of integration of different approaches, it is rich in information on biophysical and economic parameters. It characterizes current agricultural production processes and their dynamics for all districts at land unit scale in Bihar in relation to different climate change scenarios (RCPs). This dataset itself can lead to meaningful inferences for prioritizing interventions, regardless of any optimization framework, by exploring adaptation strategies for climate change though land unit or district-level analysis. Here, we present a simple agroecological analysis from the policy planning perspective for prioritizing a crop-technology portfolio across 38 districts in Bihar. The specific objective is to identify combinations of crop technology and district (agricultural land use) that lead to increases in productivity and income, and decreases in GHG emissions intensity.

2. Materials and methods

Bihar is located in the north-eastern part of India. It has geographic area of 94,163 km^2 divided into two parts by the river Ganges that flows from west to east. Over 66% of the geographic area is cultivated. Agriculture in Bihar is characterised with low productivity, substantial yields gaps, and high uncertainty and instability in production. There is a high proportion of small, marginal and landless farmers. Cropping intensity is also low (<1.4). About 60% of the gross cropped area is irrigated; tube wells are the main source of irrigation followed by canal irrigation. Bihar has a diverse climate and is prone to high climatic risks in terms of both deficit as well as excessive rainfall. Several climatic scenarios indicate the likelihood of increase in temperatures and huge shifts in rainfall patterns. The increasing temperature and changes in rainfall patterns can adversely affect the productivity and profitability of agricultural systems in the state.

2.1. Evaluation of regional resources, constraints and delineation of land units

Quantitative resource assessment remains a prerequisite for developing input-output relationships for identifying climate smart agricultural land use options. In this study, we demarcated 34 homogenous spatial units for quantitatively describing the input-output relations of the various crops and livestock activities by overlaying biophysical layers of soil texture class, drainage, flooding, rainfall and temperature (Fig. 1). Since most of the socio-economic baseline data is available at political boundary scale, we superimposed district boundaries on these 34 zones, which resulted in 194 land units; the smallest units of assessment in this study. Each land unit within an administrative block (here district boundary) differs from another by at least one biophysical attribute. This helps to characterise biophysical responses in the production process.

In the above process, soil datasets of National Bureau of Soil Survey and Land Use Planning (NBSS&LUP, 2002) at 1:1 million scale were used. This included attributes relating to information on soil depth, texture, soil pH, land drainage class and susceptibility to flooding. Soils in Bihar are dominantly sandy and loamy; however, in the southern part clay soils are dominant. Information on soil organic carbon, pH, electrical conductivity, Olsen P and available K were taken from Sharma et al. (2012). Flooding is one of the most important limiting factors in Bihar's agricultural production system during *Kharif* (rainy season) and to some extent in *Rabi* (winter season). About 41% of the total cropped area in the state is flood prone (Flood Management Information System, Government of Bihar, http://fmis.bih.nic.in/). We used long-term 10 min gridded average temperature and rainfall for Bihar based on the WorldClim dataset (Hijmans et al., 2005).

2.2. Production technology characterisation

Eight major crops, covering 90% of the gross sown area, dominate Bihar's agriculture land use. These crops are rice in rainy season (*Kharif*), Mung bean (Green gram) in summer, wheat, gram, mustard, lentil, and *khesari* (Lathyrus) in winter (*Rabi*) season, and maize in all three seasons. The suitability of these crops in different land units vary depending upon soil, water and climate. This was assessed based on expert judgement and land units unfit for a given crop were excluded from further analyses.

Crop yields in a land unit depend on its soil, climate, technology and related agronomic and monetary inputs. Farmers of Bihar follow several practices and technologies for various crops. In this study, we have considered 10 production technologies for all eight crops listed above. The baseline yields for irrigated and rainfed systems are denoted as T1 and

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