Climatic and non-climatic factors influencing changing agricultural practices across different rainfall regimes in South Asia

Gopal Datt Bhatta[1,2,*], Pramod Kumar Aggarwal[1], Patti Kristjanson[3] and Amit Kumar Shrivastava[4]

[1]CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), South Asia, and International Water Management Institute, New Delhi Office, NASC Complex, DPS Marg, Pusa, New Delhi 110 012, India
[2]Present address: Research and Reporting, Calgary Neighbourhoods, The City of Calgary, Alberta T2P2M5, Canada
[3]World Agroforestry Centre (ICRAF), PO Box 30677, Nairobi, Kenya 00100
[4]International Maize and Wheat Improvement Center, New Delhi 110 012, India

Using data from a household survey of 2660 farm-families in Bihar state of Eastern India, Terai of Nepal and coastal Bangladesh, we explore the significance of climatic and non-climatic factors in affecting farmers' decision to change their farming practices over time in a wide range of environments. We find evidence across all sites, irrespective of rainfall and climatic stresses, that market-related forces (such as higher yields and better market opportunity) and resource issues (such as declining fertility, labour shortage and biotic factors) have been a strong driver of changes in farming practices over the last ten years relative to climatic factors. Food sufficient households are likely more adaptable to a changing climate, as they are undertaking new agricultural practices. The results suggest that social protection measures aimed at enhancing the food security situation of marginal and smallholder households will increase the likelihood of them being in a better position to innovate and adopt improved agricultural practices. Our findings also indicate that additional strategies and policies aimed at more widespread uptake of new agricultural practices will also be needed, and will have to be targeted to particular environments and vulnerable groups, and special attention to institutional, resource management and market development issues if they are to succeed.

Keywords: Climate change, farming practices, non-climatic drivers, rainfall regime, South Asia.

Introduction

SOUTH Asia, home to over one fifth of the world's population, is known to be the most disaster-prone region in the world[1]. High population growth accompanied by resource degradation, rising poverty levels and food insecurity make South Asia extremely vulnerable to the impacts of climate change[2]. Agriculture in South Asia forms the livelihoods base of the world's largest concentration of poor people. Alleviating poverty and attaining food security at household and national levels is thus a major challenge in the region. Climate change is likely to compound this situation further[3]. An increase in occurrence of extreme weather events including heat waves and intense precipitation is projected in South Asia[4], along with an increase in the inter-annual variability of daily precipitation, particularly in the monsoon season[5–7].

The Indo-Gangetic Plain (IGP) region is considered a 'bread-basket of South Asia'. However, the region is highly vulnerable to climate change due to its huge population, a largely agrarian economy, a relatively limited and depleting resource base, and projected large changes in climatic risks[8–10]. While many farmers in Nepal's Terai (plains) and Bihar state of India suffer from frequent droughts, cold spells and intermittent floods, the coastal area of Bangladesh is a 'hotspot' of climate change (frequent floods, salinity, sea-level rise and cyclones)[11]. Furthermore, a majority of the farmers in the IGP are smallholders and involving them in the process of agricultural transition and linking them to new opportunities to share the benefits of such a transition is a major policy challenge.

Farmers in the IGP have been testing and adopting new agricultural practices for many years[12]. Many adaptive practices serve multiple purposes and are often interlinked[13,14]. Several researchers[15–19] have questioned whether the importance of climatic drivers relative to non-climatic forces is really significant. Others have highlighted the greater importance of non-climatic drivers compared to climatic stressors where local adaptation to changing circumstances is concerned[20–23]. Household food insecurity, for example, has been found to be a key factor limiting the ability of many poor rural households to improve their farming practices[24]. Similarly, wealth can be significantly related to the likelihood of change in farming practices[25]. For instance, households with higher

*For correspondence. (e-mail: bhattagopal@gmail.com)

asset profile are more likely to take up new farm interventions than those with poor asset profile. There is in fact relatively little evidence helping us to better understand what incentives and interventions, in different environments, will lead to enhanced adaptive capacity and resilience of smallholders to a changing climate.

To address this knowledge gap on climate resilient agriculture and the influence of climatic and non-climatic factors in uptake of new agricultural practices, we explore recent evidence from across IGP's climate 'hotspots', based on data from a comprehensive household survey of 2660 farm-households in 3 countries of the IGP (Bihar state of Eastern India, coastal Bangladesh and Terai of Nepal). As the interaction between climatic and non-climatic factors in agriculture is immensely complex, the focus was not to measure the relative weight of these factors on changing farm-related practices and food sufficiency. It simply aims at assessing the general significance of these factors in contributing to local adaptation by analysing the large portfolio of farm-related changes over the last 10 years and the key reasons of making such changes across different resource profiles (mainly land size, annual rainfall and innovativeness). This exploration of the various factors influencing households' choice of farming practices across a diverse range of sites will contribute to a better understanding of just how targeted adaptation strategies and policies need to be, and what kind of interventions may help stimulate more widespread adoption of climate resilient agricultural practices.

Methods and data

Site characteristics

A household survey was implemented in 2011–12 in the three broad agroecological zones of IGP with an average annual rainfall ranging from 930 to 3350 mm. The sites surveyed (Table 1) lie in the eastern region, which is characterized by relatively lower productivity, poorly developed infrastructure, food insecurity, and smallholder subsistence farming, and is prone to flooding and droughts[8]. Bihar represents an increasing temperature over the years, decreasing rainfall, increasing depth of groundwater and more erratic rainfall events. Terai of Nepal faces frequent floods and droughts, cold spells and westerly wind during wheat grain filling period. Coastal Bangladesh, on the other hand, is highly vulnerable to climate change. Salinity, sea level rise, floods and shortage of fresh water are common climatic issues in coastal areas of Bangladesh. The rainfall data were obtained from the Worldclim database. The annual rainfall in IGP varies from almost 500 to 3500 mm per year. Although the study sites fall under humid to subhumid tropics, we break it down further, using Kerr's classification in which areas receiving an average of 750–1125 mm annual rainfall are considered the medium rainfall zone[26]. Accordingly, areas receiving 900–1500 mm annual rainfall ($n = 1260$ sampled households) fall in the moderate rainfall zone, 1500–2100 mm ($n = 980$) is the high rainfall zone, and with the very high rainfall zone receiving >2100 mm ($n = 420$). All sites in Bihar fall in the moderate rainfall regime, most of the sites in Terai are under the high rainfall regime (three out of five sites) and many sites in coastal Bangladesh are within the very high rainfall regime (four out of seven sites) (Table 1).

Sampling process

The survey sites were selected based on a range of criteria such as rainfall and temperature; availability of the network of regional partners to facilitate scaling up of climate resilient, often referred to as 'climate smart' agriculture (CSA) interventions[27]; and potential for mitigation and/or carbon sequestration[28].

The sampling process involved first selecting a region within each target country considered to be highly susceptible to climate change with many highly vulnerable households (Bihar in India, Terai in Nepal and the coastal zone in Bangladesh). Within these large areas, smaller areas (mostly districts) were selected based largely on the

Table 1. Bio-physical characteristics of the sites (values in the parenthesis indicate average annual rainfall, mm)

Sub-regions	Description and the sites
Bihar, India	Highly fertile soil, small and fragmented landholdings, frequent floods and droughts, rice–wheat cropping pattern predominant, average temperature increasing, rainfall decreasing, soil fertility decreasing and erratic rainfall observed. Sites: Bihta (933), Piro (963), Jamui (1016), Nautan (1041), Pusa (1104), Madhepura (1151), Katihar (1278).
Coastal Bangladesh	Mostly low-income agricultural workers, salinization of water, salinity intrusion increasing due to sea-level rise, shortage of freshwater for irrigation in the dry season, aquaculture a primary source of livelihoods but rice–rice pattern also popular in the feasible landscape. Sites: Satkhira Sadar (1710), Satkhira Shyamnagar (1747), Khulna (1762), Bagerhat (2061), Jhalokathi (2330), Potuakhali (2659), Cox's Bazar (3349).
Terai, Nepal	Tropical climate, highly fertile soil, major supplier of the foods in the country, frequent floods and droughts, westerly wind during wheat grain filling period, cold spells increasing, overall rainfall almost the same but winter droughts common in many parts of the Terai and rice–wheat cropping pattern dominant. Sites: Banke (1255), Kanchanpur (1544), Rupandehi (1455), Sarlahi (1722), Sunsari (1976).

presence of potential research and development partners who could test and scale out CSA practices to a larger area. A sampling frame, consisting of a 10 km × 10 km area, was then selected purposively (this was done in order to be able to link to land health and soil carbon monitoring approaches based upon such 100 km^2 'blocks'[28]. All villages within the selected blocks/frames were enumerated and seven villages were taken randomly. Next, all household heads within each selected village were listed, based on village records and cross-triangulated with key informants. Following simple random sampling, 20 households within each village were selected. Therefore, the total sampling size was 980 households each in Bihar and coastal Bangladesh and 700 households in Terai. Although sampling of 2660 households was not designed to be representative of the entire IGP, it does capture a wide range of socio-economic and biophysical conditions found across these three regions of the three countries[28].

Survey instruments and the variables

A highly strategic baseline-oriented questionnaire was designed, tested and implemented across a wide range of sites globally. The survey questionnaire was first translated into the local languages (Hindi, Nepali and Bangla) and then back translated into English to ensure consistency in interpretation of each question. Before implementing surveys in each site, the survey team leaders and enumerators were provided with intensive training to ensure a high level of precision on sampling and data collection.

The various components of the survey include socio-economic information of the household; livelihood sources; adaptation strategies relating to crop types, crop varieties, and land and livestock management; food security; information and knowledge; and social networks. An underlying hypothesis here is that households with more diverse sources of livelihoods are in a better position to adapt to a wide range of changing local circumstances (including climate change and climatic risks). Households were also asked about the changes they made over the last 10 years with respect to a wide range of practices relating to crop types, crop varieties, and land and livestock management (there are over 55 possibilities)[24]. A rough proxy for adaptability, or innovativeness, was derived by adding up the total number of changes that each household had made over the past 10 years with respect to their farming practices. The hypothesis here is that households that have already been making changes, and are introducing new practices, are likely to be more adaptive to changing circumstances, including climatic risks, than those that have not been able to either make adjustments or introduce any innovations. The limitation of our dataset, however, is that we could not weight the changes in terms of their adaptability, link specific change to the past and with agricultural productivity. The goal is to identify broad patterns in on-farm changes; understanding detailed characteristics of particular changes will be important for future studies.

Households were asked about the reasons for making specific changes. These reasons were first grouped into six categories: market-related (higher market prices of the products, new marketing opportunities, reduced marketing costs), productivity-related (access to higher yielding crop types/varieties or more productive animal/breeds and better quality products), changes in available resources, or the quality of those resources (land, water, labour, other inputs), changes in government or non-government policies, projects or other support (including research and extension), extreme events (floods, cyclones, tides, sea level rise and high salinity), and perceived changes in weather patterns (timing or amounts of rainfall, temperature increases or decreases, fog events, etc.).

Data related to food availability during each month of the year for a 'normal' year (a year with no extreme events), and whether the food source (whether the food primarily comes from their own farm during that particular month or mainly from other sources) were also collected. We recognize that respondents' perception of each month's main food source is only a partial and imperfect proxy of food security, a broad and highly complex concept[29]. Households that are more food self-sufficient and obtaining food primarily from their own farms (including cash crop producers who primarily purchase food from the market using the returns they get by selling cash crops in the market) throughout the year, for example, are likely to be in a different position than are households that are reliant on food purchases or transfers for many months of the year. For this study we are only interested in exploring the pattern of on-farm food availability of different group of farmers (based on land size) across different rainfall regimes.

Data analysis

We examined relationships between the number of changes in farm practices and food sufficiency months across different rainfall gradients and farm sizes. However, because of a narrow range of rainfall variation within sites, the interest is not to capture a causal relationship, but to see whether any trends can be observed across rainfall gradients. Farm households owning less than 1 hectare (ha) of land were categorized as marginal farmers ($n = 1790$), those owning 1–2 ha as smallholder farmers ($n = 514$), 2–5 ha as medium holder farmers ($n = 202$) and more than 5 ha as large holders ($n = 54$)[30]. As the number of large holder farmers were negligible (almost 2%), they were not included in the analysis. In terms of farm sizes, a large number of the farmers across

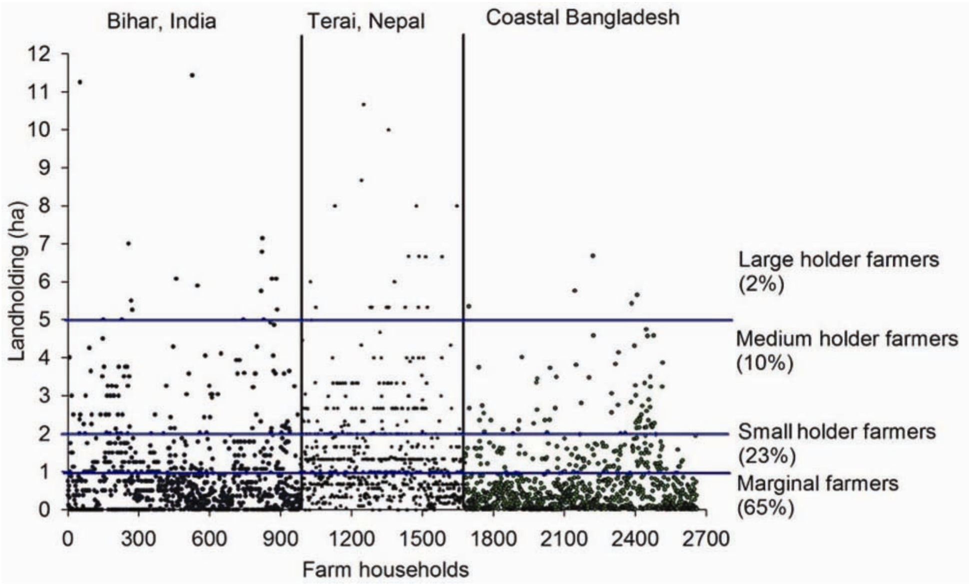

Figure 1. Distribution of farm sizes across the surveyed households.

the region have marginal farms of less than 1 ha (65%), followed by smallholders (23%) and medium holders (10%). There are slightly more large-scale farms in Terai (4%) as compared to Bihar and coastal Bangladesh. Almost 80% of the farms in coastal Bangladesh are less than one hectare (Figure 1).

Data related to the number of changes in farming practices over the last ten years were disaggregated by land size and rainfall regimes. Households were categorized as follows: those making few changes (<10 changes, $n = 1186$), a moderate number of changes (10–15 changes, $n = 1052$) and a high number of changes (>15 changes, $n = 422$). The number of changes in farming practices due to climatic, market, resource, policy and productivity-related reasons was subjected to a Kruskal–Wallis H test, a non-parametric test equivalent to the one-way ANOVA, and an extension of the Mann–Whitney U test. It allows the comparison of more than two independent groups. As the Kruskal–Wallis test does not assume normality in the data and is much less sensitive to outliers, it can be used when these assumptions have been violated[31]. As groups are not equal in size, Post Hoc Paired Comparisons were performed using Tamhane's T2. A significance level of 0.05 was fixed using the Monte Carlo method.

Results and discussion

Farming practice changes

Among the changes made in farming practices across IGP, the most common one was changing at least one crop variety in the last decade, as reported by over 80% of households from all three countries. The frequency in changes made in the timing and methods of planting (e.g. later planting, earlier planting/land preparation and a shift to mechanized planting) vary across the regions. While 45% of households in coastal Bangladesh reported making changes with respect to their planting times and methods, 65% and 75% of surveyed households made such changes in Bihar and Terai respectively (Table 2). More households in Bihar (80%) and Terai (87%) made changes in crop management practices (irrigation use and methods, agrochemical use, disease and pest management) than in coastal Bangladesh (64%). The vast majority of households (93%) reported making changes in their livestock management practices (including fisheries) in coastal Bangladesh. Although frequent cyclones, increasing salinity, floods and storm surges increase vulnerability of agriculture in coastal areas of Bangladesh[32], the data suggest that the crop types/varieties/management practices are changing less frequently than livestock and fisheries management practices.

Late or early planting, adopting new crops and/or varieties, introducing legumes in rotations, and planting improved, disease- and pest-tolerant varieties are the most frequently cited changes being made to farming practices in these surveyed areas. While we did not attempt to isolate climate-resilient practices per se, it does appear that these shifts are related to rainfall and water-related constraints. Other studies show that in certain parts of Nepal's Terai and India, many households have shifted to rice varieties that require less water and/or that can be sown at a later date to adapt to rainfall variability[33,34]. Strategies such as adjusting planting dates and new varieties have been found to contribute to climate change adaptation[35–37]. A wide range of improved practices that have been shown to increase agricultural adaptation

Table 2. Per cent of households that reported changing at least one farm-related practice in the last 10 years

Changes in farming practices	Bihar (n = 980)	Coastal Bangladesh (n = 980)	Terai (n = 700)
Crop variety	81	83	85
Planting time and methods	65	45	75
Crop management (irrigation, fertilizer, pesticide)	80	64	87
Livestock management	54	93	50

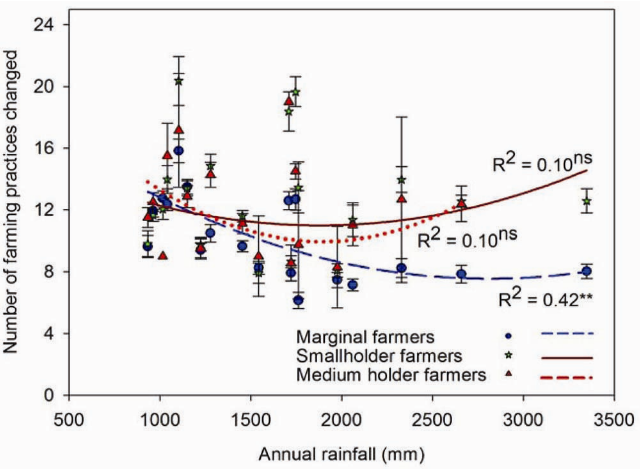

Figure 2. Relationship between farming practice changes, farm size and annual rainfall [**Highly significant ($p < 0.01$); *Significant ($p < 0.05$); ns, Non-significant ($p > 0.05$)].

to climatic risk are resource-conserving technologies (zero tillage practice introduced in certain parts of Nepal's Terai and Bihar for instance), various approaches for enhancing water use efficiency, expansion of areas under cultivation to compensate for reduced yields during droughts and switching to more drought tolerant crops[38]. Other farming practices that help deal with climatic risks are improved pasture and livestock management strategies, introduction of crop cover or mulching, planting trees on-farm (agroforestry) and the adoption of new crop varieties that are flood tolerant, disease and pest resistant, or shorter cycle, among others[24].

Our data show that a larger number of farming practices have changed over the last ten years on small and medium-sized farms compared to marginal farms (Figure 2). On average, around 9, 11 and 12 changes in farm-related practices are made by marginal, smallholder and medium holder farmers respectively. Many smallholders lack the capability to invest in soil fertility management and other inputs[39,40]. This suggests that efforts and adaptations being pursued by the lowest income groups (e.g. living on marginal and small farms) may be considered to basically be 'survival strategies'[41].

On average, 12, 10 and 10 changes in farm-related practices are made in moderate, high and very high rainfall regimes respectively. In all cases the relationship between rainfall and number of farm practices changes is polynomial and highly significant ($R^2 = 42$, $p < 0.01$) for small/marginal farms. In other words, small/marginal farmers in moderate rainfall areas have been undertaking more farm-related changes than their counterparts in high and very high rainfall areas. This is counter-intuitive given the resource constraints that households with small landholdings face[30]. A strong extension or project-related effort in these areas might be a possible explanation. For instance, households in Bihar (a moderate rainfall area) receive government support, and there are multiple projects and non-governmental organizations (NGOs) supporting marginal households in Terai.

Many of these marginal farm households (30%) actually live in very high rainfall areas of coastal Bangladesh. Salinization[42] and flooding due to sea-level rise and intrusion of salt water into groundwater aquifers are responsible for low land use and cropping intensity across this zone[43]. These farming households with limited land also face high risks in investing in new agricultural practices that will help them adapt to a changing climate.

Reasons for making changes to farm practices

Changes in farm practices are rarely made due to one factor alone, so determining the key drivers of change is challenging. We found that market-related factors such as higher market prices of the products, new marketing opportunities and reduced marketing cost are more frequently cited as reasons behind changing farm practices than are climate-related factors, irrespective of the rainfall regime and farm size. Seeking better yields (as reported by 70% of respondents), through switching crops and/or adopting improved varieties, remains the most frequently cited reason for making changes in farming practices across all regions. Issues related to land (e.g. declining soil fertility), labour (e.g. labour shortages), water (e.g. groundwater decline) and biotic factors (e.g. pest and disease outbreaks in the particular crop and/or variety) are also frequently mentioned as reasons for making changes regarding crop types and/or varieties (Table 3).

In terms of climate-related factors, we found that perception of declining total rainfall amounts was the most frequently cited reason for making changes in farming practices in all areas (reported by around 13% of households). There is a distinct spatial difference in this finding, however. Roughly 23% of households in Bihar reported making changes in farm practices because of

Table 3. Per cent of households with specific reasons for making farming practice changes (shaded rows represent changes made due to climatic reasons)

Reasons	Bihar, India (n = 980)	Coastal Bangladesh (n = 980)	Terai, Nepal (n = 700)	Total (n = 2660)
Higher yield/production	78	54	28	70
Market related	21	30	27	27
Resource issues (land and labour)	38	21	24	28
Biotic factors (pest/diseases)	17	21	20	19
Research and extension (policy changes, project supports, extension)	8	5	10	7
Lower groundwater table	9	0	0	3
Erratic rainfall	9	7	1	6
Less overall rainfall	23	11	1	13
Frequent droughts	6	12	2	7
Frequent floods	0.3	17	0.2	6
More cold spells, fogs, clouds	3	13	5	7
Increasing temperature	2	0.2	0.2	1
More cyclones	0	18	0	7
Higher salinity	0.4	25	0.3	10
Higher tides	0	4	0	1

decreasing overall rainfall levels, while only 11% and 1% of the farm households reported this in coastal Bangladesh and Terai respectively.

Farmers have also been making changes in order to adapt to the frequent droughts and floods experienced in many parts of IGP over the last 10 years. Similarly, farming practices have been adjusted in response to increasing cold spells and fogs, particularly during the winter season in many sites. Another issue of concern, particularly to Bihar, has been a depleting groundwater table, requiring changes in irrigation methods. Coupled with changing rainfall patterns, a lowering groundwater table severely challenges traditional household livelihoods. Sufficient water supplies, from rainfall and/or from groundwater sources for irrigation, are fundamental to food security, making policies and investments supporting adaptive practices related to agricultural water and irrigation critical. Bangladesh households, in particular, mentioned about making changes in their farming practices to cope with extreme weather events such as floods, cyclones, high tides, sea level rise and increased saline water intrusion (Table 3). Changes in government policies, including research and development investments, programmes and projects, have also influenced households' behavioural changes to a rather limited extent.

Reasons for making farm-related changes were analysed across land holding size, rainfall regimes and innovativeness (Table 4). On average, the number of farm-related changes corresponding to productivity motives, market-related drivers, those related to resource availability, climate-related drivers (including extreme events), and policy-related factors were 7, 8, 9, 6 and 2 respectively, over the last 10 years in all studied sites.

We found a significant difference across land size in terms of the reasons given for making farm practice changes. On average, households made at least one change, and many made more changes to their farming practices over the past 10 years. A large number of these changes were in response to changes in resource access and availability (e.g. soil fertility decline, labour scarcity, groundwater decline and disease and pest infestation), followed by market-related reasons (such as higher prices and/or better marketing opportunities), and productivity-related factors (e.g. availability of improved crops/varieties and more productive animal species/breeds). Medium-sized and smallholder farmers made significantly more changes than did marginal landholders.

We found that more households have changed their farming practices in response to the productivity related drivers in the areas with moderate rainfall compared to the areas with higher rainfall. Table 3 also depicts that households in Bihar (moderate rainfall area) have made several changes to farming practices to harvest higher yield (around 78% reported changes in varieties) than that in Terai (28%) and coastal Bangladesh (54%). Most of the changes reported in the very high rainfall areas, however, can be attributed to market, resource, climate and extreme events. This is further substantiated by the fact that relatively more percentage of the households have made changes to farming practices to adapt to changing market, resources, climate and extreme events in Terai and coastal Bangladesh (high to very high rainfall regimes) (Table 3).

Households that have been making many farming practice changes are likely more innovative than those making few changes. If we compare the behaviour of farm households in terms of their innovativeness in relation to the climate-related reasons cited as being behind those changes, we see that more innovative households made ten times more changes than did the less innovative

Table 4. Number of changes made in farm practices due to different reasons

	Productivity-related	Market-related	Resource-related	Climate-related	Extreme weather event-related	Policy-related
Land holding size						
Marginal (<1 ha)	1.90^b (± 0.07)	2.06^b (± 0.12)	2.25^b (± 0.18)	0.78^b (± 0.08)	0.81 (± 0.12)	0.66^b (± 0.04)
Smallholder (1–2 ha)	2.54^a (± 0.14)	2.89^a (± 0.25)	3.05^a (± 0.39)	1.08^a (± 0.18)	0.78 (± 0.21)	0.78^a (± 0.07)
Medium holder (>2 ha)	2.77^a (± 0.21)	3.00^a (± 0.37)	3.34^a (± 0.54)	1.05^a (± 0.26)	1.10 (± 0.34)	0.83^a (± 0.09)
Chi-square	109**	56**	120**	8*	2^{ns}	15**
Annual rainfall (mm)						
Moderate (900–1500)	2.33^a (± 0.1)	2.07^c (± 0.13)	2.53^b (± 0.25)	0.86^b (± 0.09)	0.02^c (± 0.01)	0.68^b (± 0.04)
High (1500–2100)	1.95^b (± 0.11)	2.42^b (± 0.2)	2.00^c (± 0.23)	0.74^b (± 0.12)	1.42^b (± 0.21)	0.80^a (± 0.05)
Very high (>2100)	2.00^b (± 0.2)	3.00^a (± 0.44)	4.00^a (± 0.44)	1.22^a (± 0.23)	1.94^a (± 0.37)	0.53^c (± 0.07)
Chi-square	14**	52**	30**	419**	36**	59**
Innovativeness (number of farm practices changed)						
Less (<10)	1.05^c (± 0.07)	1.00^c (± 0.09)	1.54^c (± 0.16)	0.25^c (± 0.04)	0.84^c (± 0.16)	0.68 (± 0.07)
Moderate (10–15)	2.68^b (± 0.09)	2.89^b (± 0.16)	2.58^b (± 0.26)	0.89^b (± 0.11)	0.81 (± 0.17)	0.72 (± 0.05)
High (>15)	3.81^a (± 0.15)	4.75^a (± 0.34)	4.52^a (± 0.48)	2.58^a (± 0.31)	0.92 (± 0.21)	0.75 (± 0.08)
Chi-square	981**	711**	590**	472**	2^{ns}	3^{ns}

**Highly significant ($p < 0.01$); *Significant ($p < 0.05$); ns, Non-significant ($p > 0.05$). Letters in superscript show significant difference between the groups at 5% level of significance according to Kruskal-Wallis test.

households, and almost three times more changes than moderately innovative farmers. This suggests that more innovative farmers, although driven by non-climatic reasons (up until now) to a greater extent than climatic ones, may in fact be in a much better position to adapt to climatic variability, whereas less innovative farmers still are not making the kinds of behavioural changes that will put them in a better position to be able to adapt to the increasing climatic risks they are facing. However, our data present reported changes along with the specific reason(s) why households have made those changes; but not whether a change is adaptive. It certainly implies that a change confers some benefit to the farmer who made that change[25]. Although the number of changes made over the period of last ten years does not fully reflect adaptive capacity, it may offer insight into the ability of these farm households to make future changes in response to risk. Thus, these changes and farmers making those changes present a scenario of potential adaptation.

Household on-farm food sufficiency

The relationship between on-farm food sufficiency, land size and average annual rainfall is explored in Figure 3. There is large across-site variation in on-farm food sufficiency, but the survey results show that the majority of farm families in Bihar (moderate rainfall zone) and Terai (moderate to high rainfall zone) are producing enough food to support themselves throughout the year (75% and 80% of the farm households in Terai and Bihar respectively, are self-sufficient). In these two sites, almost half of the households surveyed have irrigation, reducing their risks due to rainfall variability and allowing them to diversify their cropping systems[44]. Some of the farm households in these sites are located nearby agriculture market and they have a tendency to produce cash crops. Cash crop producers use a portion of returns to buy foods from the market, and hence these households are also considered to be food sufficient provided they could afford food purchases using returns from cash crops. Lower crop productivity, marginal farm sizes and fewer livelihood sources all contribute towards shorter periods of on-farm food availability in coastal Bangladesh. In addition, seasonal flooding due to heavy monsoonal rains along with salinity intrusion causes frequent crop failures here[43], compounded by a lack of fresh water for irrigation during the dry season, limiting agricultural diversification options. These unique constraints in coastal Bangladesh limit strict comparability with the agriculture adaptation strategies being pursued under the more moderate conditions that predominate in most of the surveyed areas of India and Nepal.

Our analysis shows that farm size does matter in terms of on-farm food self-sufficiency. The households with medium-sized farms, i.e. 2–5 ha, are producing enough food to feed their families throughout the year (11.75 months) (Figure 3). Marginal and smallholder households have fewer months of food self-sufficiency in a typical year (on an average, from 9.25 to 11 months with adequate amounts of food).

Figure 3 shows a polynomial-shaped relationship between annual rainfall and number of food sufficient months across all land sizes. Medium-size farms are virtually food sufficient year-round and thus we see no significant relationship between these variables. However, there is a significant relationship in the case of smallholders ($R^2 = 23$, $p < 0.05$) and marginal farmers ($R^2 = 43$, $p < 0.01$). For these households, we see an initial counter-intuitive declining trend in food self-sufficiency with increasing rainfall and then a gradual increase (for marginal farmers) at around 2400 mm. This suggests that

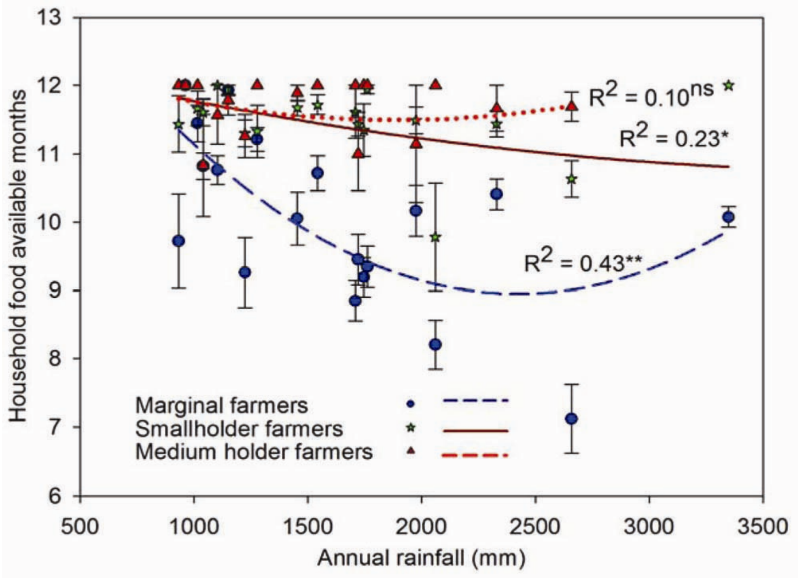

Figure 3. Relationship between on-farm food sufficiency, land size and average annual rainfall [**Highly significant ($p < 0.01$); *Significant ($p < 0.05$); ns, Non-significant ($p > 0.05$)].

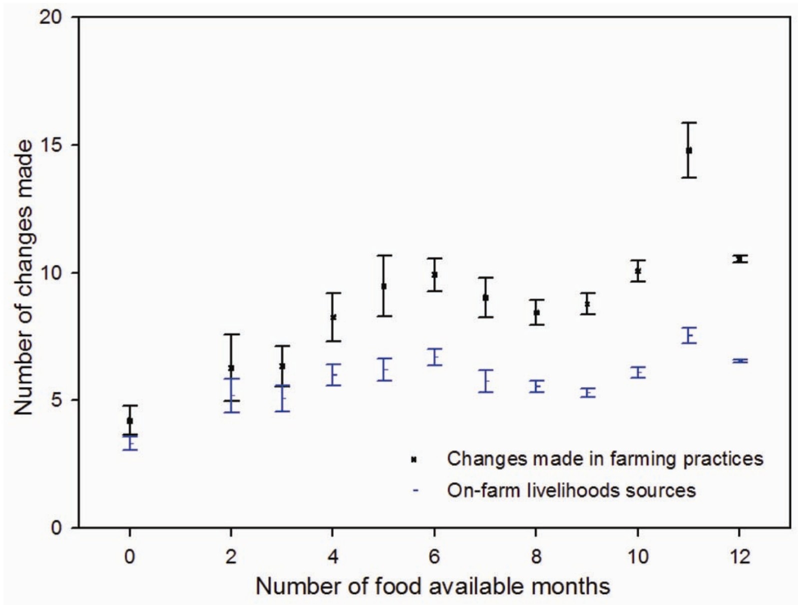

Figure 4. Relationship between household food self-sufficiency and farming practice changes.

these households may be affected by additional agricultural production risks found in high rainfall areas (e.g. increased pest and disease risk, seasonal inundation, salinity and lack of fresh water for irrigation, among others).

Figure 4 shows the relationship between the numbers of months for which households are producing enough food to meet their own needs and the number of farming practices changes made over the last ten years. It indicates that food self-sufficient households are more innovative/adaptive, i.e. are making more changes. Since this is not a causal study, it is not possible to identify the direction of the relationship. It is, therefore, possible that the households investing in new and diverse practices are likely to be more food secure[24]. Figure 4 also indicates that more on-farm livelihood sources (i.e. on-farm diversification) are also positively related with innovativeness.

Conclusions

Whereas the spatial and temporal variability of rainfall and its relation to agricultural production is fairly well studied, the specific role rainfall plays with respect to household food sufficiency and adaptation strategies is less so. Historically, households have been making changes in their farm practices, but the specific reasons why they make such changes is an area where there is little evidence. This analysis attempts to fill this gap by examining the relationship between annual rainfall, changes in farm practices and food self-sufficiency proxies for 2660 households across a diverse range of IGP sites.

Somewhat non-intuitively, we found that households located in medium rainfall areas (900–1500 mm) have been making more farming practice adaptations in response to their changing environments than those located in areas of higher average annual rainfall. The most innovative households are also the ones that are more food self-sufficient. It seems that households in the highest rainfall areas face significant additional challenges including seasonal flooding, high salinity and more frequent weather-related extreme events.

Issues related to changes in access and availability of key resources, including soil/land degradation, declining farm sizes, labour scarcities, depleting groundwater resources, and increased susceptibility to pests and diseases are found to be key factors behind behavioural changes in farming practices across all rainfall regimes, different farm sizes and degrees of innovativeness. To deal with a rapidly changing environmental, social and economic condition, households were found to change their farming practices in response to market-related and climate-related drivers included in this study.

This analysis shows that households who pursue more on-farm livelihood options (i.e. are more diversified) also tend to be more innovative, i.e. they are making more changes in their farming practices. Thus they are the ones best able to deal with the new challenges posed by a changing climate. And also not surprisingly, households with relatively larger landholdings have made more changes to their farming practices and are more food secure in terms of the number of months where they are able to rely on production from their own farms.

We are able to learn from the similarities and the differences we have found across these diverse agricultural production systems. The uniqueness of floods and salinity issues in Bangladesh is one example. The declining groundwater threat in Bihar is another. But food security remains a serious problem across these countries. A baseline survey, by definition, is broad and shallow. It is able to highlight particular areas where more in-depth, targeted research is needed. Opportunities highlighted by this analysis include the following:

- Social protection measures aimed at enhancing the food security situation of marginal and smallholder farming families will increase the likelihood that they will be in a better position to innovate and adopt improved agricultural practices.
- More investment in participatory action research with farmers (including women and youths) aimed at identifying appropriate diversification and 'climate smart' agricultural options that enhance food self-sufficiency and the resilience of households to a changing climate is needed, e.g. improved home gardens, livestock and fish management strategies, agroforestry, all can potentially enhance food security and the resilience of households to a changing climate.
- The emphasis of agricultural research, policy and development agencies dealing with climate change and risk management for smallholder farmers should not remain only on adaptation strategies at the farm level, as this analysis highlights that there remain many policy, resource management, institutional and market-related issues to address if we want to see much more widespread uptake of new agricultural practices resulting in enhanced resilience to climate risk and in the longer run, a changing climate.

1. UNEP, *GEO Year Book 2003*, United Nations Environment Programme, UNEP, Nairobi, 2003.
2. Sivakumar, M. V. K. and Stefanski, R., Climate change in South Asia. In *Climate Change and Food Security in South Asia* (eds Lal, R. *et al.*), Springer Science + Business Media B.V., 2011, p. 600.
3. Nelson, G. C. *et al.*, Climate change: impact on agriculture and cost of adaptation. Food Policy Report 21, International Food Policy Research Institute (IFPRI), Washington DC, USA, 2009.
4. Lal, M., Global climate change: India's monsoon and its variability. *J. Environ. Studies Pol.*, 2003, **6**, 1–34.
5. Lal, M., Meehl, G. A. and Arblaster, J. M., Simulation of Indian summer monsoon rainfall and its intraseasonal variability. *Reg. Environ. Change*, 2000, **1**, 163–169.
6. May, W., Simulation of the variability and extremes of daily rainfall during the Indian summer monsoon for present and future times in a global time slice experiment. *Climate Dyn.*, 2004, **22**, 183–204.
7. Giorgi, F. and Bi, X., Regional changes in surface climate interannual variability for the 21st century from ensembles of global model simulations. *Geophys. Res. Lett.*, 2005, **32**, L13701.
8. Aggarwal, P. K., Joshi, P. K., Ingram, J. S. I. and Gupta, R. K., Adapting food systems of the Indo-Gangetic plains to global environmental change: key information needs to improve policy formulation. *Environ. Sci. Pol.*, 2004, **7**, 487–498.
9. Saini, H. S., Climate change and its future impact on the Indo-Gangetic Plain (IGP). *E.-J. Earth Sci.*, 2008, **1**, 138–147.
10. New, M., Rahiz, M. and Karmacharya, J., Climate change in Indo-Gangetic agriculture: recent trends, current projections, crop-climate suitability, and prospects for improved climate model information, CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark, 2012.
11. Nicholls, R. J. *et al.*, *Coastal Systems and Low-Lying Areas*, Cambridge University Press, Cambridge, UK, 2007.
12. Ojha, H. *et al.*, Is South Asian agriculture adapting to climate change? Evidence from the Indo-Gangetic Plains. *Agroec. Sust. Food Syst.*, 2014, **38**(5), 505–531.
13. Smit, B. and Skinner, M., Adaptation options in agriculture to climate change: a typology. In *Mitigation and Adaptation Practices and Policies for Global Change*, Kluwar, The Netherlands, 2002, vol. 7, pp. 85–114.
14. Adger, W. N. *et al.*, Assessment of adaptation practices, options, constraints and capacity. In *Climate Change 2007: Impacts,*

Adaptation and Vulnerability (eds Palutikof, J. P., Linden, P. J. V. D. and Hanson, C. E.), Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 2007.
15. Mortimore, M. J. and Adams, W. M., Farmer adaptation, change and 'crisis' in the Sahel. *Global Environ. Change*, 2001, **11**, 49–57.
16. Eakin, H., Institutional change, climate risk, and rural vulnerability: cases from central Mexico. *World Develop.*, 2005, **33**, 1923–1938.
17. Reid, P. and Vogel, C., Living and responding to multiple stressors in South Africa-Glimpses from KwaZulu-Natal. *Global Environ. Change*, 2006, **16**, 195–206.
18. Ziervogel, G., Bharwani, S. and Downing, T. E., Adapting to climate vulnerability: pumpkins, people and policy. *Natural Res. Forum*, 2006, **30**, 294–305.
19. Tschakert, P., Views from the vulnerable: understanding climatic and other stressors in the Sahel. *Global Environ. Change*, 2007, **17**, 381–396.
20. Morton, J. F., The impact of climate change on smallholder and subsistence agriculture. *Proc. Natl. Acad. Sci.*, 2007, **104**, 19680–19685.
21. Mertz, O. *et al.*, Climate factors play a limited role for past adaptation strategies in West Africa. *Ecol. Soc.*, 2010, **15**, 25–39.
22. Ahmed, A. U., Hassan, S. R., Etzold, B. and Neelormi, S., Where the rain falls, case study: Bangladesh. United Nations University and Institute for Environment and Human Security (UNU-EHS), Bonn, 2012, p. 156.
23. Ecker, S., Thompson, L., Kancans, R., Stenekes, N. and Mallawaarachchi, T., *Drivers of Practice Change in Land Management in Australian Agriculture*, Sustainable Resource Management Division, Department of Agriculture, Fisheries and Forestry, Canberra, 2012.
24. Kristjanson, P. *et al.*, Are food insecure smallholder households making changes in their farming practices? Evidence from East Africa. *Food Security*, 2012, **4**, 381–397.
25. Wood, S. A., Jina, A. S., Jain, M., Kristjanson, P. and DeFries, R. S., Smallholder farmer cropping decisions related to climate variability across multiple regions. *Global Environ. Change*, 2014, **25**, 163–172; doi:10.1016/j.gloenvcha.2013.12.011.
26. Kerr, J. M., *Sustainable Development of Rainfed Agriculture in India*, Environment and Production Technology Division, International Food Policy Research Institute, Washington DC, 1996.
27. FAO, *Climate Smart Agriculture Source Book*, Food and Agriculture Organization of the United Nations, Rome, 2013.
28. Kristjanson, P., Förch, W., Barahona, C., Garlick, C. and Thornton, P., *CCAFS Baseline Household Survey Manual for Survey Sites*, Climate Change, Agriculture and Food Security (CCAFS), 2010.
29. Ericksen, P. J., Conceptualizing food systems for global environmental change. *Global Environ. Change*, 2008, **18**, 234–245.
30. Singh, R. B., Kumar, P. and Woodhead, T., Smallholder Farmers in India: Food Security and Agricultural Policy, RAP Publication 2002/03. Food and Agricultural Organization of the United Nations, Regional Office for South Asia and the Pacific, Bangkok, Thailand, 2002.
31. Field, A., *Discovering Statistics using SPSS*, Sage Publications, New Delhi, 2005.
32. IPCC, Climate Change 2007: Working Group II: impacts, adaptation and vulnerability. Appendix I: Glossary. Fourth Assessment Report. In *Climate Change 2007*, Intergovernmental Panel on Climate Change, 2007.
33. Dixit, A., Upadhya, M., Dixit, K., Pokhrel, A. and Rai, D. R., *Living with Water Stress in the Hills of the Koshi Basin, Nepal*, Institute for Social and Environmental Transition-Nepal (ISET-N), ICIMOD, Kathmandu, Nepal, 2009.
34. Lambrou, Y. and Nelson, S., Farmers in the changing climate. Does gender matter? *Food Security in Andhra Pradesh, India*, Food and Agriculture Organization of the United Nations, Rome, 2010.
35. Aggarwal, P. K., Global climate change and Indian agriculture: impacts, adaptation and mitigation. *Indian J. Agric. Sci.*, 2008, **78**, 911–919.
36. Larson, C., Losing arable land, China faces stark choice: adapt or go hungry. *Science*, 2013, **339**, 644–645.
37. Bhatta, G. D. and Aggarwal, P. K., Coping with weather adversity and adaptation to climatic variability: a cross-country study of smallholder farmers in South Asia. *Climate Dev.*, 2015; doi:10.1080/17565529.2015.1016883.
38. Mongi, H., Majule, A. E. and Lyimo, J. G., Vulnerability and adaptation of rainfed agriculture to climate change and variability in semi-arid Tanzania. *Afr. J. Environ. Sci. Technol.*, 2010, **4**(6), 371–381.
39. Chand, R., Prasanna, P. A. L. and Singh, A., Farm size and productivity: Understanding the strengths of smallholders and improving their livelihoods. *Econ. Polit. Wkly*, 2011, **46**, 5–11.
40. Girawi, F. and Mwakaje, A. E. G., Impact of microfinance on smallholder farm productivity in Tanzania: The case of Iramba district. *Asian Econ. Fin. Rev.*, 2013, **3**, 227–242.
41. Barrett, C. B. and Reardon, T., Nonfarm income diversification and household livelihood strategies in rural Africa: Concepts, dynamics, and policy implications. *Food Pol.*, 2001, **26**, 315–331.
42. Haque, S. A., Salinity problems and crop production in coastal regions of Bangladesh. *Pak. J. Bot.*, 2006, **38**, 1359–1365.
43. Thapa, G., Smallholder farming in transforming economies of Asia and the Pacific: Challenges and opportunities, Discussion on Paper prepared for the side event organized during the Thirty third session of IFAD's Governing Council, 2009.
44. Chhetri, N. and Easterling, W., Adapting to climate change: Retrospective analysis of climate technology interaction in the rice-based farming system of Nepal. *Ann. Am. Geogr.*, 2012, **100**(5), 1156–1176.

ACKNOWLEDGEMENTS. We thank all members of each site survey team for collecting data and all interviewees in the local communities (Bihar state of India, Coastal Bangladesh and Terai of Nepal). We also thank the University of Reading's statistical services group, Roger Stern, Carlos Barahona and Cathy Garlick, as well as Silas Ochieng and Alois Mandondo for their enthusiastic support in survey design, training and implementation efforts. We appreciate the support from CCAFS's numerous investors and CGIAR centre colleagues and partners. CCAFS baseline work was carried out with funding by the European Union and with technical support from the International Fund for Agricultural Development. Our sincere thanks go to the anonymous reviewers who provided sound inputs in making this paper more precise.

doi: 10.18520/cs/v110/i7/1272-1281