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Smallholder farmer cropping decisions related to climate variability across multiple regions

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A long history of household-level research has provided important local-level insights into climate adaptation strategies in the agricultural sector. It remains unclear to what extent these strategies are generalizable or vary across regions. In this study we ask about three potential key factors influencing farming households' ability to adapt: access to weather information, household and agricultural production-related assets, and participation in local social institutions. We use a 12-country data set from sub-Saharan Africa and South Asia to explore the links between these three potential drivers of agricultural change and the likelihood that farmers made farm-associated changes, such as adopting improved crop varieties, increasing fertilizer use, investing in improved land management practices, and changing the timing of agricultural activities. We find evidence that access to weather information, assets, and participation in social institutions are associated with households that have reported making farming changes in recent years, although these results vary across countries and types of practices. Understanding these drivers and outcomes of farm-associated changes across different socio-economic and environmental conditions is critical for ongoing dialogues for climate-resilient strategies and policies for increasing the adaptive capacity of smallholders under climate change.

1. Introduction

Predicted changes in climate pose a threat to agricultural production and local livelihoods worldwide. Averting this challenge requires that farmers adapt by making changes in farming and land management decisions that reduce the negative consequences associated with changing climate (Jarvis et al., 2011). Climate- or weather-driven adaptation may be a direct response to changing temperature and precipitation patterns, but may also come from an effort to reduce general weather risk even when change is not imminent. Farmers also respond to political and socio-economic factors and environmental factors other than weather and climates. At a broad scale, the negative impact of increasing temperatures on crop yields is clear (Funk and Brown, 2009; Gourdji et al., 2013; Lobell et al., 2011a, b; Lobell and Field, 2007). These negative impacts are likely to be stronger in warmer regions where increases in temperature will have a larger impact (Mendelsohn et al., 1994; Schlenker and Lobell, 2010). Most of these warmer regions also tend to include poorer countries; thus the impacts of climate change are likely to fall disproportionately on poorer nations and on poorer, agrarian households within those nations (Ericksen et al., 2011; Füssel, 2010; IPCC, 2007; Jarvis et al., 2011; Mendelsohn et al., 2006; Schmidhuber and Tubiello, 2007; Skoufias et al., 2011).

Much of the research on climate effects on agriculture at national or international scales using statistical methods (e.g., Gourdji et al., 2013; Lobell et al., 2011a, b; Lobell and Field, 2007) has provided insight into impacts, but has been unable to address household-level adaptations, since these changes will be implicit in aggregated data. Some studies have identified long- or short-run adaptation among farmers (Guiteras, 2009; Kurukulasuriya et al., 2006; Mendelsohn et al., 1994; Schlenker and Lobell, 2010; Schlenker and Roberts, 2009; Seo and Mendelsohn, 2008), but have been unable to discuss specific adaptation strategies. These

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adaptations or changes could include such behaviors as crop switching, irrigation, or investments in soil fertility that may help mitigate production losses in the presence of climate shocks.

Research at the community- and household-level has provided insight into particular adaptation strategies and impacts (Below et al., 2012; Vermeulen et al., 2011), but it remains unclear to what extent these strategies and impacts are generalizable. Though adaptation is a household-level property that depends on a myriad of context-specific factors (Badjeck et al., 2010; Christopolos, 2010), understanding factors associated with patterns in farm-level changes across multiple regions is important because policies aimed at facilitating adaptation will typically be implemented at scales greater than the individual household and community (Easterling et al., 2007). There is a gap in the literature on the particular adaptation behavior of households across multiple regions in response to changes in climate.

In this paper, we provide a multi-region, multi-country assessment of patterns in farmers' reported on-farm changes. Specifically we examine which household-level characteristics are associated with whether households reported to have made on-farm changes over a 10-year time period. We assess whether the factors that we identify to be related to change across broad regions confirm previously hypothesized determinants of change and results from previous studies (Below et al., 2012). We focus on understanding whether farmers' reports of changes in their farming practices are consistent with hypothesized determinants of household-level change. We focus on three of these key determinants: (i) access to weather information, (ii) wealth, and (iii) participation in local institutions.

Farmers may change cropping decisions without awareness of changes in environmental risk (Reilly and Schimmelpfennig, 2000) or as intentional modification of farming practices in response to changing and variable environmental conditions. Weather variability has been shown to significantly impact crop yields (Lobell et al., 2011b), yet it may be difficult for farmers to appropriately adapt to these risks on their own given difficulty for an individual to predict weather patterns that may impact crop yields. As such, reliable climate information provides farmers with predictive knowledge about environmental risks that helps them overcome prior knowledge constraints (Adger et al., 2005, 2009; Rosenzweig and Udry, 2013). Information assists farmers in deciding which agricultural technologies and adaptation mechanisms may be most useful in responding to weather variability and climate change (Hansen et al., 2007; Ziervogel and Ericksen, 2010). We thus hypothesize that access to information is associated with increased adaptation.

Assets and household wealth are necessary to allow adoption of adaptation strategies that may require access to capital (for example, key inputs such as improved seeds and fertilizer). Adaptation to climate that requires these investments is, therefore, less likely to be carried out by the poor, who are often budget constrained (Agarwal, 2010; Carter and Barrett, 2006; Schmidhuber and Tubiello, 2007; Vermeulen et al., 2011). Given that previous studies have shown that increased assets improve the adaptive capacity of groups facing capital constraints (Meinzen-Dick et al., 2002), we hypothesize that increased assets will be associated with increased potential adaptation.

Because individuals are often interdependent through familial, social, and political interactions, social capital (and social networks) play an important role in the ability of an individual to manage risk and uncertainty, especially in the absence of help from the state, by facilitating collaboration and coordination among individual actors (Adger, 2003; Ostrom and Ahn, 2003). Local institutions can also be effective at aiding knowledge generation that may be important for adaptive capacity (Pelling et al., 2008) and in the diffusion of information and technologies (Isaac, 2012). For example, savings groups may provide access to financial resources that help an individual pursue costly adaptation strategies. Not all social network structures, however, are equally facilitating (Bodin et al., 2006); some networks can impose constraining social norms that reduce adaptive capacities (Newman and Dale, 2005). Natural resources have often been managed collectively (Meinzen-Dick et al., 2002), especially in the context of environmental change, thus creating an important role for participation in local groups for adaptation at the supra-individual level (Adger, 2003; Agarwal, 2010). Thus, we hypothesize that participation in local institutions will be associated with increased adaptation.

We hypothesize that (i) farmers with more access to weather information will be more likely to make on-farm changes; (ii) less wealthy (low asset) farmers will be less likely to make on-farm changes, some of which require capital for inputs, due to budget constraints; and (iii) farmers that participate in social institutions will be more likely to make changes as these institutions may help farmers mitigate negative effects of shocks to income and production. We test our hypotheses using a data set of 4000 households across 12 countries in Africa and South Asia. This data set spans a diverse range of environmental and sociopolitical conditions and focuses on identifying changes that households have already made as well as their reasons for making those changes. By asking a consistent set of questions at each of the 29 survey locations, the surveys were constructed to allow for direct comparisons across multiple climate-vulnerable regions. This enables us to observe multi-region patterns in diverse households' potential adaptations in contrast to a comparison of location-specific case studies, which has been a limiting factor in the generalizability of household level analyses to date.

2. Data and methods

2.1. Dataset

We used data from baseline household surveys from the Climate Change, Agriculture, and Food Security (CCAFS) program at the Consultative Group on International Agricultural Research (CGIAR). This program works with global, regional, and local partners to identify and test adaptation and mitigation practices, technologies, and policies. This baseline effort developed comparable indicators for monitoring and evaluating on-farm changes across its research sites, which allows us to identify general patterns that can be understood at greater detail through in-depth research in particular locations.

Surveys were conducted with over 4000 households in 85 villages spread across 15 sites in 12 countries—Bangladesh, Burkina Faso, Ethiopia, Ghana, India, Kenya, Mali, Nepal, Niger, Senegal, Tanzania, and Uganda. These countries represent three broad regions—East Africa, West Africa, and South Asia (Fig. 1). Each region is distinct in its climate, level of agricultural investment and infrastructure, institutional and governance arrangements, and agro-ecosystems (Table S1), and thus this data set allows us to assess the generalizability of our hypotheses are across disparate regions (Fig. 2).

Regions were selected largely because they represent areas that have a high degree of economic vulnerability to climate, and they represent a range of social, political, and climatic contexts (Förch et al., 2011). In the West and East African sites, farmers largely depend on rain-fed, cereal-based agriculture, as they are located in more arid and semi-arid areas with little access to irrigation. Periodic droughts have led to regular food shortages in both regions and potential climate change—in the form of both changing means and variances of weather distributions—threatens agricultural

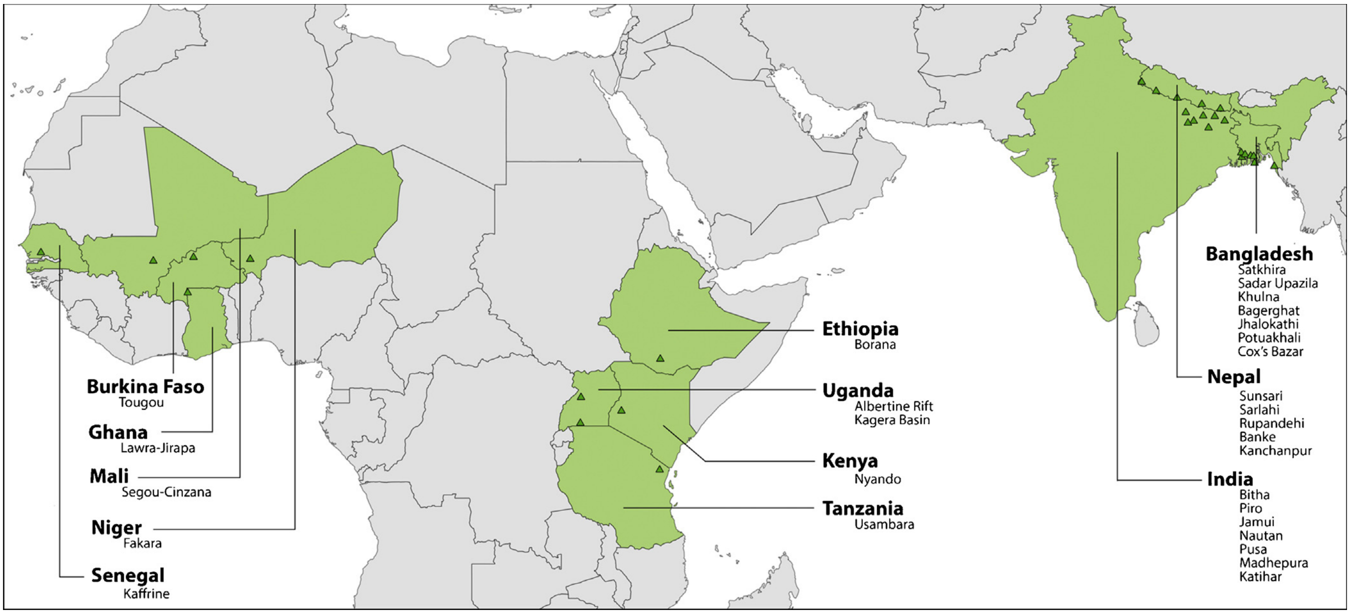

Fig. 1. Map of study locations. Individual study sites are indicated with a triangle. Specific site details are available at: http://ccafs.cgiar.org/node/669.

livelihoods (IPCC, 2007). In West Africa, cereal crops such as sorghum, millet, and maize are most common (Table S1). Much of East Africa is dominated by maize and beans, but also contains large amounts of banana and cassava (Table S1). The regions in South Asia, by contrast, are dominated by rice and wheat, with some maize and cash crops, such as bananas, chickpeas, and mustard (Table S1). In contrast to the sites in West and East Africa, the sites in South Asia are characterized by increased access to irrigation and fertile soils along with higher population densities and investments in agricultural infrastructure.

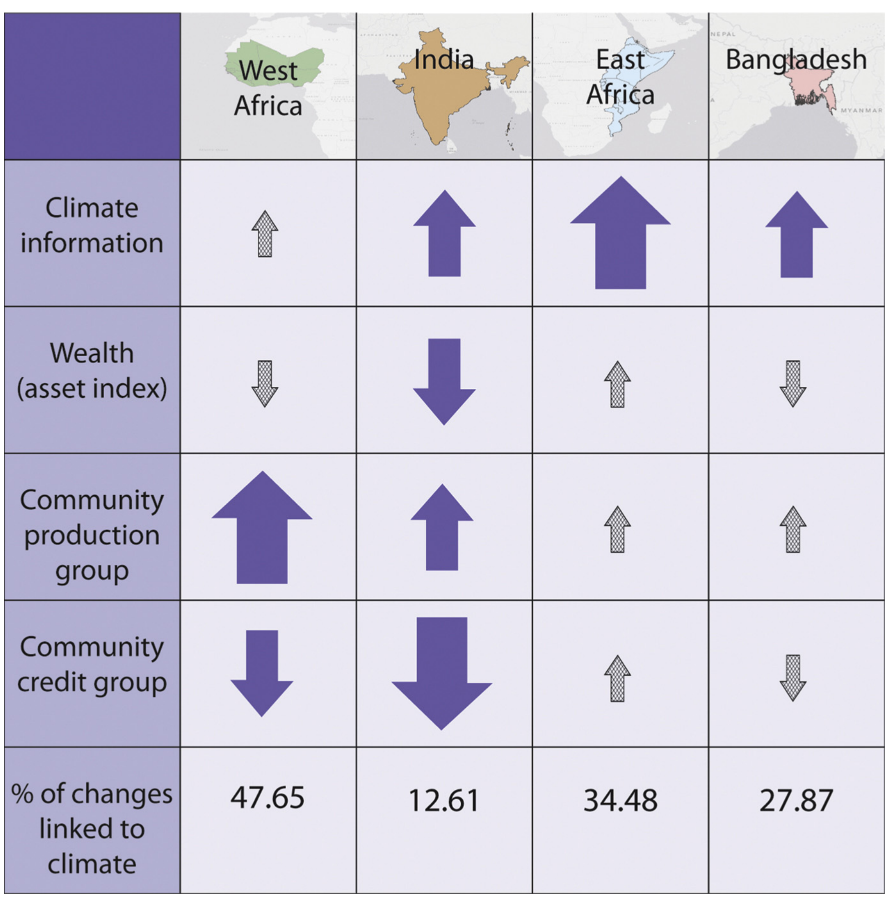

Fig. 2. Results from main regressions, with some change as the independent variable for the multi-region regression. Color and size of arrow represents significance: gray arrows are insignificant at $p = 0.05$ level, while purple arrows are significant. Medium-size arrows are significant at $p = 0.05$ and large arrows are significant at $p = 0.001$. Insignificant predictors in this regression may be significant for particular types of change, presented in Table 2.

Table 1
Relative frequency of citing various reasons for making crop-related changes in the last 10 years, by region.

Change drivers	West Africa		East Africa		Bangladesh		India	
	Total	% of all changes	Total	% of all changes	Total	% of all changes	Total	% of all changes
Climate	466	47.65	1430	34.48	311	27.87	331	12.61
Less rain	80		189		36		133	
More rain	2		165		10		8	
Higher temperatures	34		17		0		11	
Late start of rains	84		77		2		20	
Labor	96	8.18	681	16.42	106	9.50	554	21.11
Land	188	16.03	698	16.83	185	16.58	404	15.40
Market	118	10.06	554	13.36	432	38.71	1135	43.25
Better yield	53		188		168		596	
Better price	33		183		157		451	
Pests and diseases	37	3.15	293	7.07	55	4.93	185	7.05
Projects and policy	68	5.80	484	11.67	0	0.00	14	0.53
Other	5	0.43	7	0.17	27	2.42	1	0.04
No change	526	–	338	–	626	–	365	–

'No Change' is the total number of farmers who reported making no crop practice-related change. Multiple reasons were possible, and are grouped into 7 categories, with some further breakdowns of those categories also shown in Table 1. Percentages are the percentage of all changes made that are of that type.

2.2. Measures of change

We compiled information related to the changes in agricultural practices that households reported having made at any time from 2001 to 2010 (Table S6). Our main dependent variable is whether a farmer made some change over 10 years. This variable is binary and is an aggregate of all possible specific changes identified in the survey (Table S6). We also generated more detailed response variables indicating particular types of reported changes that we grouped into categories—for instance, planting a higher yielding variety, shorter cycle variety, and drought tolerant variety were some of the changes aggregated into an 'improved variety' category (Table S6). Not all of the changes identified in the survey are reflected in these disaggregated categories, and thus the aggregate response "some change" is different than the sum of the sub-categories. Although the aggregate categories are coarser than the individual types of changes, the goal of this study was to identify broad patterns in on-farm changes; understanding particular changes in more detail will be important for future study. To better identify why farmers made these on-farm changes, we also included response variables measuring reported reasons for change, such as changes due to higher temperature or a later start of rains (Tables 2 and S6). It is important to note that our data set examines whether farmers made any on-farm change over a 10 year time period. While the coarse temporal-resolution of the data do not allow us to statistically assess whether farmers made these changes due to weather variability and climate change, they still allow us to assess whether farmers stated that they made changes due to perceived changes in weather.

Our data reflect only reported changes, and not whether a change was adaptive, a concept implying that a change confers some benefit to the farmer that made that change. Furthermore, we primarily examined whether farmers made on-farm changes due to any reason, and not only changes that were specifically in response to weather and climate patterns. Changes on farms may have been made for many reasons (e.g. experimentation with new techniques or in response to market shocks), and not all changes are likely to be adaptive. Our response variable is only a proxy measure of potential adaptation and adaptive capacity. Adaptive capacity is defined as the ability of a farmer to make changes to mitigate risk (Panda et al., 2013). Thus, considering whether farmers made actual changes over the time period of our study may offer insight into the ability of these farmers to make future changes in response to risk, though it does not fully reflect adaptive capacity since there may be changes farmers are able to make that they have not made in the past. Since our measure is an imperfect proxy for adaptive capacity and adaptation, we call it a proxy measure of potential adaptation. The data also only refer to whether a change was made at any point over the last 10 years—a coarse time period—which make it difficult to identify why farmers made specific changes. Furthermore, our data do not reflect whether changes were dominant or minor over that time period.

2.3. Drivers of change

For independent variables, we compiled data on access to weather information, household wealth, participation in social institutions and other relevant socio-economic factors (Table S7). Weather information available to farmers varies among regions. The types of information range from shorter-term (one to three day forecasts) to longer-term (seasonal forecasts). Since we expect farmers' capacity to make on-farm changes to be influenced by wealth, we constructed an asset index to characterize household wealth (Filmer and Pritchett, 2001). The asset index is constructed by performing a Principal Components Analysis of several asset variables. The first principal component is used to capture the variance in asset ownership by assigning a "score" to each grouping of assets. This allows for asset levels to be compared across households (grouped into quintiles of asset wealth levels), and the variable is constructed for each country individually to allow for different assets to be more or less important measures of wealth in different regions. Assets included in construction of the index include durable household and farm goods, land ownership, and the ownership of livestock (though data on numbers of livestock were not available; see Supplementary Information for more details on asset index). The raw factor scores are then converted into quintiles within each country. This means that we refer only to relative wealth within a country, not absolute wealth across the entire sample (*i.e.*, a top quintile household in Tanzania may be considerably less wealthy than a top quintile household in India, but wealthy relative to others within Tanzania itself).

Given that adaptation is a dynamic process with social, as well as individual, components, we used participation in savings and/or credit groups and agricultural production groups as proxy measures of participation in social institutions. Participation in a credit group indicates whether the respondent—or any other household member—belonged to a group involved in savings and/or credit activities. Production groups refer to groups engaged jointly in any agricultural production-related activity, including planting trees on farms, soil improvement activities, crop introduction or substitution, and agricultural water management activities such as irrigation.

Table 2
Results for all logit models at multi-region-level.

	Type of change					Reason for change					
	Some change	Improved variety	Agricultural timing	Land Mgmt.	Increased fertilizer	Less rain	More rain	Higher temp.	Late rains	Better yield	Better price
Information											
Weather information	0.78****	0.57****	0.53***	0.70****	0.34*	0.47	1.05*	−0.02	0.61	0.71**	0.67***
	(0.24)	(0.14)	(0.19)	(0.16)	(0.18)	(0.36)	(0.58)	(0.36)	(0.46)	(0.34)	(0.25)
Education, household head	0.21**	0.21****	−0.06	0.11	0.27****	0.42***	0.29***	0.32****	0.20	0.16**	−0.01
	(0.10)	(0.05)	(0.07)	(0.07)	(0.06)	(0.14)	(0.11)	(0.09)	(0.24)	(0.07)	(0.09)
Social institutions											
Production group	0.67***	0.21	−0.84***	0.13	−0.15	0.46	0.41	0.68	0.67**	−0.50*	−0.71**
	(0.26)	(0.33)	(0.31)	(0.21)	(0.29)	(0.25)	(0.43)	(0.61)	(0.31)	(0.27)	(0.34)
Credit group	−0.62***	0.28**	−0.16	0.50***	0.27	−0.47*	−0.57	−1.24**	−0.58	0.16	0.44**
	(0.22)	(0.14)	(0.21)	(0.15)	(0.18)	(0.26)	(0.37)	(0.60)	(0.48)	(0.22)	(0.19)
Wealth											
Asset Index	−0.18*	0.20****	0.26****	0.22****	0.22****	−0.17	−0.05	0.10	−0.10	0.08	0.03
	(0.11)	(0.06)	(0.06)	(0.05)	(0.06)	(0.11)	(0.11)	(0.15)	(0.18)	(0.06)	(0.06)
Cash from outside sources	−0.30*	0.06	0.04	0.11	0.30**	0.02	0.28**	0.05	0.01	−0.00	0.07
	(0.17)	(0.17)	(0.13)	(0.15)	(0.13)	(0.17)	(0.14)	(0.25)	(0.22)	(0.13)	(0.19)
Hire farm labor	0.66****	1.50****	0.46***	1.09****	1.52****	0.66****	0.63	0.85**	0.65*	0.95****	1.11****
	(0.18)	(0.27)	(0.17)	(0.23)	(0.27)	(0.19)	(0.55)	(0.38)	(0.35)	(0.21)	(0.20)
Produce large livestock	0.23	0.36**	0.41***	0.57****	0.63****	0.50**	−0.82	−0.00	−0.11	0.47***	0.39**
	(0.20)	(0.16)	(0.15)	(0.13)	(0.14)	(0.24)	(0.58)	(0.46)	(0.35)	(0.15)	(0.19)
Other covariates											
Household size	0.00	0.01*	−0.01	0.00	−0.01	−0.03***	−0.02	−0.03	−0.02	−0.00	0.01
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.03)	(0.03)	(0.02)	(0.01)	(0.01)
Gender (HH head)	−0.17	−0.24*	−0.37***	−0.51****	−0.26**	0.00	0.25	−0.50	0.28*	−0.31	−0.26
(0 = Male, 1 = Female)	(0.16)	(0.13)	(0.14)	(0.10)	(0.12)	(0.16)	(0.42)	(0.55)	(0.17)	(0.19)	(0.23)
Deviance	2221.8	3553.7	3505.1	3759.4	3689.1	1617.1	542.0	361.7	774.6	2417.4	2472.6
D.F.	3959	3958	3958	3958	3958	3079	3003	3020	3081	3197	3154
n	3998	3998	3998	3998	3998	3100	3070	3087	3148	3082	3222

Robust standard errors are reported in parentheses. Errors are clustered at the site level.
Columns are separate regressions, for which each column is a different dependent variable. Rows are explanatory variables included in the model. The overall model that includes all changes made is indicated by 'some change.' Other columns assess the influence of variables on particular types of changes (separated into 'types of change') and the influences of variables on changes made for particular reasons (separated into 'reasons for change'). The values given are partial regression coefficients, which indicate marginal effects on log odds ratios.

**** $p < 0.001$.

*** $p < 0.05$.

** $p < 0.01$.

* $p < 0.1$.

2.4. Statistical analyses

We used a linear regression modeling approach to explore the relationship between the number of reported farm changes, access to weather information, wealth, group membership, and other covariates. Our model was a generalized linear model with a binomial link function, for which the probability of making any change was the key response variable. More specific models were also fit to examine the likelihood of making a particular type of change—e.g., adding an improved crop variety—or the reason for making a general change—e.g., less rainfall. We included site as a fixed effect to control for unobservable differences between locations. We also clustered standard errors by sampling area, which controls for covariation between observations that experience the same "treatment", usually belonging to the same site, thus conservatively correcting our standard error estimates.

The coefficients of the logistic models should be interpreted as the estimated increase in the log of the odds of the response variable (likelihood of making a change) per unit increase in the value of the predictor variable (e.g., access to weather information). The odds are the ratio of the probability of making a change to the probability of not making a change, though this relationship should be interpreted as correlational and not causal. Because our cross-sectional data only allow identification of correlation, the magnitude of the coefficients should be considered with caution; the sign, however, signifies a positive or negative association between variables. We consider variables significant at an alpha threshold of 0.05 and mild significance as less than 0.10 (Burnham and Anderson, 2002). Parameter estimates for logistic regression are generated through maximum likelihood estimation, not ordinary least squares. Thus, common measures of goodness-of-fit (e.g., R^2) are not possible. Because maximum likelihood minimizes the sum of deviance residuals, we report the deviance statistic as a measure of goodness-of-fit. Smaller values indicate a better fit to the data.

To better understand the heterogeneity among regions, models were fit separately for each region. The regions we defined were West Africa, East Africa, India, Nepal and Bangladesh. In the site selection, India, Bangladesh, and Nepal were grouped into South Asia. Because the number of household surveys was much higher in the South Asian region than in either of the African regions, we split the South Asian region into its separate countries, making each of our four regions approximately the same size. Splitting the data set by region significantly reduced the sample size for each subsequent model (from ~4000 for the multi-region model to between ~400 and ~1000 for the regional models) and we consequently lost precision in our estimates. For instance, due to lack of variation in the response variable for Nepal (only seven people out of 800 reported making a change, likely indicating a data quality issue for this particular information in this region), we excluded Nepal from the analyses. The reasons for making changes, especially the climate-related ones, varied considerably across these diverse regions. For example, in Bangladesh, changes associated with perceptions of higher temperatures and a later start of rains were only mentioned by a few people; therefore these factors were excluded from the analysis.

3. Results

3.1. Access to weather information

At the multi-region level, we found that households that reported having access to immediate or short-run weather forecasts were more likely to have made some change to their farming practices in the last 10 years ($p < 0.001$) (Table 2). Access to weather information is also significantly positively related to the likelihood of adopting improved crop varieties ($p < 0.001$), making adjustments in the timing of agricultural activities ($p < 0.01$), and investing in improved land management practices ($p < 0.001$), and is mildly significantly related to increasing fertilizer use ($p < 0.1$).

Access to weather information in the India sites was found to be significantly positively related to the overall likelihood of change ($p < 0.05$), as well as adopting improved varieties ($p < 0.001$) and investing in improved land management practices ($p < 0.01$) (Table 4). In East Africa, adoption of improved varieties and increased fertilizer use is related to weather information (Table S3). However, the relationship between receiving weather information and making farming practice changes was not significant for the West African sites (Table 3).

With respect to household perceptions of the reasons, or drivers, of farming practice change, in West Africa accessing weather information is significantly and negatively related to the weather-related drivers of less overall rainfall, higher temperatures and a later start of the rains (Table 3). In India, more overall rainfall is a perceived driver (Table 4), in Bangladesh it is less rainfall (Table S4), and in East Africa (Table S3) it is higher temperatures that are significantly linked to household access to weather information.

We also found suggestive evidence that, at the broad scale, a household's access to weather information matters less for farm decisions when farmers are part of a group ($p < 0.01$) (Table S5, generated by re-running models with an interaction term between information and institutions). These results were significant even after controlling for site-specific variation.

3.2. Wealth

Counter-intuitively, we found that household and agricultural production-related assets (as captured in the asset index as a proxy for wealth) are marginally negatively related to the likelihood of having made any farm change at some point in the last 10 years at the multi-region scale ($p < 0.10$, Table 2). This may be because lower asset farmers may be more vulnerable and thus have a higher likelihood of making on-farm changes to mitigate risk. However, having more assets is significantly positively related to the several specific practices that require access to capital: improved crop varieties ($p < 0.001$), investing in land management ($p < 0.001$), and increasing fertilizer use ($p < 0.001$)—though all of

Table 3
Results for all logit models for West Africa.

	Types of change					Reasons for change				
	Some change	Improved variety	Agricultural timing	Land Mgmt.	Increased fertilizer	Less rain	Higher temp.	Late rains	Better yield	Better price
Information										
Weather information	0.01	0.14	0.03	0.02	−0.08	-0.49^{****}	-0.77^{****}	-0.27^{***}	0.21^{****}	−0.49
	(0.16)	(0.28)	(0.25)	(0.39)	(0.39)	(0.01)	(0.11)	(0.09)	(0.06)	(0.50)
Education (HH head)	0.63^{*}	−0.10	-0.29^{*}	−0.09	0.13	0.58^{*}	0.49^{****}	0.66^{*}	-0.19^{*}	−0.02
	(0.36)	(0.15)	(0.19)	(0.19)	(0.11)	(0.32)	(0.08)	(0.35)	(0.11)	(0.42)
Social institutions										
Production group	0.59^{****}	0.31	-1.18^{****}	−0.01	−0.15	1.03^{****}	1.22	0.72^{****}	−0.47	−1.02
	(0.16)	(0.42)	(0.28)	(0.17)	(0.37)	(0.29)	(0.77)	(0.18)	(0.34)	(0.64)
Credit group	-0.67^{**}	0.14	−0.16	−0.10	0.66	-1.40^{**}	−1.64	-1.24^{**}	-0.69^{***}	-0.85^{****}
	(0.30)	(0.19)	(0.27)	(0.17)	(0.43)	(0.68)	(1.61)	(0.50)	(0.27)	(0.25)
Wealth										
Asset index	−0.59	0.20^{*}	0.36^{****}	0.37^{****}	0.30^{**}	-0.57^{***}	0.08^{****}	−0.44	0.08	−0.11
	(0.39)	(0.11)	(0.08)	(0.10)	(0.14)	(0.21)	(0.01)	(0.27)	(0.25)	(0.24)
Cash from outside sources	0.08	0.10	0.37^{*}	0.42	0.27	-0.40^{*}	0.28	-0.07^{****}	−0.08	-0.37^{****}
	(0.53)	(0.28)	(0.21)	(0.41)	(0.24)	(0.23)	(0.39)	(0.01)	(0.58)	(0.01)
Hire farm labor	0.34^{*}	−0.05	−0.26	0.02	0.21	0.69	1.03^{**}	0.69^{*}	−0.21	−0.11
	(0.19)	(0.07)	(0.24)	(0.18)	(0.17)	(0.55)	(0.44)	(0.38)	(0.26)	(0.63)
Produce large livestock	0.52	−0.43	0.20	0.17	0.03	0.87^{*}	-0.66^{***}	0.66^{*}	0.07	0.85
	(0.35)	(0.23)	(0.25)	(0.30)	(0.21)	(0.46)	(0.24)	(0.40)	(0.33)	(0.45)
Other covariates										
Household size	0.02^{*}	0.02^{***}	−0.01	−0.00	-0.02^{**}	−0.00	−0.00	−0.02	−0.01	0.04
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.02)	(0.02)	(0.03)	(0.06)
Gender (HH head)	-0.79^{****}	−0.24	0.16	−0.06	0.26	0.04	-1.20^{****}	−0.12	−0.27	−0.42
(0 = Male, 1 = Female)	(0.20)	(0.34)	(0.28)	(0.21)	(0.40)	(0.23)	(0.22)	(0.13)	(0.38)	(0.57)
Deviance	352.9	711.5	631.17	656.29	835.8	190.3	115.0	194.5	204.8	107.7
D.F.	669	669	669	669	669	433	372	435	435	392
n	697	697	697	697	697	460	399	462	462	419

Robust standard errors are reported in parentheses. Errors are clustered at the site level.
Columns are separate regressions, for which each column is a different dependent variable. Rows are explanatory variables included in the model. The overall model that includes all changes made is indicated by 'some change.' Other columns assess the influence of variables on particular types of changes (separated into 'types of change') and the influences of variables on changes made for particular reasons (separated into 'reasons for change'). The values given are partial regression coefficients, which indicate marginal effects on log odds ratios.

**** $p < 0.001$.
*** $p < 0.05$.
** $p < 0.01$.
* $p < 0.1$.

Table 4
Results for all logit models for India.

	Type of change					Reason for change					
	Some change	Improved variety	Agricultural timing	Land Mgmt.	Increased fertilizer	Less rain	More rain	Higher temp.	Late rains	Better yield	Better price
Information											
Weather information	1.19**	0.48****	0.37	0.96***	0.42	0.75	18.51****	0.25	2.07	0.97*	0.84**
	(0.52)	(0.12)	(0.36)	(0.32)	(0.29)	(0.46)	(0.67)	(0.22)	(1.53)	(0.56)	(0.36)
Education (HH head)	0.23***	0.15	−0.01	−0.02	0.35	0.70****	0.03	0.15	0.18	0.25**	−0.15
	(0.09)	(0.16)	(0.09)	(0.16)	(0.09)	(0.14)	(0.27)	(0.24)	(0.19)	(0.10)	(0.14)
Social institutions											
Production group	3.52**	11.88****	−0.82	−0.88	12.16****	1.55***	2.28****	−16.25****	2.98****	−0.17	1.09
	(1.48)	(1.06)	(1.11)	(0.75)	(0.76)	(0.59)	(0.37)	(0.70)	(0.72)	(1.32)	(1.28)
Credit group	−1.47****	0.32	−0.10	1.24***	0.57*	−0.20	0.22	−1.39*	−0.27	0.83**	0.91****
	(0.34)	(0.50)	(0.38)	(0.39)	(0.31)	(0.37)	(1.82)	(0.81)	(0.75)	(0.38)	(0.24)
Wealth											
Asset index	−0.29**	0.10	0.06	0.02	0.19*	−0.44***	−0.24	0.37	−0.63**	0.00	0.01
	(0.14)	(0.15)	(0.10)	(0.11)	(0.11)	(0.15)	(0.62)	(0.28)	(0.27)	(0.12)	(0.11)
Cash from outside sources	−0.48**	−0.49	−0.36*	−0.17	0.20	−0.37	1.04*	0.28	−0.70	−0.24	−0.27
	(0.23)	(0.31)	(0.20)	(0.23)	(0.15)	(0.23)	(0.61)	(0.81)	(0.46)	(0.21)	(0.27)
Hire farm labor	0.88*	2.53****	0.94***	1.66****	1.81****	0.68*	19.91****	1.92***	2.02**	1.09***	1.12****
	(0.49)	(0.53)	(0.31)	(0.48)	(0.22)	(0.35)	(1.04)	(0.64)	(0.96)	(0.35)	(0.30)
Produce large livestock	0.34	0.86**	0.74**	0.98***	1.23****	0.59**	−0.05	−0.14	0.02	0.62***	0.51*
	(0.42)	(0.41)	(0.31)	(0.30)	(0.31)	(0.27)	(1.37)	(0.26)	(0.49)	(0.23)	(0.30)
Other covariates											
Household size	−0.02	0.07	0.01	0.05**	0.01	−0.03	−0.27**	−0.12****	−0.07	0.03	0.02
	(0.04)	(0.05)	(0.02)	(0.02)	(0.04)	0.04	(0.12)	(0.02)	(0.05)	(0.02)	(0.02)
Gender (HH head)	−0.55	−0.75****	−0.76****	−0.72***	−0.59***	−0.55***	−19.67****	−1.47	−0.77*	−0.73**	−0.68**
(0 = Male, 1 = Female)	(0.44)	(0.18)	(0.17)	(0.28)	(0.20)	(0.18)	(0.94)	(1.72)	(0.44)	(0.35)	(0.27)
Deviance	615.9	595.6	1081.6	850.0	692.7	579.4	N/A	N/A	136.35	862.18	1044.7
D.F.	950	950	950	950	950	948	949	950	948	950	949
n	981	981	981	981	981	981	980	981	979	981	981

Robust standard errors are reported in parentheses. Errors are clustered at the site level.
Columns are separate regressions, for which each column is a different dependent variable. Rows are explanatory variables included in the model. The overall model that includes all changes made is indicated by 'some change.' Other columns assess the influence of variables on particular types of changes (separated into 'types of change') and the influences of variables on changes made for particular reasons (separated into 'reasons for change'). The values given are partial regression coefficients, which indicate marginal effects on log odds ratios. N/A values for the deviance statistic indicate linear separation of the data for that model, making a perfect model fit artificially possible.
**** $p < 0.001$.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

these also require labor investment. These results suggest that, across all regions, wealthier farmers are more likely to make changes requiring access to capital. The overall negative effect, however, suggests that there are types of changes that are negatively correlated with wealth that counteract observed positive effects.

Regional regression results suggest that it is largely the wealthier households within West Africa, East Africa, and Bangladesh that are making changes (Tables 3, S3 and S4). In India, arguably a wealthier region, most significant effects related to the asset index were negative, suggesting that, in this context, it is the lower-asset households that have been making changes in farming practices, particularly changes due to less rain ($p < 0.01$) and a late start of rains ($p < 0.05$) (Table 4).

3.3. Participation in social institutions

The multi-region analysis shows that participation in a local agricultural or natural resource management-related group is positively related to the likelihood of change ($p < 0.01$) (Table 2). Though production group members are more likely to make farming system changes, these results did not always hold when considering specific changes such as adjustments in the timing of management practices ($p < 0.01$) (Table 2). Savings and/or credit group participation, by contrast, is negatively correlated with the broad likelihood of change ($p < 0.01$), although it is positively associated with it when considering particular types of change, such as adopting an improved variety ($p < 0.05$) or making a change associated with an opportunity to earn a better price ($p < 0.05$) (Table 2). The result suggests that government and non-governmental support and investments in these types of groups can help enhance farming households' adaptive capacity.

Agricultural and natural resource management group membership is positively related to change for households in West Africa ($p < 0.001$). Specifically, it is positively related to changes made for the stated reasons that there is presently less overall rainfall ($p < 0.001$) and that rains are starting later ($p < 0.001$). It is negatively related to changes made in agricultural management timing ($p < 0.001$; Table 3). In India, participation in these groups is positively related with uptake of improved varieties ($p < 0.001$), increased fertilizer use ($p < 0.001$), and management changes made due to perception of less rain ($p < 0.01$), more rain ($p < 0.001$), and a later start to the rains ($p < 0.001$) (Table 4). Participation in these groups, however, is negatively related to changes due to higher perceived temperatures in India ($p < 0.001$), indicating the differential response of farmers to rainfall and temperature as different aspects of climate and weather change.

Production group membership is positively related to land management practice changes ($p < 0.001$) and uptake (or increased use of) fertilizer ($p < 0.01$) in East Africa, and to decisions made regarding new practices with the goal of increasing yields in Bangladesh ($p < 0.05$). Similarly to West Africa, groups are not important with respect to changes in the timing of agricultural activities in Bangladesh. Unlike findings from East Africa, group participation in Bangladesh does not appear to influence fertilizer use decisions.

4. Discussion and conclusions

This study is one of the first to assess and compare factors associated with reported changes in agricultural practices by smallholder farmers across multiple regions. Though we are unable to make claims about the direction of causation or the specific mechanisms for such changes we find that wealth, participation in local institutions (production or credit group membership) and access to weather information are often significantly associated with a change in farming practices. Stratifying the sample by region shows that there is considerable heterogeneity in responses.

4.1. Access to weather information

We hypothesized that farmers with greater access to weather-related information would be more likely to make changes in their farming practices. We found that while access to such information is significantly and positively related to the probability of change for most regions, the relationship is either negative or insignificant for West Africa. This result is surprising because, compared to other regions, West Africa has the largest percentage of farmers that made climate-related farming practice changes (Table 1). It is, therefore, not clear if the insignificant (and sometimes-negative) impact of weather information is because it is perceived as less useful, credible and legitimate than in other regions (Cash et al., 2003; Kristjanson et al., 2009; Rosenzweig and Udry, 2013). Communities may also have already become accustomed to highly variable weather, characteristic of the Sahel (Giannini et al., 2008; Zeng et al., 1999), in which case weather forecasts do not provide actionable knowledge to farmers.

4.2. Assets

We hypothesized that low-asset farmers are less likely to make changes because they lack access to key financial capital resources allowing them to invest in new practices. Our results at the regional level support the hypothesis that wealth can be significantly related to the likelihood of change. In South Asia, where per capita incomes are higher than they are in Africa, we find more farming practice changes, on average, than in Africa (Table S8). Within our semi-arid West African sites, we find that it is the higher-asset farmers that are most likely to take up new agricultural and natural resource management practices, which are typically capital-intensive changes. When we disaggregate the types of change that farmers made, increased assets are most associated with changes that require capital investment, like the adoption of new seed varieties. This suggests that asset-poor households face constraints that prevent them from adopting new practices that require some capital investment, though not all farm changes require access to capital.

However, we also find that it is the poorer farmers within India, a relatively wealthier country, that are more likely to adopt new practices. This may be because wealthier farmers in this region have access to irrigation and technology that allow farmers to maintain the same farming practices even in the face of changing climates. Poorer farmers, who do not have access to these resources, may be more vulnerable and thus more likely to alter their cropping strategies to cope with climate variability. In addition, wealthier households may be better able to reduce economic vulnerability with off-farm changes such as investment in education, high wage earnings, and migration (Fishman et al., 2013); poor farmers also seek off-farm wages, but may not earn as much as individuals with prior capital access. Farm families, thus, may maintain the same system of farming through either existing access to technologies or through external income sources that buffer vulnerabilities.

At the multi-region level, we find that lower asset farmers are more likely to make some change to their on-farm practices. This may be because poorer farmers are often most vulnerable, and thus it may be more necessary for these farmers to make low-cost adjustments to their cropping strategies (e.g. shifting planting dates) to mitigate risk. Also, given that more farmers made changes in India than the other regions considered in our study (Table S8), the effect at the multi-region level may be most strongly influenced by the negative relationship between wealth and on-farm changes that we see in India due to sample size.

4.3. Participation in social institutions

We hypothesized that farmers who participate in social institutions, such as credit/savings and loan groups and/or agricultural or natural resource management-related groups, are more likely to make changes in farming practices than those that are not members in such groups. We found that the agricultural-related groups matter more than the savings/credit groups to the likelihood of making a change across all households in the three regions. Positive effects of savings/credit groups were found, however, to be associated with particular changes such as switching to improved varieties, and changes made in response to market factors (e.g. better yields or prices). These particular changes, which require greater capital input, are what would be expected from access to credit. Even though access to credit is associated with fewer changes overall, it is positively associated with the sorts of changes to which credit access is relevant. These results imply that investments and support to these types of groups is likely to help farmers make potentially adaptive changes.

In West Africa, we find that the impact of agricultural and natural resource management group membership is generally positive, though this is not the case for savings/credit group participation. In India, production group participation is often strongly significantly positive, except for changes made due to market factors, for which participation in credit groups mattered more. Further exploration is needed of the reasons why local savings/credit groups seem to facilitate multiple farm-level changes (e.g. environmental, economic, social) in East Africa and much of India, but not in West Africa.

4.4. Links between access to weather information and social groups

We found that access to weather information matters less for farm decision-making when farmers are part of a group (Table S5). This could suggest that participation in groups helps buffer against high weather variability, that group participation facilitates diffusion of weather-related information even if individual household access is limited, or that farmers in groups as less exposed to climate by self-selection. The exception to this pattern is the positive interaction found between weather information and agricultural group membership in the context of better prices, suggesting that prices drive the need for more information even among groups. We also found a positive interaction between information and savings/credit group membership with regards to changes in farming practices attributed to perceived higher temperatures, suggesting that temperature may be a particularly important climate variable to consider. This fits with modeling work showing negative crop yield responses to increases in temperature (Gourdji et al., 2013; Lobell et al., 2011a, b; Lobell and Field, 2007).

4.5. Methodological advances, limitations, and future research

This study provides an important methodological development in the adaptation literature by employing a large, multi-country data set that spans a wide range of environmental conditions to assess multiple hypotheses of drivers of on-farm changes. The sample size of around 4000 households is larger than most studies used to date. This allows us to provide insight into long-posed hypotheses about the importance of certain drivers of farm management changes.

Though this cross-site approach allows for new opportunities to assess hypotheses, there are several caveats based on the data used for this study. First, the study design and surveys used were not designed to determine causality. Though we may find that in certain locations wealthier farmers are more likely to make a farm change, we cannot determine whether they are more likely to make a change because they are wealthier or if they are wealthier because they have made farm changes. Also, given the coarse scale of data collection (i.e. whether any changes was made over a 10 year time period), it is difficult to statistically assess why farmers made these on-farm changes; farmers may have made changes due to climate, market forces, environmental degradation, or any range of other possible factors. Future work could determine causality by employing panel fixed effect methods, which would control for cross-site differences and identify causality. In addition, studies that measure the welfare outcomes of on-farm changes are essential to classify whether a change is actually adaptive. Second, we cannot identify the mechanisms leading to the observed patterns. Further work, including natural experiments or long-term observational studies, is needed to determine why certain patterns are observed within each region, why differences occur among regions and to understand the long-term outcomes of potentially adaptive changes. For example, we hypothesized that wealth facilitates adaptation, but we find that though this may be true in poorer regions, poorer farmers in wealthier regions may be more likely to make farm changes. Understanding this result for each region would allow for more targeted adaptation policies that reflect needs at varying levels of wealth. Third, because the survey data used refers to shorter-term weather, our results should not be interpreted as a relationship between weather information and farm changes that are made because of climate change. The extent to which responses to short-term weather fluctuations can indicate longer-term adaptive capacity is an open and important area of research that should be incorporated into future studies (Dell et al., 2013). Additionally, we see that changes are made for numerous reasons, including market forces, social institutions, and weather, and the extent to which these actions confer benefits in the face of climate change even if not directly resulting from climatic changes themselves, is an important question for further study.

4.6. Conclusions

This work offers novel insight into whether factors associated with on-farm changes are generalizable across multiple regions. Although there are some generalities between regions, many factors influencing change and adaptation vary across regions (Kristjanson et al., 2012).

It is important to note that generalizable associations occurring across multiple regions may reflect different processes. For instance, in East Africa and India, access to weather information does seem to influence the probability of making farm-associated changes. However, the means to access weather information differs widely among the regions (Table S2). This suggests that policies to increase access to weather information should be tailored to the medium (e.g. radio, newspaper, word of mouth) that is most useful for a given region. Future work that documents outcomes from, and not just patterns of, farmer change should identify who does and does not benefit from policies, such as efforts to provide climate information. While some factors may be generalizable, the relative importance of that factor for making on-farm changes may vary across regions. For example, in West Africa, weather-related reasons were more frequently noted to be important to changes in practices than in India, where market-related factors were most often cited (Table 1).

Other factors showed different patterns across the regions considered in our analyses. For example, increased wealth was associated with increased on-farm changes in West Africa, but with decreased on-farm changes in India. This may be because in West Africa, wealthier farmers have increased access to the types of on-farm changes that are typically made in the region. For example, assets are needed for costly changes including switching to improved crop varieties and increasing inputs like irrigation and fertilizer. In India, wealthier farmers may not make as many on-farm changes because they already have access to inputs and technologies, like secure irrigation, that make them less vulnerable. Or, wealthier farmers may make off-farm changes, like diversifying income sources, that are not captured in our survey.

Our results thus demonstrate some general patterns, and some interesting differences in changes made by farmers. Knowing which types of changes are adaptive (e.g., have positive outcomes) and in which contexts will be needed for effective design and targeting of interventions, investments and policies aimed to facilitate adaptation to climate change. Because of numerous local-level factors that impact the adaptive capacities of farmers, future work should place these broad trends in local context to understand the impact of climate on local livelihoods.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.gloenvcha.2013.12.011.

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