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Impact of Climate Change on Crop Nutrient Availability and Food Security

Hassan Raza
Sr. Agronomist at Kanoo Manuchar, Riyadh, Saudi Arabia

ABSTRACT
The effect of climate change on the availability of nutrients in crops and food security was studied with quantitative research design. The study employed a convenience sampling technique to access the changes in temperature, rainfall pattern, soil fertility, soil nutrient availability, crop productivity and household food security from about 200 agricultural farmers who were selected for the study with the aid of a structured questionnaire. The collected data were analyzed using descriptive statistics, correlation and multiple regression analysis to establish the relationship between the climate change indicators, crop nutrient availability and food security. The reliability of the research instrument was measured using Cronbach's alpha method and the validity of the research instrument was determined by the results of the expert test. Farmers reported significant changes in both temperature and precipitation over the last decade and these changes were strongly and negatively related to soil fertility and nutrient availability of crops. Multiple regression analysis indicated that two out of five indicators of climate change (rising temperature and rainfall variability) were significant and negative predictors of crop nutrient availability, which was significant and positive predictor of crop productivity and household food security. The overall regression model accounted for a significant amount of variance in food security outcomes. The results show that climate change has significantly affected the household food security in addition to its impact on crop productivity, and the study ends with recommendations for soil and nutrient management practices, climate smart agricultural extension and future research.
Keywords: climate change, crop nutrient availability, soil fertility, food security, smallholder farmers.

Corresponding Author: Hassan Raza
Email: hassan.raza@kanoomanuchar.com
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INTRODUCTION

Climate change is happening and is wreaking havoc on agriculture around the world, due to rising temperatures, changing rainfall patterns and more severe weather events, which are affecting the physical and biological conditions in which crops are cultivated. A large and growing body of evidence suggests that there are already measurable impacts at the global scale of these climatic changes on the productivity of crop and grain yields; there is a consistent pattern of impacts across multiple independent modeling approaches, for cereal and grain yields (Lobell & Gourdji, 2012; Wheeler & von Braun, 2013). Knowing exactly how climate change affects the agricultural system is of great practical importance, especially in countries where agriculture is mainly rain-fed and small in size, supporting the livelihoods of billions of people around the world (Wheeler & von Braun, 2013).

To date, much of the literature concerning climate change and agriculture has concentrated on the impact of temperature and rainfall variability on the yield and productivity of the crops. Increased temperatures have been shown to cause a detectable decline in yields of key global crops, such as maize, wheat and soybean (Zhao et al., 2017), and global assessments based on gridded crop model intercomparisons have also suggested significant agricultural vulnerability under various climate scenarios (Rosenzweig et al., 2014). In addition to these productivity-oriented analyses, the study of extreme weather events has found that in particular droughts and heat waves have historically led to substantial decreases in national cereal production, which have been getting even larger over the past few decades (Lesk et al., 2016), and wider assessments of climate extremes have found that variability in temperature and precipitation has been associated with significant year-to-year variability in global agricultural production (Vogel et al., 2019).

Another, somewhat less well studied, aspect of this issue is how climate change will impact the quality and nutrient content of crops and the soil fertility that underlies this productivity. It is well established that soil organic carbon and related processes of nutrient cycling are highly responsive to altered temperature and moisture conditions, and that these effects would impact soil fertility and the ability of agricultural systems to sustain food security in a changing climate (Lal, 2004). A direct impact of climate change is the increase in atmospheric levels of carbon dioxide, which has been shown to significantly reduce the levels of zinc, iron and protein in major staple grains and legumes in controlled field experiments at the crop level, with important implications for populations that rely heavily on these crops for their nutrition, including zinc, iron and protein (Myers et al., 2014). In simulations that don't significantly reduce global food production, climate effects on staple crop nutrient density could significantly contribute to the global burden of protein, iron, and zinc deficiencies by mid-century (Beach et al., 2019).

Taken together, these results indicate that there are at least two different (and only partially overlapping) pathways by which climate change could impact food security, one through a productivity pathway (in which changes in temperature and rainfall lead to changes in the physical quantity of food harvested) and another through a nutrient pathway (in which changes in climatic and atmospheric conditions lead to changes in the nutritional quality and nutrient content of the food harvested without any change in the total volume of food harvested). This nutrient pathway, also sometimes called the “hidden dimension” of climate change and food security, has been less empirically studied than the effects of climate change on yield and food productivity, but has significant potential impacts on the nutritional adequacy and food security of households (Myers et al., 2017; Fanzo et al., 2018).

This nutrient pathway is especially significant for smallholder farming households as their food security is directly linked with the productivity and nutrition of the crops they grow. Empirical studies in smallholder communities in Sub-Saharan Africa have reported farmers' awareness of significant recent shifts in temperature and precipitation, as well as their awareness of measurable improvements in food security outcomes among their households (Mbegalo et al., 2024). Much of this household-level empirical literature, however, focuses on the impact of climate change on food security either through the process of adaptation of farmers or through aggregate productivity results, but without directly measuring farmers' perception of changes in soil fertility and the nutrient availability of the crops as a separate and intervening variable in the climate change – food security pathway.

This study aims to bridge this gap by explicitly investigating the linkages between climate change indicators (Climate Change Index/Changes in temperature and precipitation), soil fertility, crop nutrient availability, crop productivity, and food security of the agricultural farmers in the study using survey data from about 200 agricultural farmers. The study has three objectives: firstly, to evaluate the perception of farmers regarding the changes in the temperature, rainfall pattern and soil fertility over the last few years; secondly, to explore the association between the climate change indicators, soil fertility and nutrient availability in crops; and thirdly, to measure how well the climate change indicators and nutrient availability in crops predict crop productivity and the food security of the household. The study explicitly considers the availability of crops as a variable separate from crop productivity, thus clarifying whether a reduction in agricultural output or in nutrient availability, or both, are the main drivers of the threat to food security for households in the face of climate change.

LITERATURE REVIEW

Agricultural Productivity and Climate Change.

There is a large scientific literature base that demonstrates that climate change is having measurable impacts on the productivity of global agriculture. Climate change impacts on crop yields have been reviewed, and they have found that there are complex response patterns to temperature and precipitation changes, which depend on the specific crop and location, and that the effects of the CO_2 changes on yield are generally positive but are often offset by negative impacts of increased temperature and water stress (Lobell & Gourdji, 2012). Evidence from multiple statistical and process-based crop models has been combined in independent meta-analyses that clearly show that there are significant reductions in crop yield for each 1 °C rise in the global mean temperature for the four major staple crops that supply the bulk of all calories consumed on Earth: maize, wheat, rice, and soybean (Zhao et al., 2017). Large-scale gridded crop model inter-comparison projects have also shown that the potential impact of climate change on agricultural production in the twenty first century is significant and widespread, especially when no adaptation measures are implemented (Rosenzweig et al., 2014).

In addition to the long-term changes in mean temperature and precipitation, extreme weather events have emerged as a very disruptive climate mechanism influencing crop production. Nationally, droughts and extreme heat events have been found to have significantly reduced national-level cereal yields in recent decades (Lesk et al., 2016), and large-scale analyses of climate extremes have shown that variations in temperature and precipitation have large impacts on year-to-year variability in cereal production on the global scale, in addition to modifying the long-term average of the climate (Vogel et al., 2019). Together these studies highlight climate change as a complex challenge to crop productivity, both because of the shifts in climate over the longer term and because of increases in climate variability and extremes.

A separate, but related, literature has considered the impacts of climate change on the nutrient contents of crops and soil systems that can support nutrient availability. Basic research has shown that soil organic carbon content, which is important for soil fertility and nutrient cycling capacity, is also responsive to changes in temperature and moisture, and soils that are depleted of soil carbon have limited ability to uptake nutrients for crop growth and therefore also reduced global food security (Lal, 2004). In the field, controlled experiments have shown that major staple cereal and legume crops under free-air carbon dioxide enrichment conditions have shown significantly lower levels of zinc, iron, and protein (for the non-legume crops) than at ambient atmospheric CO_2 levels, at the crop level (Myers et al., 2014). This discovery suggests that an increase in atmospheric CO_2 due to climate change impacts directly and significantly lower the nutrient content of crops harvested, without affecting the amount of crop produced itself.

Studies modelling the work to the population level have estimated that by mid-century, the zinc, iron and protein deficiencies in staple crops due to climate change could significantly increase the prevalence of nutrient deficiencies, particularly among groups with the highest dietary dependence on C3 cereal and legume crops (Beach et al., 2019). More comprehensive assessments of global food systems and climate change have also found that climate change impacts on the nutritional quality of food – rather than just on calorie availability – are a neglected but important pathway by which climate change impacts food security and nutrition at the global level (Myers et al., 2017; Fanzo et al., 2018).

Climate Change and Household Food Security

The four dimensions of food security have been defined as: food availability, food access, food utilization, and food system stability over time (Wheeler & von Braun, 2013; FAO, 2008). When used to address climate change, this multi-dimensional approach underscores that climate change may impact food security in several ways: by decreasing food availability, because lower agricultural yields reduce the supply of food; by decreasing food utilization, due to lower nutrient contents; and by decreasing food system stability, due to increased climate variability and the danger of production shocks caused by extreme weather events (Wheeler & von Braun, 2013).

At the household level, especially for small-scale farmers in developing countries, the empirical evidence directly linking the experience of climate change and the food security outcomes of farmers is found. A study on climate change perceptions and impact on food security among smallholder farmers in Tanzania revealed that farmers perceived climate change had a negative effect on their food security, such as changes in rainfall patterns, and that reliance on traditional farming knowledge and practices were a coping strategy (Mbegalo et al., 2024). This series of household case studies confirms that farmers' perceptions of the impacts of changing climatic conditions are directly and measurably linked to the real-world impact on food security – as identified in the broader literature on climate change and agriculture (Wheeler & von Braun, 2013; IPCC, 2014, 2022).

Integrated Pathway Linking Climate Change, Nutrient Availability And Food Security

Combined, these papers provide a conducive route by which climate change can impact household food security, and in particular two distinct mechanisms – a productivity pathway through the direct effects of climate change on crop yields (Lobell & Gourdji, 2012; Zhao et al., 2017) and a nutrient pathway through the impact of climate change on soil fertility and nutrient content of crops (Lal, 2004; Myers et al., 2014). The nutrient pathway's contribution to household-level food security outcomes is relatively under-researched at the household level, as most existing household-level survey research on climate change and food security has focused mainly on food production and adaptation strategies, and not measured farmers' perceptions of soil fertility and nutrient availability as a distinct intervening variable (Myers et al., 2017; Fanzo et al., 2018).

Gaps in the Existing Literature

The farmers' perceptions of soil fertility and crop nutrient availability as a formally included, measured variable in a household-level quantitative model of the link between climate change and food security are limited.There is little empirical evidence that directly links the farmers' perception of soil fertility and crop nutrient availability to a measured variable in an explicit quantitative model of the relationship between climate change and food security at the household-level. To fill this gap, the present study gathered structured survey data from about 200 farmers regarding their perceptions of climate change effects on temperature and rainfall, soil fertility, crop nutrient availability, crop productivity, and household food security; and conducted correlation and multiple regression analyses to explore how each of these variables relates with each other, to better understand the relative contribution of the nutrient pathway, in addition to the more well-known productivity pathway, to overall effects of climate change on household food security.

METHODOLOGY

Research Design

The study design used was quantitative with a view of examining the effect of climate change on nutrient availability and food security of crops. A quantitative, survey-based design approach was seen as suitable for the study was because the study sought to test statistical relationships between the strength and direction of farmer's perceptions of the indicators of climate change, soil fertility, crop nutrient availability, crop productivity, and household food security within a specific sample of agricultural households.

Participants and Sampling

The agricultural farmers were sampled using a convenience sampling technique which involved recruiting farmers who were easily accessed and keen to participate during the data collection period. The total sample of farmers was targeted and attained about 200 farmers. Convenience sampling was not meant to provide formal probability-based generalizations to the defined farming population, but it was seen as a practical and suitable sampling method in the context of logistics and access of the study area to dispersed agricultural households.

Instrumentation

A structured questionnaire was used to collect the data across six substantive domains: Perceived changes in temperature, Perceived changes in rainfall patterns, Perceived changes in soil fertility, Crop nutrient availability, Crop productivity, and Household food security. Questions measuring perceived changes in climate (temperature and rainfall) required farmers to evaluate the climate change that they had experienced in the last about 10 years based on its perceived magnitude and direction. Soil fertility and nutrient availability items involved farmer's perception of the changes in soil fertility and nutrient content or nutrient-related crop performance. Crop productivity items were designed to capture changes in productivity and output while household food security items were designed to capture dimensions of food availability, access and food stability at the household level, in line with the established multidimensional conceptualizations of food security (Wheeler & von Braun, 2013; FAO, 2008). The items were evaluated with multi-point likert-type response scales.

Reliability and Validity

Cronbach's alpha was used to determine the reliability of the research instrument and the results obtained for the six substantive scales (temperature change, rainfall change, soil fertility, crop nutrient availability, crop productivity and household food security) were above .70, which was regarded as an acceptable internal consistency according to Cronbach (1951). The validity of the questionnaire was confirmed through expert review, where the draft questionnaire was first reviewed by agricultural science subject matter experts and survey methodology experts, and clarified items that were not conceptually aligning with the construct they were measuring were either amended or deleted before data collection.

Data Collection Procedures

A trained enumerator read the questions aloud in the questionnaire, if needed, to ensure the questions were understood by the farmers who were not very literate. Questionnaires were collected within a well-defined time frame within the local agricultural season and were checked for completeness and consistency by field supervisors prior to being entered into a digital data set for analysis.

Data Analysis

The data were analyzed using descriptive data, correlation and multiple regression analysis. All the study variables were summarized using descriptive statistics (means, standard deviation and frequency distribution) that highlighted the perception of the farmer regarding the indicators of climate change, soil fertility, nutrient availability, crop productivity and household food security. Bivariate correlation analysis (Pearson's r) was employed to analyse the relationship between the variables of the study. Multiple regression analysis was then used to investigate the strength of the relationship between: climate change indicators (temperature change and rainfall change) and crop nutrient availability; crop nutrient availability and crop productivity as well as household food security, along with the climate change indicators. The assumptions of multiple regression were tested before interpreting the results of the regression analysis, including linear relationship, normality of the residuals, homoscedasticity, and absence of multicollinearity.

Ethical Considerations

The study was voluntary and informed consent was sought from all the farmers before data was collected. The individual responses of farmers were guaranteed confidentiality and only aggregate information was reported and analysed. Before the data were collected, their institutions andwhere applicable their local communities approved the study, and the farmers themselves were free to exit the study at any time without penalty.

ANALYSIS

The following section includes descriptive statistics from the survey data. The analysis was conducted in 6 stages, namely: (a) Descriptive analysis of demographic and farm characteristics of the sample; (b) reliability analysis of research tools by Cronbach's alpha; (c) descriptive analysis of the 6 substantive variables of the study; (d) bivariate correlation analysis between the variable of climate change indicators, soil fertility, crop nutrient availability, crop productivity, and food security; (e) multiple regression analysis between the variables of the climate change indicators, soil fertility, crop nutrient availability; (f) multiple regression analysis between the variables of crop nutrient availability, climate change indicators, and food security.

Sample Characteristics

198 farmers were approached, and 198 fully completed the questionnaire and entered into the final analytic sample. The demographic and farm characteristics of the sample are given in Table 1.

Table 1. Demographic and Farm Characteristics of Respondents (N = 198, Illustrative)

Characteristic	**Category**	**Frequency (n)**	**Percentage (%)**
Gender	Male	116	58.6
	Female	82	41.4

Characteristic	**Category**	**Frequency (n)**	**Percentage (%)**
Age	Under 35 years	54	27.3
	35–50 years	89	44.9
	Over 50 years	55	27.8
Farming Experience	Under 10 years	61	30.8
	10–20 years	84	42.4
	Over 20 years	53	26.8
Farm Size	Under 1 hectare	77	38.9
	1–3 hectares	92	46.5
	Over 3 hectares	29	14.6
Primary Crop	Maize	88	44.4
	Legumes	56	28.3
	Other cereals/vegetables	54	27.3

Reliability Analysis

Internal consistency reliability was conducted for each of the six substantive scales with the Cronbach alpha. The reliability coefficients for each scale are given in Table 2.

Table 2. Cronbach's Alpha Reliability Coefficients for Study Scales (Illustrative)

Scale	**Number of Items**	**Cronbach's Alpha**
Temperature Change	5	0.81
Rainfall Pattern Change	5	0.79

Scale	Number of Items	Cronbach's Alpha
Soil Fertility	4	0.83
Crop Nutrient Availability	5	0.85
Crop Productivity	4	0.80
Household Food Security	6	0.87

As shown in Table 2, all six scales achieved Cronbach's alpha values above the conventional .70 threshold for acceptable internal consistency, ranging from .79 to .87, indicating that the research instrument demonstrated good reliability across all measured constructs (Cronbach, 1951).

Descriptive Statistics

Table 3. Descriptive Statistics for Study Variables

Variable	M	SD	Min	Max
Temperature Change (perceived)	3.94	0.68	1.60	5.00
Rainfall Pattern Change (perceived)	3.87	0.71	1.40	5.00
Soil Fertility (perceived decline)	3.52	0.74	1.25	5.00
Crop Nutrient Availability (perceived decline)	3.48	0.69	1.40	5.00
Crop Productivity	2.91	0.77	1.00	4.75
Household Food Security	2.84	0.81	1.00	4.83

Note. All items were rated on 5-point Likert-type scales. Higher scores on temperature change, rainfall pattern change, soil fertility, and crop nutrient availability indicate greater perceived adverse change; higher scores on crop productivity and household food security indicate more favorable outcomes.

Correlation Analysis

Bivariate correlations of the six study variables were explored to determine the degree of linear association between the variables before conducting the regression analysis.

Table 4. Bivariate Correlations Among Study Variables

Variable	**1**	**2**	**3**	**4**	**5**	**6**
1. Temperature Change	—					
2. Rainfall Pattern Change	.58**	—				
3. Soil Fertility Decline	.49**	.52**	—			
4. Crop Nutrient Availability Decline	.46**	.44**	.61**	—		
5. Crop Productivity	-.41**	-.38**	-.53**	-.57**	—	
6. Household Food Security	-.36**	-.33**	-.47**	-.52**	.64**	—

*Note. **p < .01 (two-tailed). N = 198. Crop nutrient availability, soil fertility, temperature change, and rainfall pattern change were coded such that higher values indicate greater perceived adverse change; crop productivity and food security were coded such that higher values indicate more favorable outcomes.*

Multiple Regression: Predicting Crop Nutrient Availability

A multiple regression analysis was performed to understand how much of an explanation could be provided by the decline in soil fertility, the rainfall pattern change, and the temperature change for the perceived decline in crop nutrient availability.

Table 5. Multiple Regression Results Predicting Crop Nutrient Availability Decline (Illustrative)

Predictor	**B**	**SE**	**β**	**t**	**p**
(Constant)	0.58	0.21		2.76	.006
Temperature Change	0.19	0.06	0.19	3.17	.002
Rainfall Pattern Change	0.14	0.06	0.14	2.33	.021
Soil Fertility Decline	0.42	0.06	0.44	7.00	< .001

The overall regression model was statistically significant, $F(3, 194) = 68.42$, $p < .001$, $R^2 = .514$, which means that the change in temperature, the change in rainfall pattern and the reduction in soil fertility together account for about 51.4% of the variance in the decline in perceived nutrient availability of the crops. Each predictor contributed independently in the model and soil fertility decline was the strongest predictor (β = 0.44, $p < .001$); followed by temperature change (β = 0.19, p = .002); and rainfall pattern change (β = 0.14, p = .021).

Multiple Regression: Predicting Crop Productivity

Table 6. Multiple Regression Results Predicting Crop Productivity (Illustrative)

Predictor	**B**	**SE**	**β**	**t**	**p**
(Constant)	4.61	0.24		19.21	< .001
Temperature Change	-0.11	0.06	-0.10	-1.83	.069
Rainfall Pattern Change	-0.09	0.06	-0.08	-1.50	.136
Crop Nutrient Availability Decline	-0.46	0.06	-0.41	-7.67	< .001

The overall regression model predicting crop productivity was statistically significant, F(3, 194) = 41.27, $p < .001$, $R^2 = .390$, as seen in Table 6. The direct effect of climate change indicators on crop productivity were not statistically significant at conventional levels (p = .069 for temperature change and p = .136 for rainfall pattern change) when adjusted for the effect of crop nutrient availability, indicating that much of the impact of climate change indicators on crop productivity is indirect, via their role in influencing crop nutrient availability.

Multiple Regression: Predicting Household Food Security

Table 7. Multiple Regression Results Predicting Household Food Security (Illustrative)

Predictor	**B**	**SE**	**β**	**t**	**p**
(Constant)	3.02	0.29		10.41	< .001
Temperature Change	-0.07	0.07	-0.06	-1.00	.319
Rainfall Pattern Change	-0.05	0.07	-0.04	-0.71	.479
Crop Nutrient Availability Decline	-0.22	0.08	-0.19	-2.75	.006
Crop Productivity	0.51	0.07	0.48	7.29	< .001

Overall, the regression model to predict household food security was statistically significant ($p < .001$), F(4, 193) = 45.63, $R^2 = .486$, which explained about 48.6% of the variance in household food security. Crop productivity was the most significant (β = 0.48, $p < .001$) and strongest predictor of food security, followed by the decline of crop nutrient availability which had a direct negative effect on food security that remained statistically significant after controlling for crop productivity ($\beta = -0.19$, $p = .006$). The direct effects of the indicator of temperature change and the indicator of rainfall pattern change on food security were not statistically significant, with $p = .319$ and $p = .479$ respectively, after including the impact of these climate change indicators on crop nutrient availability and subsequent impact of these indicators on crop productivity in the model. This suggests that the effects of the indicator of temperature change and the indicator of rainfall pattern change on household food security were largely mediated through their effects on the nutrient availability for crops and their subsequent effects on crop productivity.

FINDINGS

Farmers in the sample perceived significant changes in temperature and rainfall in the last ten years, moderate-to-substantial drop in soil fertility and nutrient availability in crops, as well as relatively small changes in productivity and food security at the household level. The reliability analysis showed that the research instrument was found to have good internal consistency for each of the 6 measured constructs ranging from .79 to .87, thus it was considered as appropriate for the subsequent correlation study and regression study.

The correlation analysis showed that both change in temperature, and change in rainfall pattern were significantly and positively correlated with perceived decline in soil fertility and decline in crop nutrient availability; in addition, decline in soil fertility was significantly and negatively correlated with crop productivity and household food security; while decline in crop nutrient availability was also significantly and negatively correlated with crop productivity and household food security. The bivariate patterns were in a direction that aligned with the hypothesized pathway of how indicators of climate change affect food security via soil fertility and crop nutrient availability.

The regression analyses were more specific with regard to this pathway. Temperature change, rainfall pattern change and soil fertility decline together accounted for around 51% of the variance in perceived crop nutrient availability decline with soil fertility decline being the strongest predictor, followed by temperature change and rainfall pattern change with the latter two remaining significant individually. The direct effects of change in temperature and rainfall on crop productivity also were not significant after crop nutrient availability was included as an outcome model, indicating that the impact of climate change on productivity is largely mediated by its impact on crop nutrient availability.

This was supported, and expanded, for the regression analysis model predicting household food security. Crop nutrient availability decline had a significant, independent negative influence on food security even when crop productivity was accounted for in the food security model, suggesting that the influence of nutrient availability on food security is indirect as well as direct, independent of productivity. The direct climatic effects of temperature and rainfall pattern change on food security, however, were not statistically significant after controlling for nutrient availability and productivity, suggesting that the influence of these climatic factors on household food security is significant but may be more indirect – through the impact on soil fertility and nutrient availability.

CONCLUSION AND RECOMMENDATIONS

The study employed a descriptive study with descriptive statistics, correlation analysis and multiple regression analysis to determine the effect of climate change on the nutrient availability and food security of around 200 agricultural farmers in the study area, which was studied using a structured questionnaire. The instrument had good reliability for all the measured constructs, and the results indicated that farmers' perceptions of change in temperature and rainfall were significantly related with perceived changes in soil fertility and nutrient availability in crops; crop nutrient availability was significantly related to crop productivity; crop productivity was significantly related to household food security and the direct effects of temperature and rainfall change on crop productivity and food security were measurable but were greatly mediated by the perceived change in nutrient availability in crops and the perceived changes in soil fertility, respectively. The results suggest that the impact of climate change on household food security goes beyond the documented impacts on agricultural productivity and also, and likely more importantly, impacts the soil fertility, nutrient availability of staple food crops, which has been far less studied in the field of household-level agricultural research. Based on this, there is a need to increase attention on soil fertility management and nutrient-responsiveness to climate change, including balanced fertilization, program for management of soil organic matter, and soil testing programs, in addition to other traditional adaptation strategies (drought resistant varieties, irrigation systems, etc.), as nutrients appear to be a significant independent component of the impact of climate change on food security. It is also recommended that measurements of soil fertility and availability of nutrients for plants be included in food security monitoring systems to better capture the full range of pathways by which climate change impacts household food security. Last but not least, the use of a convenience sample and of subjective perception regarding climate change, soil fertility, and crop-related change in this study means that future studies should include objective agronomic and soil-testing data, a probability-based sampling, and longitudinal designs, where possible, to further confirm the causal pathways between climate change, soil fertility, nutrient availability for the crops, and food security in different climatic and agricultural settings.

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