Crop Yield Responses to Climate Change in the Tropical Region of Nepal

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Abstract

The empirical relationships between n crop yield and climate variables are important for predicting agricultural production. The study assesses the effects of climate variables on crop yield and the uniformity of effects across crops, growing seasons, and locations in Nepal. The research covers three districts in the tropical region of Nepal, and considers four major food crops as paddy, maize, wheat, and potato. The data represent the observed district level averages on crop yield and climate variables (rainfall, maximum temperature, and minimum temperature) between1975 and2011. A multivariate regression analysis, based on the first difference time series of crop yield and climate variables, is employed to estimate the empirical relationships between crop yield and climate variables. The regression results show that climate variables significantly influence the crop yield, but not uniformly on all crops and in all growing seasons and districts. Increase or decrease of maximum and minimum temperature shows heterogeneous effects on the yield of some crops. Deviations of climate variables within growing seasons also show heterogeneous effects on crop yield. The study concludes that climate variables and their deviations within the growing seasons are the important determinants of crop yield. The effects of climate variables on crop yield depend on crop types, growing seasons, and locations. The effects can be significantly positive or negative or insignificant.

Keywords: Climate change, climate variables, crop yield, regression analysis

JEL classification: C32, Q10, Q54

1. Introduction

Variations in climatic conditions are associated with the variability of crop yield (Kim and Pang, 2009; Ines and Hansen, 2006 (Hoogenboom, 2000). Climate change affects crop growth and development, due to changes in the mean and variability of temperature and rainfall (Challinora and Wheeler, 2008). Temperature rise and rainfall variation cause drought, flood, landslide, and soil degradation that lead to declining global agricultural productivity (IPCC, 2007). The year-to-year variability of rainfall and temperature is the primary source of agricultural production risk that causes uncertainty in crop yield (Cabas *et al.*, 2010; Park and Sinclair, 1993). Farmers face variable income from year to year

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primarily because of variable weather conditions, diseases, and pests (Pannell *et al.*, 2000; Berbel, 1993; Fleisher, 1990). There is no uniformity in the direction and magnitude of climate variable effects on crops (Granger, 1980).

There is the likelihood of an asymmetric change in temperature where nighttime temperature increase is greater than the daytime temperature increase (Nagarajan*et al.*, 2010; Lobell and Ortiz-Monasterio, 2007; Dhakhwa and Campbell, 1998; Rosenzweig and Tubiello, 1996). Higher variability in temperature (higher maximum and lower minimum) negatively affects the yield of several crops (McCarl *et al.*, 2008). For example, the nighttime temperature increase beyond 22°C significantly adversely affects grain yield and quality in rice and reduction in spikelet fertility and grain weight per plant accounts for the decline in rice yield (Nagarajan *et al.*, 2010).The high temperature for a short period can affect the quantity and quality of wheat yield (Stone and Nicolas, 1995).

The impacts of climate change are severe in developing countries because they have rain-fed farming systems and weak capabilities in their technological adaptation (Ogallo *et al.*, 2000). Rain-fed agriculture is likely to be affected adversely by climate change (Pant, 2009). Because of high dependence on the agricultural sector, loss of agricultural productivity due to climate change significantly affects the economy of many developing countries (Gebreegziabher *et al.*, 2011). The impacts of climate change have already been noticed in the agricultural sector in Nepal. Nepalese agriculture is rain-fed and relies mainly on weather patterns, so even small and short period weather extremities adversely affect the production.The agricultural sector dominates Nepalese economy; the contribution of agriculture and forestry sectors to total Gross Domestic Product (GDP) over 2001/02 to 2010/11 is 34.2% on average (MoAD, 2012). Agricultural dependence makes the economy sensitive to climate variability (World Bank, 2002).

The impacts of climate change on crop yield is an important field of conducting research. The existing literature informs about the overall impact of climate change and requirements for suitable coping strategies to develop the agricultural sector. Previous studies (e.g. Welch *et al.*, 2010; McCarl*et al.*, 2008; Sheehy *et al.*, 2006; Chen *et al.*, 2004) suggest that there are heterogeneous effects of climate variables on crop yield that depend on crop types, growing seasons, and regions. However, these studies mainly consider large scales and generalize the climate variables' effects on crop yield and the effects depend on crop types and geographic-regions. The existing studies do not cover the assessments of the intra-regional site-specific variations of the impacts of climate change on crop yield. Spatial patterns of climate and their effects on crop yield are essential to identify vulnerability and determine the suitable regional agricultural adaptive strategies to climate change (Tao *et al.*, 2008). A better understanding of the empirical relationships between crop yield and climate variables is essential for implementing adaptation to climate change in agriculture (OECD, 2012).

There are few studies in Nepal (e.g. Poudeland Kotani, 2012; Joshi *et al.*, 2011; Malla, 2008) that empirically evaluate the effects of climate variables on crop yield. Malla (2008) analyzes the relationships between climate scenarios (elevated temperature and CO_2) and agriculture, which is based on data generated in a controlled experimental condition. Joshi *et al.* (2011) assess the relationships between crop yield and climate variables by using time series analysis, but their study does not cover the heterogeneity of climate change impacts on crop yield across spatial dimensions within Nepal and has limitations incapturing the effects of the intra-seasonal variations of climate variables on crop yield. Poudel and Kotani (2012) assess the relationships between crop yield and climate variables and the heterogeneity of impacts across growing seasons and altitudes in the central region of Nepal, but do not assess the heterogeneity of climate change impacts on crop yield within geographic regions and their study has limitations incapturing the effects of day versus night temperature on crop yield.

This study evaluates the empirical relationships between crop yield and the corresponding growing seasonal climate variables in different sites within a tropical region of Nepal. The study assesses the impacts of growing seasonal climate variables on the yield of the major food crops (paddy, maize, wheat, and potato) across crop types, growing seasons, and locations and adds information and insight to the existing literature of climate change impacts on Nepalese agriculture. The findings are useful for estimating climate variable effects on crop yield and the most vulnerable crops for prioritizing strategies for adapting to climate change.

2. Methods and Data

2.1 Regression Analysis

Application of regression models to predict crop yield changes due to changes in climate variables, based on historical data on crop yield and climate variables, is common (Poudel and Kotani, 2012; Joshi *et al.*, 2011; Welch *et al.*, 2010; Lobell and Burke, 2010; Schlenker and Lobell, 2010; You *et al.*, 2009; Kim and Pang, 2009; Schlenker and Roberts, 2009; Tao *et al.*, 2008; McCarl *et al.*, 2008; Tannura *et al.*, 2008; Lobell, 2007; Lobell and Field, 2007; Iglesias and Quiroga, 2007; Sheehy *et al.*, 2006; Tao *et al.*, 2006; Schlenker and Roberts, 2006; You *et al.*, 2005; Chen *et al.*, 2004; Chang, 2002; Nicholls, 1997; Granger, 1980). The regression model using observed data of crop yield and climate variables is based on time series or panel or cross-section data. In this study, a multivariate time series regression model is employed. The primary advantages of the time series regression model over the panel and cross-section models are to capture the behavior specific to the given area and control the errors from omitted variables such as crop management and soil quality that vary spatially (Lobelland Burke,2010). A common approach (Joshi *et al.*, 2011; Tao *et al.*, 2008; Lobell, 2007; Lobelland Field, 2007) based on the first difference time series (difference in values from one year to the next) for yield and climate variables is used. It is assumed that crop yield responds to year-to-year changes of climate variables, and use of the first difference time series of the crop yield helps to remove the non-climatic influences such as adoption of new varieties and changes in crop management practices (Joshi *et al.*, 2011;Lobell, 2007;Lobell and Field, 2007).

This study considers the widely used climate variables as rainfall and temperature to assess the impacts of climate change on the crop yield. Both maximum and minimum air temperatures are considered to assess the effects (direction and magnitude) of the day and night temperature on crop yield, assuming difference in the influence of day versus night temperature on crop. Maximum and minimum temperature can impactdifferently indifferent crops and ondifferent regions; temperature increase during the day can have different effects on the crop than temperature increase during the night. The understanding of the effects of temperature during the day and night on crop yield is necessary because warming trend during the day and night differs; minimum temperature has been rising faster than the maximum temperature in some Asian countries (Welch *et al.*, 2010). In most regions, maximum temperature increase is more harmful to crop yield than minimum temperature increase (Lobell, 2007).

Rather than using annual average data of rainfall and temperature, crop-specific growing seasonal averages are used to make the regression results realistic. Consideration of the growing seasonal average for each climate variable for each crop produces the best-fit model R^2 (Lobelland Field, 2007). This study considers the total growing seasonal rainfall, average growing seasonal maximum and minimum temperatures, and standard deviations of monthly rainfall and temperature within the growing season. The standard deviations of rainfall and temperature were included in the regression model to assess the intra-seasonal effects of climate variables on crop yield. The standard deviations of monthly rainfall and temperature within a growing season were considered on the basis that sub-seasonal variations (e.g. long dry period, intense rainfall) are critical to crop growth.

The Ordinary Least Square (OLS) method was used to estimate the contribution of climate variables to crop yield. The STATA was used to run the regression model. The multiple regression function estimated in the study is expressed as (Gujarati, 2004):

$$Y_i = \beta_0 + \sum_{n=1}^{k} \beta_n X_{ni} + \varepsilon_i \tag{2}$$

Where, i = the ith observation; Y_i (dependent variable) is the annual change in crop yield; β_0 is the constant term (intercept term); β_0 is the average value; and ε_i is the model prediction error (stochastic disturbance term); and X_n are independent variables.

More specifically, the regression model developed for this study is:

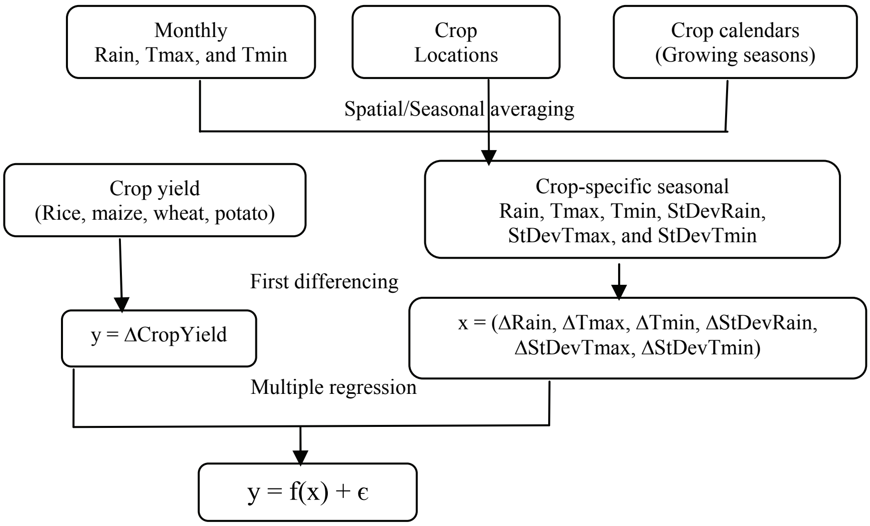
$$\Delta CropYield_i = \beta_0 + \beta_1 \Delta Rain_i + \beta_2 \Delta Tmax_i + \beta_3 \Delta Tmin_i + \beta_4 \Delta StDevRain_i + \beta_5 \Delta StDevTmax_i + \beta_6 \Delta StDevTmin_i + \epsilon_i \tag{3}$$

Where,

$$\Delta CropYield = f(\Delta Rain, \Delta Tmax, \Delta Tmin, \Delta StDevRain, \Delta StDevTmax, \Delta StDevTmin) \tag{4}$$

Figure 1 presents the sequential steps followed in the regression analysis. First, spatial and growing seasonal averages of the crop yield and the climate variables were estimated, followed by estimation of the first difference time series (year-to-year changes). Then the co-linearity among the predictor variables (climate variables) was checked, essential for interpreting the regression results (Welch *et al.*, 2010; Sheehy *et al.*, 2006). Correlations among the climate variables allow considering the presumed climate variables in the regression model. The response variable in the regression model is the first difference in the crop yield (ΔCropYield), and the predictor variables are the first differences in total growing seasonal rainfall (ΔRain), average growing seasonal maximum temperature (ΔTmax), average growing seasonal minimum temperature (ΔTmin), standard deviation of monthly rainfall within the growing season (ΔStDevRain), standard deviation of monthly maximum temperature within the growing season (ΔStDevTmax), and standard deviation of monthly minimum temperature within the growing season (ΔStDevTmin).

Figure 1: Overview of steps to estimate the crop yield-climate relationships



Source: Lobell, 2007.

2.2 Study Area and Data

The geographic divisions of Nepal include three regions as mountain, hill, and *Tarai*. The research represents the *Tarai* region of Nepal, representing three locations (west, center, and east). The *Tarai* region of Nepal holds large shares in the national agricultural production of the total land holding in *Tarai* which 34% is under cultivation, which accounts for 56% of the total cultivated land in the country (CBS, 2008). The *Tarai* lies in the low altitude region in the south of Nepal, which is flat, has a tropical climate, and is most vulnerable to climate change (Alamand Murray, 2005). In recent years, *Tarai* has witnessed an increase in frequency of erratic rainfall, floods, drought, heat waves, cold waves, and hailstorms and has the greatest risk of flooding that reduces agricultural productivity and disrupts economic activities (Dulal*et al.*, 2010). In such a context, this study covers three districts (one in each location): Banke (west), Chitwan (center) and Morang (east) in *Tarai*. Four major food crops —-paddy, maize, wheat, and potato — (Subedi, 2003) are considered.

The data secondary are observed crop yield and climate variables, obtained from the government offices in Nepal. Based on the availability of crop yield and climate data, the data used in the regression model cover the period from 1976/77 to 2010/11 for Banke (35 observations), from 1980/81 to 2010/11 for

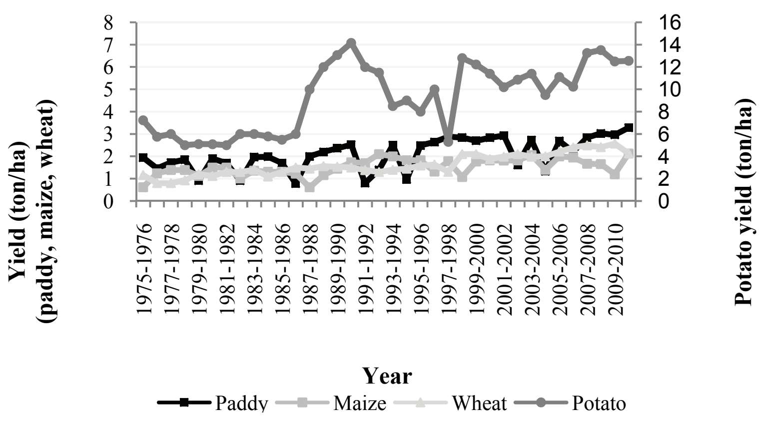
Chitwan (31 observations), and from 1975/76 to 2009/10 for Morang (35 observations). The sections that follow in brief offer explanations on the crop yield and climate data.

Crop Yield

The time series data on crop yield (district averages) were compiled from different publications such as statistical information on Nepalese agriculture by the Agri-Business Promotion and Statistics Division (ABPSD) of the Ministry of Agricultural Development (MoAD). The crop yield data follow the country's accounting period (fiscal year). Nepal's fiscal year (FY) begins from 16 July of the preceding year and ends on 15 July of the succeeding year for the country's accounting period of twelve months. The crop yield data represent the district average, which is the annual average of its growing seasons. In the study districts, paddy and maize are grown in summer and spring seasons, and wheat and potato in the winter season.

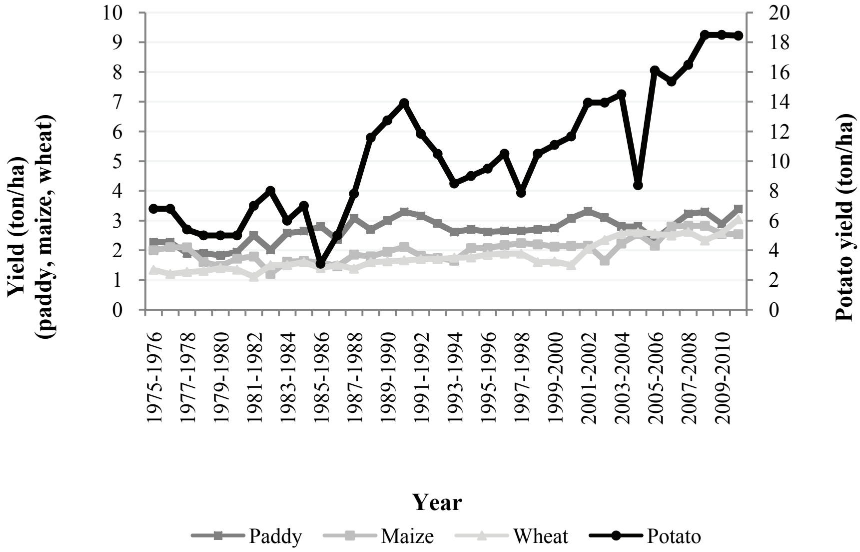
Time has a positive influence on crop yield because technological progress and crop management improvements occur over time (year). The crop yield observed in the study districts also increases over time; however, there are high fluctuations in the crop yield over the years. High variation in climate patterns could be one of the causes of crop yield fluctuations. Figures 2, 3, and 4 present the trends of paddy, maize, wheat, and potato yield from 1975/76 to 2010/11 in Banke, Chitwan, and Morang respectively.

Figure 2: Yearly Average of crop yield in Banke



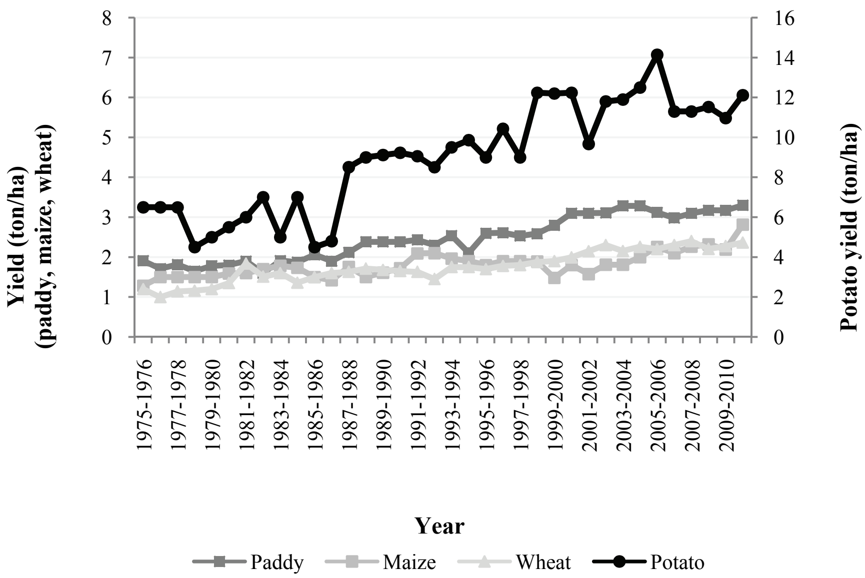
Source: MoAD, 1975/76-2010/11.

Figure 3: Annual average of crop yield in Chitwan



Source: MoAD, 1975/76-2010/11.

Figure 4: Annual average crop yield in Morang



Source: MoAD, 1975/76-2010/11.

Climate Variables

The data obtained on rainfall and temperature from various weather (meteorological) stations were provided by the Department of Hydrology and Meteorology (DHM) of the Ministry of Environment (MoE). The data are for twelve months from January to December. The monthly data on rainfall, maximum temperature, and minimum temperature were from thirteen meteorological stations in the study districts (Banke 7, Chitwan 3, Morang 3). District-wise averages of monthly rainfall and temperature were estimated by grouping available monthly data from the meteorological stations of each district.

Total growing seasonal rainfall and average growing seasonal maximum and minimum temperatures were considered in the regression analysis. Rainfall and temperature data were defined and separated for the three growing seasons (summer, winter, and spring) in a year. The summer season includes the months from July to October, the winter from November and December of the preceding year, January to February of the succeeding year, and the spring season includes the months from March to June. Monthly rainfall and temperature were considered to estimate seasonal rainfall and temperature. Total growing seasonal rainfall was obtained by adding the rainfall of four months in a growing season. The average growing seasonal temperature was obtained by taking an average of four months in a growing season. The population standard deviation was considered to calculate the standard deviations of monthly rainfall and temperature within the growing season.

Table 1 presents the summer, winter, and spring seasonal characteristics of rainfall and temperature and comparisons of their means among the study districts. Though all three districts represent the tropical region of Nepal, there are significant differences in the rainfall and temperature observed among the districts. Therefore, regression analysis for each crop across the study districts was done to assess the site-specific climatic impacts on crop yield.

Table 1: Characteristics of the growing seasonal climate variables in the study districts

Climate variable	Growing season	Statistics	District			Comparing means	
			Banke	Chitwan	Morang	F-value	Significance
Total seasonal rainfall (mm)	Summer	Average	1,022.13	1,390.70	1,370.67	17.739	0.000
		s. d.	248.65	301.87	310.44		
	Winter	Average	63.35	55.73	44.43	1.786	0.173
		s. d.	40.62	48.02	37.77		
	Spring	Average	285.49	568.44	575.86	44.259	0.000
		s. d.	110.28	156.23	166.20		

Climate variable	Growing season	Statistics	District			Comparing means	
			Banke	Chitwan	Morang	F-value	Significance
Seasonal maximum temperature (˚C)	Summer	Average	32.70	32.88	31.96	27.953	0.000
		s. d.	0.47	0.58	0.54		
	Winter	Average	24.48	25.38	25.81	26.136	0.000
		s. d.	0.78	0.76	0.79		
	Spring	Average	35.43	34.43	32.75	89.112	0.000
		s. d.	0.92	0.84	0.76		
Seasonal minimum temperature (˚C)	Summer	Average	23.82	23.58	24.22	11.177	0.000
		s. d.	0.61	0.61	0.44		
	Winter	Average	10.08	10.13	11.39	27.905	0.000
		s. d.	0.73	0.96	0.78		
	Spring	Average	20.41	19.66	21.05	29.895	0.000
		s. d.	0.68	0.78	0.72		

Source: Authors' calculations; data from DHM (Banke: 1976-2011, Chitwan: 1980-2011, Morang: 1975-2010).

3. Results and Discussion

3.1 Crop Yield-Climate Relationship

The results of regression show that climate variables play a significant role in predicting crop yield. However, the direction and magnitude of relationships between crop yield and climate variables vary substantially. The relationships which could be significantly positive, negative or insignificant depend on the existing trends of climate variables in the study districts. The regression model shows the variation in crop yield due to climate variables ranges from 12% (spring maize in Morang) to 61% (summer rice in Banke). In three districts, considering three significance levels1%, 5%, and 10%, three (16.6%) have rainfall coefficient significant, five (27.7%) have maximum temperature coefficient significant, three (16.6%) have minimum temperature coefficient significant, four (22.2%) have s. d. of rainfall coefficient significant, five (27.7%) have s. d. of maximum temperature coefficient significant, and five (27.7%) have s. d. of minimum temperature coefficient significant (tables 2, 3, and 4). These observations underscore the absolute importance of variations in climate variables for year-to-year changes in crop yield.

Table 2: Regression coefficients of growing seasonal climate variables for rice yield

Δ Climate variable	Δ Paddy yield in summer season (ton/ha)			Δ Paddy yield in spring season (ton/ha)		
	Banke	Chitwan	Morang	Banke	Chitwan	Morang
Δ Total seasonal rainfall (mm)	0.00049 (0.00055)	0.00026 (0.00024)	0.00009 (0.000)	-0.00175 (0.00228)	0.00007 (0.00087)	0.00100** (0.00038)
Δ Average seasonal maximum temperature (˚C)	-0.70328** (0.26248)	- 0.07487 (0.12879)	-0.03640 (0.078)	-0.24354 (0.16204)	-0.03943 (0.08807)	0.09508** (0.04211)
Δ Average seasonal minimum temperature (˚C)	0.26602* (0.14410)	0.11972 (0.15900)	0.04877 (0.076)	0.23342 (0.14374)	0.00880 (0.08660)	-0.05105 (0.05088)
Δ s. d. of rainfall (mm)	0.00027 (0.00194)	-0.00033 (0.00104)	-0.00021 (0.000)	0.00664 (0.00585)	-0.00052 (0.00263)	-0.00313*** (0.00111)
Δ s.d.of maximum temperature (˚C)	-0.74165** (0.32051)	-0.27430 (0.19579)	-0.04848 (0.134)	-0.39243** (0.14909)	-0.00734 (0.08360)	-0.00569 (0.04726)
Δ s. d. of minimum temperature (˚C)	0.04342 (0.24139)	0.12455 (0.18249)	-0.05758 (0.097)	-0.27748 (0.24212)	-0.12671* (0.07196)	-0.09303** (0.04638)
Model fit (R^2)	0.61	0.17	0.14	0.37	0.13	0.31

Note: Numbers in parentheses are standard errors. Statistical significance: *** at 1% level, ** at 5% level, * at 10% level.

Table 3: Regression coefficients of growing seasonal climate variables for maize yield

Δ Climate variable	Δ Maize yield in summer season (ton/ha)			Δ Maize yield in spring season (ton/ha)		
	Banke	**Chitwan**	**Morang**	**Banke**	**Chitwan**	**Morang**
Δ Total seasonal rainfall (mm)	-0.00002 (0.00033)	0.00039** (0.00017)	-0.00004 (0.00013)	-0.00102 (0.00113)	0.00090 (0.00072)	0.00016 (0.00040)
Δ Average seasonal maximum temperature (˚C)	-0.35039** (0.15787)	-0.01218 (0.09359)	0.04017 (0.07227)	-0.21449** (0.08049)	0.05171 (0.07259)	.02184 (0.04464)
Δ Average seasonal minimum temperature (˚C)	0.06862 (0.08666)	0.25913** (0.11554)	0.00211 (0.07066)	0.10650 (0.07140)	0.02252 (0.07138)	0.02147 (0.05394)
Δ s. d. of rainfall (mm)	-0.00230** (0.00116)	-0.00202** (0.00075)	0.00036 (0.00042)	0.00187 (0.00291)	-0.00222 (0.00217)	-0.00118 (0.00118)
Δ s. d. of maximum temperature (˚C)	-0.62549*** (0.19277)	-0.18606 (0.14227)	-0.13782 (0.12439)	-0.07113 (0.07405)	0.03234 (0.06890)	-0.02571 (0.05010)
Δ s. d. of minimum temperature (˚C)	0.30109** (0.14518)	0.21821 (0.13261)	-0.03035 (0.08987)	0.10737 (0.12027)	-0.07686 (0.05931)	0.04218 (0.04916)
Model fit (R^2)	0.37	0.38	0.16	0.30	0.16	0.12

Note: Numbers in parentheses are standard errors. Statistical significance: *** at 1% level, ** at 5% level.

Table 4: Regression coefficients of growing seasonal climate variables for wheat and potato yields

Δ Climate variable	Δ Wheat yield in winter season (ton/ha)			Δ Potato yield in winter season (ton/ha)		
	Banke	Chitwan	Morang	Banke	Chitwan	Morang
Δ Total seasonal rainfall (mm)	-0.00046 (0.00110)	0.00057 (0.00125)	0.00056 (0.00092)	-0.01839* (0.00965)	-0.00006 (0.01458)	-0.00403 (0.00815)
Δ Average seasonal maximum temperature (˚C)	0.09122** (0.04266)	-0.03292 (0.04535)	0.03620 (0.02832)	0.57072 (0.37169)	-0.56062 (0.52916)	0.17186 (0.25079)
Δ Average seasonal minimum temperature (˚C)	-0.04230 (0.03861)	-0.04829 (0.03908)	-0.04022 (0.02850)	-0.37164 (0.33646)	0.41873 (0.45596)	0.01597 (0.25240)
Δ s. d. of rainfall (mm)	0.01092** (0.00514)	-0.00029 (0.00426)	0.00214 (0.00415)	0.04374 (0.04485)	-0.04844 (0.04970)	-0.02181 (0.03680)
Δs. d. of maximum temperature (˚C)	0.10338* (0.05500)	0.04266 (0.05683)	-0.03632 (0.04024)	0.43986 (0.47917)	1.13646* (0.66304)	-0.06209 (0.35630)
Δ s. d. of minimum temperature (˚C)	0.02746 (0.06478)	0.03739 (0.05682)	-0.02973 (0.04554)	0.14643 (0.56439)	1.21379* (0.66302)	0.77093* (0.40327)
Model fit (R^2)	0.26	0.22	0.16	0.41	0.32	0.27

Note: Numbers in parentheses are standard errors. Statistical significance: ** at 5% level, * at 10% level.

In Banke, climate variables significantly affect paddy (summer), maize (summer), and wheat yields. The regression results show that temperature increase would drastically reduce paddy yield in Banke. Increased temperature could decrease paddy yield due to spikelet sterility and higher respiration loss

(Wassmann*et al.*, 2009). Climate variables significantly affect maize yield (summer) in Chitwan. Paddy yield (spring) in Morang is significantly affected by climate variables. Crops demand water, and rainfall is expected to have a positive influence on the crop yield. Regression coefficients also show significant negative influences of rainfall on crop yield (e.g. potato yield in Banke). The effect of rainfall on crop yield depends on water requirements of the crop. Farmers irrigate the field in winter and spring as per the requirements of the crops in critical growing stages. If there is rainfall immediately after irrigation, there would be excess water and the water logging conditions that exist in the fields can negatively affect crop yield.

There is high variability in the regression coefficients of maximum and minimum temperature; the day versus night temperature affects crops differently. In many cases, maximum temperature increase has a negative influence on crop yield. However, minimum temperature increase has a positive influence. For example, the maximum temperature increment can significantly negatively affect and the minimum temperature increment can significantly positively affect the summer season paddy yield in Banke. The minimum temperature rise benefits paddy yield whereas the maximum temperature rise harms it. The standard deviations of climate variables within a growing season also play major roles in predicting crop yield. The direction and magnitude of the effects of standard deviations of climate variables on crop yield also vary. In many cases, increased standard deviations of climate variables within a growing season have a negative influence on yield, but, in some cases, they leave a positive influence. In Banke, increased standard deviation of monthly rainfall within the growing season significantly negatively affects maize (summer) yield, but significantly positively affects wheat yield.

3.2 Crop Yield Responses to Climate Variability Under Different Climate Change Scenarios

The climate is changing day-by-day. The predictions of crop yield in changing climates are important for developing the agricultural sector. It is difficult to predict accurately the future climatic patterns. Therefore, assumptions are based on the historical climatic records. The past climatic trends show high annual, seasonal, and intra-seasonal variations of rainfall and temperature in the study districts. Temperature has been slightly increasing over the years whereas rainfall greatly varies (might be increased or decreased). Five hypothetical climate change scenarios have been considered to assess the possible impacts of climate change on crop yield. The first scenario represents a 2˚C increment in average growing seasonal maximum and minimum temperatures. The second scenario represents 20 percent reduction in total growing seasonal rainfall. The third scenario represents20 percent increment in total growing seasonal rainfall. The fourth scenario represents 2˚C increment in average growing seasonal maximum and minimum temperatures, along with a 20 percent reduction in total growing seasonal rainfall. The fifth scenario represents 20 percent increment in the standard deviations of rainfall and temperature within the growing season.

The impacts of the hypothetical climate change scenarios on crop yield were observed on the base scenarios. The base scenarios represent the existing trends that are the averages of the observed crop yield, the growing seasonal total rainfall, and average maximum and minimum temperatures from 1975 to 2011 (Banke: 1976-2011; Chitwan: 1980-2011; Morang: 1975-2010). The average yield impact of the climate change scenarios was computed by using regression coefficients for each crop across growing seasons and districts. The regression model is used for each crop at each site to compute the change in crop yield due to changes in the seasonal climate variables in five climate change scenarios. The crop yield change in the climate change scenario was expressed as a percentage change relative to the average of the observed historical yield.

The crop yield changes due to changes in climate variables in different climate change scenarios differ across the crop types, growing seasons, and locations (Table 5). The inter-district variations in changes in crop yield are due to the significant variations in district averages of rainfall and temperature. For example, the temperature increment would negatively affect paddy and maize yields in Banke where 2˚C increase in temperature leads to 38.4% reduction in paddy yield and 33.4% reduction in maize yield in summer. However, summer paddy yield would be increased by 3.2% and 1.0% respectively in Chitwan and Morang. The maize yield in summer in Chitwan would be increased by 24.2% with a 2˚C increase in temperature. There is inter-district variability in the average total summer seasonal rainfall lower: in Banke and comparatively higher in Chitwan and Morang. Increment in temperature brings drought in Banke, because there is less rainfall, and drought negatively affects crop yield.

Table 5: Percentage change in crop yield due to changes in seasonal climate variables in different climate change scenarios

Crop	District	Percentage change in crop yield in the hypothetical climate change scenarios				
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Paddy (summer)	Banke	-38.41	-4.77	+4.77	-43.18	-2.43
	Chitwan	+3.20	-2.58	+2.58	+0.62	-1.31
	Morang	+1.02	-1.02	+1.02	0.003	-0.96
Paddy (spring)	Banke	-0.96	+4.76	-4.76	+3.79	+1.74
	Chitwan	-2.19	-0.28	+0.28	-2.47	-1.33
	Morang	+3.62	-4.74	+4.74	-1.12	-4.87

Crop	District	Percentage change in crop yield in the hypothetical climate change scenarios				
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Maize (summer)	Banke	-33.45	+0.26	-0.26	-33.19	-8.80
	Chitwan	+24.21	-5.32	+5.32	+18.89	-5.73
	Morang	+4.75	+0.62	-0.62	+5.37	+0.27
Maize (spring)	Banke	-13.93	+3.76	-3.76	-10.18	+2.76
	Chitwan	+7.28	-5.02	+5.02	+2.26	-3.72
	Morang	+4.87	-1.04	+1.04	+3.83	-2.08
Wheat (winter)	Banke	+6.00	+0.36	-0.36	+6.36	+6.68
	Chitwan	-8.59	-0.34	+0.34	-8.93	+0.58
	Morang	-0.76	-0.29	+0.29	-0.75	+0.33
Potato (winter)	Banke	+4.27	+2.50	-2.50	+6.77	+4.78
	Chitwan	-2.57	+1.01	-1.01	-2.56	-0.54
	Morang	+4.22	+0.40	-0.40	+4.62	-0.61

Note: Scenario 1: 2˚C increment in average growing seasonal maximum and minimum temperature; Scenario 2:20 percent reduction in total growing seasonal rainfall; Scenario 3:20 percent increment in total growing seasonal rainfall; Scenario 4:2˚C increment in average growing seasonal maximum and minimum temperature, along with 20 percent reduction in total growing seasonal rainfall; Scenario 5:20 percent increment in the standard deviations of rainfall and temperature within the growing season.

4. Conclusion

Regression model, based on temporal and/or spatial variations in crop yield and climate patterns, is efficient to estimate the effects of climate change on crop yield. The spatial variations of climate patterns play a significant role in predicting the effects of climate variables on crop yield. The time series regression model is good for capturing site-to-site similarities/dissimilarities in crop yield responses to climate variables. Climate change patterns and their impacts on crop yield are spatially diverse across the regions (Tao *et al.*, 2006; Ogallo *et al.*, 2000). Changes in climate variables influence crop yield; however, the effects and their magnitudes differ across crop types, growing seasons, and locations .Climate change can have both negative and positive impacts on crop yield that depend on the characteristics of crops and physical growing locations (Kim and Pang, 2009). High intra-regional variations in the averages of rainfall and temperature are the major reasons for dissimilar impacts of climate change on crop yield in different locations of a region.

The study concludes that climate variables and their deviations within the growing seasons are the primary determinants of crop yield in rain-fed agriculture. The crop yield-climate relationship heavily depends on crop types, growing seasons, and spatial trends of climate variables. Intra-regional variations in climate patterns also influence crop yield differently in different locations within the same climatic region. It is, therefore, difficult to generalize the effects of climate change on crop yield. Agriculture adaptation strategies for minimizing the risk of climate change have to be identified and prioritized on the basis of crop types, growing seasons, and locations.

The empirical analysis does not capture the details of crop physiology, but it does capture the net effect of the processes by which climate variables affect yield. Besides climate variables (rainfall and temperature), other factors such as crop management practices (crop varieties, cultural practices etc.) also play a significant role in determining crop yield. The estimates of rainfall and temperature in this study do, therefore, not represent the correct determinants of crop yield. The findings are useful for estimating climate change impacts on crop yield and determining the most vulnerable crops for prioritizing adaptation strategies for climate change.

Acknowledgements

We are thankful to the government offices of Nepal, the Department of Hydrology and Meteorology (DHM) for providing the observed climate data and the Ministry of Agricultural Development (MoAD) for providing time series data oncrop yield. The German Academic Exchange Service (DAAD), Germany, financially supported this research.

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