Journal of Agricultural Science and Technology B 4 (2014) 38-48
Earlier title: Journal of Agricultural Science and Technology, ISSN 1939-1250

Climate Influence on Rice, Maize and Wheat Yields and Yield Variability in Nepal

Mahadeb Prasad Poudel[1], Shwu-En Chen[2] and Wen-Chi Huang[2]

1. District Agriculture Development Office under the Ministry of Agriculture Development, Triyuga Municipality, Udayapur, Nepal

2. Department of Agribusiness Management, National Pingtung University of Science and Technology, Pingtung 912, Taiwan

Received: November 18, 2013 / Published: January 20, 2014.

Abstract: The weather has a significant influence on yield fluctuations in Nepal, particularly for grains. This study examined the effect of seasonal precipitation, maximum and minimum temperatures and extreme climatic variables on yield levels and variability of rice, maize and wheat yields. The authors applied a stochastic production function approach as suggested by Just-Pope for panel data at the district level. The estimation results indicated that climate trends in Nepal had a significant influence on crop yield levels and variances in various magnitudes and directions. The results showed an increase in precipitation negatively influenced maize yield levels and positively influenced wheat yield levels; however, a positive influence was found to reduce yield variability in rice and wheat. Similarly, an increase in maximum temperature apparently led to decreased maize and increased wheat yield levels, respectively, and also led to increased yield variability in rice and maize. Likewise, the minimum temperature was helpful to increase yield levels for all crops and to decrease the yield variability in rice and maize. Moreover, the extreme climates such as low precipitation and high maximum temperatures significantly influenced the reduction in yield levels of rice and maize, respectively that could be used to design an index insurance product for Nepal.

Key words: Climate change, extreme climate, stochastic production function, yield variability, Nepal.

1. Introduction

The economy of Nepal is based on agriculture and it plays a crucial role in overall economic development. In 2010-2011, agriculture shared 36.5% contribution to total gross domestic product (GDP) [1]. The heavy dependency on agriculture and its fluctuations of production in this sector negatively influence overall economic growth. Moreover, production fluctuation influences economic growth and the food supply of Nepal. The area under irrigation is only 47% of the total agricultural land [2]; therefore, agricultural production, especially food grain production, is heavily dependent on the climate. As its weather dependency is higher, Nepal has developed a food surplus in years with favorable weather and a food deficit in others [3].

On the other hand, climate change has been observed in Nepal. Monsoon rains (about 80% of total annual precipitation in Nepal) have shown changes in intensity and amounts. The average precipitation in Nepal showed an increasing trend from 1976 to 2005. However, this trend indicated diverse patterns, such as negative to positive, in different regions of Nepal [4]. Similarly, at disaggregated levels, pre-monsoon, monsoon and post-monsoon precipitation have shown changing trends. Likewise, overall country average maximum temperature indicated an increasing trend [4-6], whereas the minimum temperature showed a decreased trend in the North and West parts with an increased trend in the South-East parts of Nepal [4]. The country has observed erratic precipitation, droughts and floods in recent years.

Recent studies claim that climate change and

Corresponding author: Mahadeb Prasad Poudel, Ph.D., agricultural economist, research fields: economic analysis of agriculture production and marketing. E-mail: mahadeb200@hotmail.com.

global warming have influenced agriculture, particularly for crop yields [4, 7-14]. These studies present the mixed effects of temperature on crop yields. Lobell and Asner (2003) [7] reported that increased temperatures in the US had a negative effect on corn and soybean yields, with no relationship for yields on changes in precipitation and solar radiation. Likewise, Lobell et al. (2011) [15] reported that increased temperatures in different countries have influenced a net decrease in maize and wheat yields by 3.1% and 4.9%, respectively. In contrast, Nicholls (1997) [16] reported that increased minimum temperatures contributed to 30%-50% of the total wheat yield increases in Australia since 1952.

Although previous studies examined the effect of climate change on crop yields in different countries, only a few have used Nepal [5, 17]. Joshi et al. (2011) [5] indicated that summer rains had a positive effect on rice and summer maximum temperatures had a negative effect on maize, from data based on national level climates and crop yields. However, Nepal's geography presents huge climate diversities on one hand and heterogeneous climate change patterns on the other hand. Therefore, any studies based on national level aggregate data with a diverse geographical and climatic change may exist and may incorrectly capture the effect of climate change.

Moreover, in recent years, the government of Nepal has recognized the problem of crop yield fluctuations and prioritized the need for crop insurance in Agricultural Policy: 2004 [18, 19]. In view of climate influence on crop yields, crop insurance feasibility studies carried out in Nepal suggested that weather index crop insurance products are a suitable insurance product [20]. Unfortunately, no studies followed to examine the effect of climatic factors on crop yield levels and variance.

Given some patterns of climate change in Nepal and the prospect of supporting the development of an index insurance product, this study examined the effect of seasonal precipitation, maximum and minimum temperatures as well as extreme conditions of climatic factors on yield levels and the variability of rice, maize and wheat yields.

This study contributes to the present literature by developing a regression model including extreme climatic situations to determine the effect of climate change on yield levels and yield variances. This paper is organized as follows: section two explains methodology; section three gives the results and discussion; finally, section four concludes the study by explaining its implications.

2. Methodology

In recent literature, temperature, precipitation and solar radiation have been used to evaluate climate change effects on the crop yields [21, 22]. Solar radiation and temperature are positively correlated. It is a possibility of the multicollinearity effect in the analysis [5]. Other recent studies have applied precipitation and temperature in similar studies [5, 8, 12]. Both minimum and maximum temperatures are suitable variables in climate change effect studies to capture the effects of both temperatures. The authors selected precipitation, minimum and maximum temperatures as drivers in this study. Moreover, to capture the effect of technological and management progresses on yield, they included trend variables as part of the analysis.

In addition, different levels of precipitation and temperature could affect crop yields in various directions and at different magnitudes. However, it is not convenient to evaluate a series of extreme climatic conditions. Rosenzweig et al. (2002) [23] presented the negative effects of mean plus one standard deviation of precipitation on maize yields. For the estimation precision, the authors used the approach of Rosenzweig et al. (2002) [23] and considered extreme climatic conditions as the levels of climate variables that exceed the mean plus/minus one standard deviation. Based on this, the authors categorized climatic situations in three groups such as high-extreme, low-extreme and normal situations. The high-extreme situation is defined as greater than average plus one standard deviation, the low-extreme situation is defined as less than average minus one standard deviation, and the remaining conditions are the normal situations (Fig. 1).

2.1 Empirical Model

Simulation models are widely applied to estimate the impact of climate change on crop yields [21, 24-27]. However, relatively few studies have applied regression models [7, 12, 14, 28]. The simulation models are primarily based on biophysical attributes, while regression models are based on observed data from past periods. This analysis followed the maximum likelihood models for empirical study.

Linear and quartile regression models are also commonly applied to assess the effects of climate change on yield levels [5, 7, 12, 15], whereas Just and Pope production functions are used to investigate the yield variability effects [8, 9, 13, 14]. This study follows model suggested by Just and Pope (1978) [29] production functions and primarily focuses on the climate change effects on yield variability. Production functions as developed by Just and Pope have two parts: (1) deterministic and (2) stochastic. The deterministic part explains yield levels and the stochastic part captures yield variations. The Just and Pope production function is:

$$Y_i = f(X_i, \beta) + h(X_i, \alpha)\varepsilon_i \tag{1}$$

where, Y_i is crop yield; the functional form $f(X_i, \beta)$ is a deterministic functional form, which is the average production function; $h(X_i, \alpha)$ is the variance function; X_i is a vector of independent variables; β and α are parameters. Moreover, functional form $h(X_i, \alpha)$ uses the heteroscedasticity error, which explains the variability effect of independent variables on yields. Estimates of each β and α parameters explain the effects of the corresponding explanatory variables, which, in turn, assess the effect of independent variables on the mean and the variance of the yield, respectively.

Just and Pope production function estimation is interpreted by using heteroscedasticity error term as:

$$Y_i = f(X_i, \beta) + u_i \tag{2}$$

$$u_i = h(X_i, \alpha) \tag{3}$$

where, Y_i are the dependent variables; X_i is the set of the independent variables; u is the disturbance term with mean 0 and variance $\sigma^2_{u_i}$.

In the economic literature, ordinary least squares (OLS), feasible generalized least squares (FGLS) and maximum likelihood estimation (MLE) were applied to optimize linear and nonlinear functional forms. FGLS is preferred over OLS when heteroscedasticity

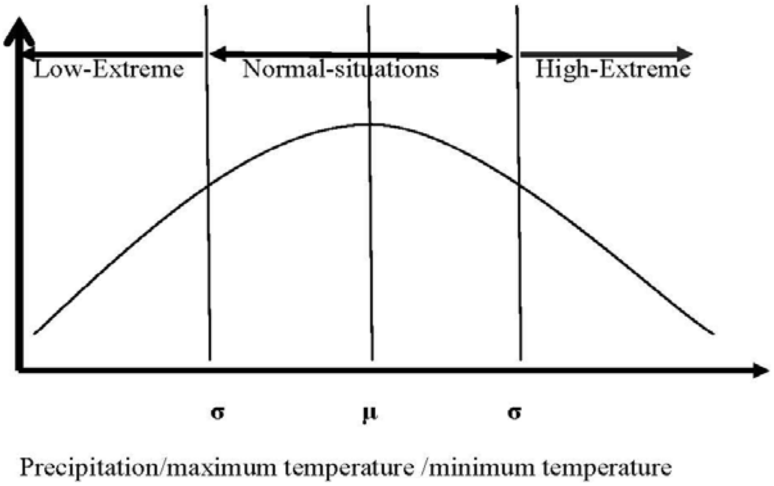

Fig. 1 Schematic diagram shows the low-extreme, high-extreme and normal-situations of precipitation, maximum temperature and minimum temperature.

is present in the samples. Likewise, MLE dominates FGLS when the sample numbers are small. Since, the time series data lengths are small, MLE has been applied. The authors followed the log-likelihood equation of Chen et al. (2004) [8] and Saha et al. (1997) [30] which is:

$$\ln L = -\frac{1}{2}\left[n \times \ln(2\pi) + \sum_{i=1}^{n} \ln(h(X_i, \alpha)^2) + \sum_{i=1}^{n} \frac{(Y_i - f(X_i, \beta))^2}{h(X_i, \alpha)^2} \right] \quad (4)$$

where, L represents likelihood function; Y_i represents yields of rice, maize and wheat; X_i represents the time trend, precipitation, maximum temperature, minimum temperature and six dummy variables of extreme climatic variables. The authors applied dummy variables for low- and high-extreme values on precipitation, minimum and maximum temperatures. Likewise, n represents the number of observations; i represents time, i.e., 1, 2, … , n. Table 1 explains the dependent and independent variables.

2.2 Data Sources

Yield data for rice, maize and wheat was obtained from the Ministry of Agriculture Development, Nepal [3] from 1990/1991 to 2009/2010. The yields are expressed in kg/ha. Monthly total precipitation, average maximum temperature and minimum temperature were obtained from the Department of Hydrology and Meteorology, Nepal [31]. The precipitation is measured in mm and minimum and maximum temperatures are measured in degree Celsius (°C). Originally, the authors collected 19 stations data—covering 19 administrative districts out of 75 districts in Nepal—on precipitation, maximum and minimum temperatures from 1990 to 2010. However, due to missing values in the original data from seven districts, it was able to use only 12 districts all together. These 12 districts cover all ecological zones such as Terai (plain area), hills and mountains as well as Eastern, Central, Western, Mid-Western and Far-Western regions of Nepal (Fig. 2). The country is divided into three agro-ecological zones based on altitude. Pariwar (2008) [32] explained ecological divisions in Nepal as: Terai < 500 m, hills 501-2,500 m and mountains > 2,501 m from mean sea level.

Furthermore, the crop growing seasons vary among the different ecological zones in Nepal. In general, rice is grown from June to November across Nepal, whereas wheat is grown from November to May in the mountain region and November to April in the hills and the Terai regions. Similarly, majority of maize is

Table 1 Description of the dependent and independent variables.

Variables	Description
Crop yield	Annual average yields (kg/ha) of rice, maize and wheat in each sample district.
Time	Time trend: e.g., 1 for 1991, 2 for 1992, …, 21 for 2010.
Precipitation	Total precipitation (mm) during growing season of rice, maize and wheat in each sample district.
Maximum temperature	Average maximum temperature (°C) during growing season of rice, maize and wheat in each sample district.
Minimum temperature	Average minimum temperature (°C) during growing season of rice, maize and wheat in each sample district.
High-precipitation	It is a dummy variable. High-precipitation = 1, if seasonal total precipitation in any year > average seasonal precipitation (μ) + one standard deviation (σ); 0, otherwise.
Low-precipitation	It is a dummy variable. Low-precipitation = 1, if seasonal total precipitation in any year < average seasonal precipitation (μ) − one standard deviation (σ); 0, otherwise.
High-maxtemp	It is a dummy variable. High-maxtemp = 1, if seasonal average maximum temperature in any year > average seasonal maximum temperature (μ) + one standard deviation (σ); 0, otherwise.
Low-maxtemp	It is a dummy variable. Low-maxtemp = 1, if seasonal average minimum temperature in any year < average seasonal minimum temperature (μ) − one standard deviation (σ); 0, otherwise.
High-mintemp	It is a dummy variable. High-mintemp = 1, if seasonal average minimum temperature in any year > average seasonal minimum temperature (μ) + one standard deviation (σ); 0, otherwise.
Low-mintemp	It is a dummy variable. Low-mintemp = 1, if seasonal minimum temperature in any year < average seasonal minimum temperature (μ) − one standard deviation (σ); 0, otherwise.

Fig. 2 Study districts along with ecological and political divisions of Nepal.

Table 2 Descriptive statistics of rice, maize and wheat yields (kg/ha) and their growing season precipitation (mm), minimum temperature (°C) and maximum temperature (°C).

Variables	Districts Numbers	Observations	Mean	Std. Dev.	Minimum	Maximum
Panel A: rice						
Rice yield	12	252	2,585.63	506.12	761.00	3,900.00
Precipitation (mm)	12	252	1,822.11	778.71	478.4	4,347.50
Max. Temp. (°C)	12	252	30.36	3.01	22.83	33.63
Min. Temp. (°C)	12	252	22.07	3.70	8.2	24.27
Panel B: maize						
Maize yield	12	252	1,910.99	425.37	934.00	3,140.00
Precipitation (mm)	12	252	1,234.49	1,086.34	160.10	4,682.50
Max. Temp. (°C)	12	252	30.44	3.22	21.97	34.62
Min. Temp. (°C)	12	252	17.62	2.83	6.33	21.70
Panel C: wheat						
Wheat yield	12	240	1,881.12	516.45	538.00	3,472.00
Precipitation (mm)	12	240	164.56	103.29	0.00	535.20
Max. Temp. (°C)	12	240	25.68	3.62	15.90	30.40
Min. Temp. (°C)	12	240	10.75	3.87	-3.54	15.10

Source: authors' estimation based on MoAD (2011) [3] and DMH (2011) [31] data.

grown from March to September in mountains and hills, and February to June in the Terai region [5]. Moreover, the authors estimated the seasonal total precipitation (mm), seasonal average maximum and minimum temperature (°C) in a particular district based on the growing season or crop calendar of the concerned crop. According to the growing season, the authors obtained a 21-year data set for yields and seasonal climatic variables for rice and maize in all sampled districts. Only 20-year data set of yield and seasonal climatic variables were obtained for wheat. Thus, one data set (yields and all climatic variables) for wheat was lost because of its crop calendar from November to March/April. Table 2 presents summary statistics of the data.

The study applied the panel linear regression model on seasonal precipitation, minimum and maximum temperatures for rice, maize and wheat with time tends. Regression results revealed that seasonal maximum and minimum temperatures for all crops showed a statistically significant positive trend; however, no trend was found in seasonal precipitation for the crops in this study.

Since the authors applied panel data in the analysis, a unit root test was conducted. The literature explains that time series data with more than 20 years should be tested for stationarity since a spurious result could arise due to non-stationarity on the time series variables [12]. Accordingly, the authors conducted a panel unit root test by applying the model proposed by Im et al. (1997) [33], because panel data were applied for the analysis. The results showed that all the dependent and independent variables rejected the null hypotheses of unit root at 0.01 significance level, which meant that the variables were stationary at that level. Moreover, the authors applied the Hausman test statistics to ascertain the correct panel data model for random effects or fixed effects. Based on the test statistics, they failed to reject the null hypothesis of random effect at 0.1 level, which meant that the random effect model was consistent and efficient. Since the random effects model is more consistent and efficient than the fixed effects model for all the estimated yield equations, they applied a random effect model in this study.

3. Results and Discussion

3.1 Average Yield

Table 3 presents MLE results of average functions. The estimation results of the average rice yield function showed a statistically significant positive trend of 38.42 kg/ha/year. The coefficient for minimum temperature showed a positive sign to indicate that the minimum temperature had a statistically significant positive effect on rice yield levels, so that an increase of 1 °C in minimum temperature increased rice yields by 68.03 kg/ha/year. The results also showed that there was an insignificant effect of precipitation and maximum temperature on average rice yields. The effect of minimum temperature on rice yields was in contrast with the results of Joshi et al. (2011) [5]. They presented negative effects but lacked the significant effect of minimum temperature on rice yields. Their results were derived by applying the national level average yields and climate data, whereas this analysis is based on the panel data analysis using district level data. Therefore, the differences observed between both studies may be the result of disparities in data aggregation.

In addition, results in Table 3 have indicated that low precipitation had a statistically significant negative impact on rice yield levels; however, high precipitation and low and high conditions of maximum and minimum temperatures were insignificant. Hence, if seasonal precipitations decrease by one standard deviation on the average precipitation, rice yields are reduced by 138.028 kg/ha/year compared to normal-situations. The negative effect of shortage of precipitation on yield levels met the authors' expectations because rice is a higher water-demanding crop; therefore, a shortage of precipitation might have a negative effect on average yields. This is perhaps the most important outcome to take into account for the design of an index insurance product for rice, in relation to the precipitation based on the critical amounts of one standard deviation less than the average precipitation.

In the case of maize, these results showed a significant positive trend with an increase in yields by

37.868 kg/ha/year. The seasonal precipitation coefficient showed a negative sign and predicted that 1 mm precipitation increases will negatively influence maize yields by 0.06 kg/ha/year. Maize is grown during summer, which is a major rainfall period in Nepal. Thus, heavy rainfall might have a negative impact on maize yields. On the other hand, the minimum temperature coefficient showed statistically significant positive signs to indicate a positive impact of raised minimum temperature on maize yields. The statistics showed that a 1 °C increase in minimum temperature determined an increase in maize yield of 71.03 kg/ha/year. The coefficient of maximum temperature indicated a negative impact on maize yields, which could be quantified in a decrease in yield of 23.56 kg/ha/year for a 1 °C increase in maximum temperature. These findings on temperature effects are somehow consistent with the results of Lobell and Field (2007) [10], which also pointed out that an increase in average temperature had a negative effect on maize yield. The relation of night and day temperatures could explain the positive effect of minimum temperature and the negative effect of maximum temperature on maize yields during the reproductive stage. To a certain extent, the increase of night (minimum temperature) and day temperatures (maximum temperature) increased maize yields. However, yields start to decline after crossing a particular threshold for the higher levels of the average temperature, because heat might shorten the reproductive stage and net assimilation periods [34].

A decrease in precipitation had a significant positive influence on maize yields (Table 3) that increased by 101.56 kg/ha/year. Similarly, low minimum temperature increased yields by 93.01 kg/ha/year when compared to normal-situations. The signs of low precipitation and low minimum temperature were unexpected. These results might be linked to the fact that maize crops are grown during the monsoon period, which is a high rainfall period for Nepal. Maize crops do not tolerate soil water-logging conditions; therefore, low precipitation could be beneficial for growth and yield. Likewise, the majority of the sample districts are from Terai area, where minimum temperature is also higher for maize growing season, i.e., summer time, and may not provide the ideal ambient conditions to maximize net assimilation. Thus, low minimum temperature might have positive effects on maize yield levels. Similarly, the high minimum temperature showed a significant positive influence on maize yield that could be estimated to be higher than normal-situations yield by 184.42 kg/ha/year. In contrast, a high maximum temperature has a significant negative influence on yields, which was quantified in a reduction of 112.01 kg/ha/year when compared to normal-situations. These outcomes might be expected, since higher minimum temperature in hill and mountain districts determine favorable conditions for vegetative as well as for reproductive stages.

In contrast, for maximum temperature, the explanation could be different. As the maximum temperature crosses the upper limit of ambient temperature, it might have negative influence on the net assimilation; consequently, on the yield level. The outcome of negative effect of high maximum temperature on maize yield level could be crucial for developing index insurance products for maize based on the critical level of maximum temperature, i.e., one standard deviation greater than the average maximum temperature.

The results on wheat yields indicated a statistically significant positive trend by 46.47 kg/ha/year. Similarly, precipitation, maximum and minimum temperatures had a positive influence on wheat yields. After controlling for the effect of other variables, the results indicated that an increase of 1 mm precipitation, 1 °C maximum and minimum temperature impacted wheat yields to 0.782, 56.00 and 44.856 kg/ha/year, respectively. These results contrast with the results of Chen et al. (2004) [8]. The results of Chen et al. (2004) [8] showed the negative effect of precipitation and

Table 3 MLE results of average crop yield functions ($f(X_i, \beta)$).

	Rice	Maize	Wheat
Constant	90.653 (293.165)	997.787 (180.229)***	-636.837 (301.325)**
Time	38.421 (3.281)***	37.868 (3.508)***	46.472 (3.370)***
Precipitation	-0.013 (0.022)	-0.055 (0.021)***	0.782 (0.367)**
Maximum temperature	25.615 (19.186)	-23.258 (14.020)*	56.003 (14.208)***
Minimum temperature	68.032 (17.357)***	71.030 (20.716)***	44.856 (10.777)***
High-precipitation	-41.507 (47.633)	-88.798 (58.197)	-44.399 (70.899)
Low-precipitation	-138.028 (64.048)**	101.560 (52.165)*	-49.3999 (63.681)
High-maxtemp	-44.901 (42.352)	-112.101 (49.443)**	-95.833 (61.658)
Low-maxtemp	-4.732 (49.597)	55.220 (52.895)	47.540 (63.059)
High-mintemp	-75.485 (69.549)	184.417 (86.552)**	31.167 (55.230)
Low-mintemp	5.205 (78.204)	93.011 (51.743)*	3.233 (65.809)
Wald test statistics	418.150	189.170	883.860
Probability > Chi-squared	0.000	0.000	0.000

note: ***, ** and * indicate significant at 0.01, 0.05 and 0.1 level, respectively.

temperature. The positive relation of wheat yields to precipitation may be caused by wheat growing during winter in Nepal and is relatively a dry season. Therefore, good precipitation can have a positive effect on wheat yields. Moreover, positive relations for wheat yields to maximum and minimum temperatures could be caused by some sample districts that are from hill and mountain regions where both temperatures are relatively low, therefore, the increase of both temperatures may have a positive effect on average yields. However, the result has further showed that there was an insignificant effect of low and high situations climatic factors on wheat yield levels in Nepal during the study period.

3.2 Yield Variability

Table 4 presents the results of yield variability effects of climate change. The results indicate that there was a lack of significant effect for time trends on rice yield variances, whereas a significant positive effect for time trends was observed for maize and wheat yields in Nepal. Similarly, estimation results showed that precipitation had a significantly negative effect on rice and wheat yield variances; however, it had no significant effect on maize yield variances. The results indicated that precipitation was seen as a risk decreasing factor for rice and wheat in Nepal. The wheat yield results are consistent with results presented by Chen et al. (2004) [8]. The results could be explained as that rice is a higher water-demanding crop and wheat is grown during the dry season in Nepal. Therefore, higher precipitation may help to reduce the yield variability in these crops. Likewise, results have indicated that minimum temperature had a significant negative influence on rice and maize yield variances to indicate the minimum temperature was helpful to reduce the yield risks for rice and maize. In contrast, maximum temperature had a significant positive influence on rice and maize yield variances to indicate that the maximum temperature was helpful to increase the yield risks for rice and maize. Chen et al. (2004) [8] reported that average temperature was helpful to increase the maize yield variances; this is somehow consistent with the authors' results.

Among the high and low climatic variables, the high minimum temperature showed significant positive signs on rice yield variances; therefore, the authors observed risk increasing effects of high minimum temperature on the rice yields. Likewise, high precipitation had a statistically significant positive influence on wheat yields to indicate that high precipitation was helpful to increase the wheat yield variability in Nepal. The low maximum temperature revealed the risk increasing effect on maize yields.

Table 4 MLE results of yield variability function ($h(X_i, \alpha)$).

	Rice	Maize	Wheat
Constant	-155.507 (247.044)	-46.157 (160.946)	1,118.432 (451.799)**
Time	2.348 (2.875)	11.684 (2.915)***	31.825 (5.278)***
Precipitation	-0.049 (0.024)**	-0.016 (0.017)	-1.157 (0.416)***
Maximum temperature	42.536 (19.715)**	25.966 (12.127)**	-29.261 (21.533)
Minimum temperature	-40.741 (18.648)**	-32.746 (18.162)*	-2.349 (18.527)
High-precipitation	23.359 (48.240)	17.978 (41.951)	195.62 (99.182)**
Low-precipitation	74.134 (48.807)	39.696 (42.306)	-140.591 (76.439)
High-maxtemp	-59.793 (47.879)	-56.833 (41.273)	-34.340 (54.463)
Low-maxtemp	16.414 (42.375)	79.264 (39.240)**	-54.069 (75.693)
High-mintemp	93.249 (46.496)**	91.353 (74.205)	49.723 (113.947)
Low-mintemp	86.730 (62.245)	-31.580 (47.630)	12.506 (39.959)

note: ***, ** and * indicate significant at 0.01, 0.05 and 0.1 level, respectively.

Table 5 Elasticity of mean yield and yield variance to climatic factors change.

Climate variables	Crop elasticities		
	Rice	Maize	Wheat
Mean yield			
Precipitation	N.S.	0.505	0.068
Maximum temperature	N.S.	-0.370	0.765
Minimum temperature	0.581	0.655	0.256
Variance			
Precipitation	-0.035	N.S.	-0.101
Maximum temperature	0.499	0.414	N.S.
Minimum temperature	-0.348	-0.302	N.S.

note: elasticities of average yields are coefficients (Table 3) multiplied by the ratios of average climatic factors to average yield, whereas elasticities of yield variance are coefficients (Table 4) multiplied by the ratios of average climatic factors to average yield. N.S. indicates not significant.

3.3 Yield Elasticity

The study also examined the elasticities of average yield and yield variances for rice, maize and wheat in relation to precipitation, maximum and minimum temperatures. Table 5 shows the estimation results and the average yield elasticities for rice, maize and wheat in relation to the respective seasonal precipitation, maximum and minimum temperatures that were seen positive except maize yield elasticity with maximum temperature. However, the average yield elasticity of rice, maize and wheat with concerning seasonal precipitation, maximum temperature and minimum temperature were observed less than 1% to indicate that average yields were inelastic to the climatic factors. Similarly, yield variance elasticities for rice, maize and wheat with concerning seasonal precipitation, maximum and minimum temperatures were also observed less than 1%. Thus, yield variances of rice, maize and wheat were inelastic to the climatic factors in Nepal.

4. Conclusions

The weather has a significant influence on agricultural production in Nepal, as it is heavily dependent on weather. Nepal has developed a food surplus in years with favorable weather and a food deficit in others. Thus, the authors examined the effect of seasonal precipitation, maximum and minimum temperatures as well as extreme conditions of climatic variables on yield levels and variability of rice, maize and wheat yields. Following Just-Pope (1978) [29] stochastic production function, they developed a framework to estimate the potential influence of climate changes in rice, maize, wheat yields and yield variability in Nepal. They applied panel data for rice, maize and wheat yield as dependent variables and seasonal precipitation, maximum and minimum temperatures of concerning crops as well as the extreme situations of climatic factors. MLE results showed a change in average climatic conditions significantly influenced yield levels in crops; however, the effects differed for different crops. Increase in precipitation and maximum temperatures separately showed no significant effect on rice yields, a negative effect on maize yields, and a positive effect on wheat yields. In contrast, an increase in minimum temperature helped to increase the yield levels for all the three corps. On the other hand, the variability results indicated that precipitation was found helpful to decrease variability on rice and wheat yields. The minimum temperature was found helpful to reduce the yield variability on rice and maize, whereas the contrast effect was observed due to maximum temperature.

Importantly, the extreme climatic factors such as low precipitation and high maximum temperatures significantly influenced reduction in rice and maize yields, respectively. The results of extreme climate conditions on yields reduction are helpful to develop an index based crop insurance product for rice and maize in Nepal. Since this study was based on limited intensities such as mean plus/minus standard deviation of extreme climate conditions, it may not properly figure out the critical level of climate condition that influences the crop yields and yield variability. Thus, future studies should focus on analysing the effect of various levels of precipitation, minimum temperatures and maximum temperatures on rice, maize, and wheat yields and yield variability.

Acknowledgments

The authors would like to express sincere thanks to Kul Prasad Tiwari, Jhalak Nath Kandel, Raju Ghimire and Badri Khanal for their contributions to access the climate and yield data for this study. In addition, the authors would also like to thank to K.C. Rupak for his help to prepare the map, and NPUST University Writing Center for editorial work.

Reference

[1] Ministry of Finance (MoF), Economic Review: 2010-2011, Ministry of Finance, Government of Nepal, Signha Darbar, Kathmandu, Nepal, 2011.

[2] Department of Irrigation (DoI), Development of Database for Irrigation Development in Nepal, Final Report, Government of Nepal, Ministry of Water Resources, Department of Irrigation, Planning, Design, and Monitoring and Evaluation Division, Jawalakhel, Lalitpur, Nepal, 2007.

[3] Ministry of Agriculture Development (MoAD), Statistical Information on Nepalese Agriculture (various issues), Ministry of Agriculture Development, Government of Nepal, Signgha Darbar, Kathmandu, Nepal, 1990-1991 to 2010-2011.

[4] Practical Action, Temporal and Spatial Variability of Climate Change over Nepal 1976-2005, 2009, Practical Action Nepal Office.

[5] N.P. Joshi, K.L. Maharjan, L. Piya, Effect of climate variables on yield of major food-crops in Nepal: A time-series analysis, Journal of Contemporary India Studies: Space and Society 1 (2011) 19-26.

[6] A.B. Shrestha, C.P. Wake, P.A. Mayeweki, J.E. Dibb, Maximum temperature trends in the Himalaya and its vicinity: An analysis based on temperature records from Nepal for the period 1971-1994, J. Clim. 12 (1999) 2775-2786.

[7] D.B. Lobell, G.P. Asner, Climate and management contributions to recent trends in U.S. agricultural yields, Science 299 (2003) 1032.

[8] C. Chen, B.A. McCarl, D.E. Schimmelpfennig, Yield variability as influenced by climate: A statistical investigation, Clim. Change 66 (2004) 239-261.

[9] M. Isik, S. Devadoss, An analysis of the impact of climate change on crop yields and yield variability, Appl. Econ. 38 (2006) 835-844.

[10] D.B. Lobell, C.B. Field, Global scale climate—crop yield relationships and the impacts of recent warming, Environ. Res. Lett. 2 (2007) 1-7.

[11] M. Ozdongan, Modeling the impacts of climate change on wheat yields in Northwestern Turkey, Agr. Ecos. Environ. 141 (2011) 1-12.

[12] M.A.R. Sarker, K. Alam, J. Gow, Exploring the

relationship between climate change and rice yield in Bangladesh: An analysis of time series data, Agric. Syst. 112 (2012) 11-16.

[13] I. Boubacar, The effect of drought on crop yields and yield variability: An economic assessment, International Journal of Economics and Finance 4 (2012) 51-60.

[14] B.A. McCarl, X. Villavicencio, X. Wu, Climate change and future analysis: Is stationarity dying? Am. J. Agric. Econ. 90 (2008) 1241-1247.

[15] D.B. Lobell, W. Schlenker, J. Costa-Robert, Climate trends and global crop production since 1980, Science 333 (2011) 616-620.

[16] N. Nicholls, Increased Australian wheat yield due to recent climate trends, Nature 387 (1997) 484-485.

[17] J.L. Nayava, R. Singh, M.R. Bhatta, Impact of climate, climate change and modern technology on wheat production in Nepal: A case study at Bhairahawa, Journal of Hydrology and Meteorology 6 (2009) 1-14.

[18] Government of Nepal (GoN), National Agricultural Policy: 2004, Government of Nepal, Singha Darbar, Kathmandu, Nepal, 2004.

[19] Government of Nepal (GoN), Agricultural Development Strategy, Assessment Report, Government of Nepal, Singha Darbar, Kathmandu, Nepal, 2012.

[20] The World Bank, Agricultural Insurance Feasibility Study for Nepal, Report No. 46521, 2009.

[21] R. Mahmood, Air temperature variations and rice productivity in Bangladesh: A comparative study of the performance of the YIELD and the CERES-Rice models, Ecol. Model. 106 (1998) 201-212.

[22] X. Yang, C. Chen, Q. Luo, L. Li, Q. Yu, Climate change effects on wheat yield and water use in oasis cropland, Inter. J. Plant Prod. 5 (2011) 83-94.

[23] C. Rosenzweig, F.N. Tubiello, R. Goldberg, E. Mills, J. Bloomfield, Increased crop damage in the US from excess precipitation under climate change, Global Environ. Change 12 (2002) 197-202.

[24] J. Eitzinger, Z. Zalud, V. Alexandrov, C.A. van Diepen, M. Trnka, M. Dubrovsky, et al., A local simulation study on the impact of climate change on winter wheat production in North-East Austria, Ecol. Econ. 52 (2001) 199-212.

[25] M. Parry, C. Rosenzweig, M. Livermore, Climate change, global food supply and risk of hunger, Phil. Trans. R. Soc. B 360 (2005) 2125-2138.

[26] X. Cai, D. Wang, R. Laurent, Impact of climate change on crop yield: A case study of rain-fed corn in Central Illinois, Journal of Applied Meteorology and Climatology 48 (2009) 1868-1881.

[27] V.M. Mehta, N.J. Rosenberg, K. Mendoza, Simulated impacts of three decadal climate variability phenomena on dry land corn and wheat yields in the Missouri River Basin, Agr. Forest Meteorol. 152 (2012) 109-124.

[28] D.B. Lobell, M.B. Burke, On the use of statistical models to predict crop yield responses to climate change, Agr. Forest Meteorol. 150 (2010) 1443-1452.

[29] R.E. Just, R.D. Pope, Stochastic specification of production functions and economic implications, J. Econometrics 7 (1978) 67-86.

[30] A. Saha, A. Havenner, H. Tolpaz, Stochastic production function estimation: Small sample properties of ML versus FGLS, Appl. Econ. 29 (1997) 459-469.

[31] Department of Hydrology and Meteorology (DHM), Climate data in Nepal, Department of Hydrology and Meteorology, Ministry of Science, Technology and Environment, Government of Nepal, Singha Darbar, Kathmandu, Nepal, 2011.

[32] D. Pariwar, Country Pasture/Forage Resource Profiles, Publishing Policy and Support Branch, Office of Knowledge Exchange, Research and Extension, Food and Agriculture Organization of the United Nations (FAO), Viale delle Terme di Caracalla, Rome, Italy, 2008.

[33] K.S. Im, M.H. Pesaran, Y. Shin, Testing for Unit Roots in Heterogeneous Panels, Department of Applied Economics, University of Cambridge, Working Paper 9526, 1997.

[34] L. Harrison, J. Michaelsen, C. Funk, G. Husak, Effects of temperature changes on maize production in Mozambique, Climate Res. 46 (2011) 211-222.