

Relationship between Climatic Variables and Finger Millet Yield in Syangja, Central Nepal

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Abstract

Temperature and rainfall are important climatic variables on which the yield of crops depends. The increase in temperature and changing pattern of rainfall in an area reliably influence the yield of crops. This paper is based on a study conducted in Syangja district of central Nepal and analyses the climatic variables and yields of finger millet (*Eleusine coracana*). Changes in the total harvestable area, yearly yield and relationship of climatic variables on yield were analyzed based on correlation and regression analysis of detrended yield and climatic variables for 1980-2016 periods. The total growing season precipitation at different stations of district showed mixed trends of increasing and decreasing. The growing season mean temperature of Chapakot station was not changed but that of Syangja station has increased by 0.009 °C/year from 1980- 2016. Both maximum and minimum temperature of Syangja station showed increasing rate of 0.026°C but that of Chapakot station showed maximum temperature increased at the rate of 0.017°C and minimum temperature decreased by 0.012°C annually. The result showed that there was a positive and normal relationship between maximum temperature and yield ($r=0.298$) whereas there were negative relationship with minimum temperature and rainfall. The multi-linear regression model described that 42.8% of finger millet yield is controlled by climatic variables. If the temperature and rainfall continue to rise, the impact is likely to be negative on finger millet production in future. However, overall crop production can be positive with increase in the temperature at relatively higher altitudes provided basic conditions like fertilizers are met.

Key words: Climate change, Detrend, Precipitation, Temperature, Yield

INTRODUCTION

The temperature of earth is expected to increase continuously by 1-3.7°C at the end of 21st century (IPCC 2013). Several studies pointed that the rate of minimum temperature rise (night temperature) is higher than maximum temperature rise(day temperature) (IPCC 2001; Vose *et al.* 2005; Rao *et al.* 2014) and also predicted that the asymmetric rising between minimum and maximum temperature will continue in future (Sillmann, *et al.* 2013). The rate of rise of temperature in higher altitudes, especially in the mountains and Himalaya of Nepal is higher than that of the global average (Shrestha, *et al.* 1999;

Shrestha, *et al.*, 2012). The crops have been facing warmer temperature even in night that ultimately affects the yield (Tao and Zhang, 2010). Warmer temperature and change on patterns of precipitation not only influence the crop yield but also the soil properties and whole ecosystem processes (IPCC 2001; Chaudhary and Aryal 2009). It has also been reported that high maximum temperature is positively correlated (Lucidos 2013) and low minimum temperature is negatively related with height of C4 plant (Uehara *et al.*, 2009) including finger millet which ultimately affects the yield.

Paddy, wheat, maize, finger millet, buckwheat, barley and foxtail millet are major cereal crops of Nepal. Paddy and wheat are preferred crops in low land of Terai and other crops are mostly grown in the mid-hill and high mountain. Finger millet [*Eleusine coracana* (L.) Gaertn] is one of the important staple crops in mountain regions of Nepal followed by rice, maize and wheat (MOAD 2016). The total area of cultivation for finger millet accounts to 277,799 ha land with annual average production of 309,397 tons covering about 9 per cent of the total cultivated land of the country (MOAD 2016). Moreover, 75 per cent of the cultivation for finger millet is carried out in the mid-hills where food demand is exceeding the requirement (Subedi *et al.* 2009; Adhikari 2012), contributing to 0.14 per cent of the national Gross Domestic Product (MOAD 2012). Among other regions, Gandaki, Bagmati, Sagarmatha and Lumbini zones are considered to be the basket for finger millet production in the country (Adhikari 2005; MOAD 2014; Luitel *et al.* 2017). In central Nepal, Syangja is one of the major finger millet producing districts, with a total of 116400 ha of land dedicated for its cultivation (62.48% of total agricultural land area of district). It is cultivated mainly as mixed crop with maize in 22,665 ha land in Syangja (DADO, 2016).

Close assessment of single crop and relationship with its growing season temperature and rainfall help to understand the impact of climate change on yield of the crops. There have been several studies with respect to effect of climate change on crop yield at global, regional and even national levels (Parry *et al.* 2004; Lobell and Field 2007; Lobell *et al.* 2007; Kim and Pang 2009; Lobell *et al.* 2005; Carew

et al. 2009; Bhatta *et al.* 2014). There are some studies on climate change and its effects on cereal crops in different regions of the Nepal (IPCC 2007; Joshi *et al.* 2011; Bhandari 2013; Bhatta *et al.* 2014; Tiwari *et al.* 2015; Poudel and Shaw 2016; Aryal *et al.* 2016; Bocchiola 2017), however there were no studies focusing on finger millet despite its several importance and crucial roles the mountain livelihoods. Its cultivation is major part of farming system without use of external inputs in the mountain terrain (marginal land) where agriculture land is limited and food deficit is a common problem. The paper analyses the effects of growing season temperature and rainfall on yields of finger millet in Syangja district depending upon historical climatic and yield data.

MATERIALS AND METHODS

Study Area

The study was conducted in Syangja district of Central Nepal where finger millet is one of the major cereals with respect to cultivation area within districts (DADO 2016). Located at latitude 27° 50'-28°15' north and longitude 83°27'-84° 46' east of central Nepal, Syangja covers 1164 sq. km. of total country's area with an altitudinal variation of 366m to 2512 m above the sea level. The total area of the district can be categorized as 62.48 per cent of cultivable land, followed by 27.22 per cent, 8.81 per cent and 1.47 per cent of forest area, rangeland area and others like grazing land respectively (DADO 2016). Similarly, about 15 per cent of the land in Syangja can be considered as a low land with tropical climatic condition, while 70 per cent lies in the mid-land area and 15 per cent in the high mountains (DADO 2016). Due to topographic and altitudinal variation

within the district, the temperature and rainfall also varies both spatially and seasonally. Summer is considered as the major growing period of finger millet though nursery preparation for seedlings transplantation and maturation and harvesting of crops is carried out during the spring and autumn respectively. The maximum temperature during the summer reaches the mark of 40°C in some lowland areas. Majority of the rainfall takes place during the monsoon, while some winter rainfall occurs due to the effect of westerly winds. Varied topography, elevation and climatic conditions are major factors affecting the biodiversity, agro-ecology and water resources in Syangja district.

Yield and Climatic Variables Data

Annual production and cultivated area of finger millet were collected for the last 36 years (1980 to 2016) of Syangja district from the Ministry of Agriculture Development (MoAD), and Department of Agriculture and District Agriculture Development Office (DADO), Syangja.

Time series data of two weather variables – temperature and rainfall– were obtained from the Department of Hydrology and Meteorology (DHM), Nepal. These include daily minimum and maximum temperature and daily rainfall data from 3 stations (Chapakot, Syanja and Waling), although there are four stations. The recorded data from Dandaswara station (fourth station) was excluded in this study mainly due to availability of data for less than 30 years period. These climatic station lies at elevations ranging from 460m to 1432m above sea level. The length of these data vary from 37 years (1979-2016) to 17 years (1999-2016). More information about the meteorological stations used in these studies is presented in Fig-1 and Table-1. The data were assembled into a panel data set by computing the growing season annual averages. The data represented the averages of the district level. The growing season average maximum and minimum temperature, and mean temperature were constructed.

Table 1: Detail of Meteorological Stations in Syangja

SN	Station Name	Latitude (N) and Longitude (E)	Elevation(m)	Station type	Duration
1	Dandaswara	28 ° 08'; 83 ° 92'	1432	Precipitation	1999-2016
2	Chapakot	27° 53', 83° 49'	460	Climatology	1979-2016
3	Waling	27° 59'; 83° 46'	750	Precipitation	1988-2016
4	Syangja	28° 06', 83° 53'	868	Climatology	1992-2016

Source: <http://www.dhm.gov.np/meteorological-station>

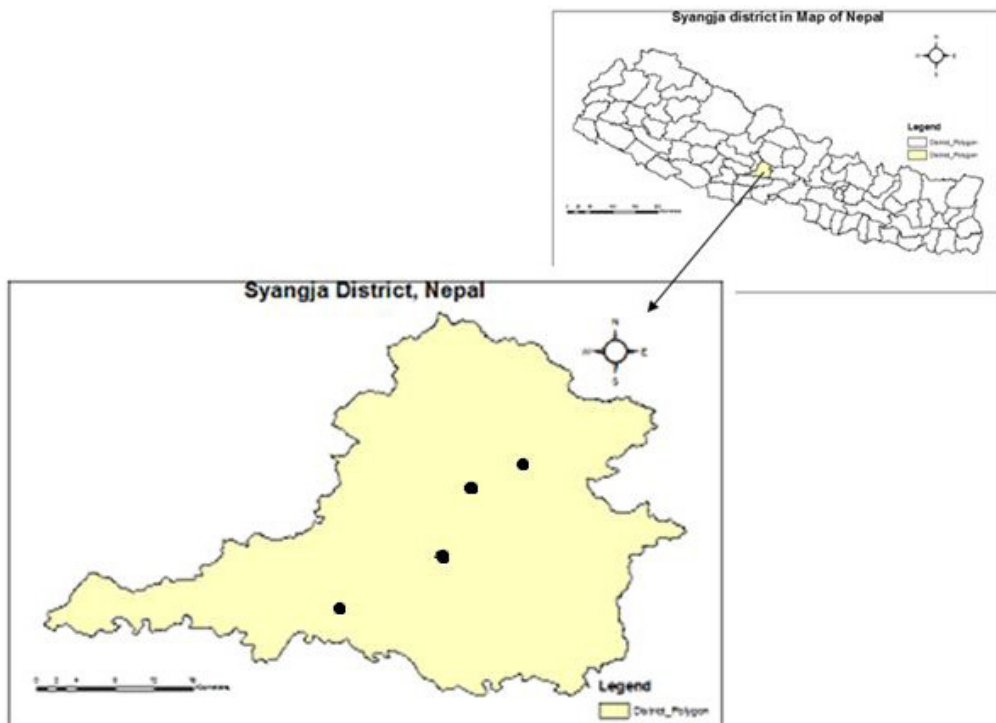


Figure 1: Map of Nepal Highlighting Study Area of Syangja and the Location of Meteorological Stations

Growing Season and Data Analysis

The typical growing seasons (rounded to whole month) and growth stages for finger millet in district were recorded from the field survey during May-November 2016 and 2017. Discussions with the local farmers were conducted and the information gathered from those discussions were compared with published literature (Joshi *et al.* 2011; Poudel and Shaw 2016) to derive the typical growing season of finger millet in Syangja. The relationship between yield and monthly temperatures (minimum and maximum) and rainfall during the growing season was evaluated using correlation and regression analysis. The relationship of yield and climatic variables were used to predict the impact of climatic variables on change in finger millet yield. The change

in climatic variables was analyzed through scatter plots in Microsoft office excel 2010 program.

RESULTS AND DISCUSSION

Trends of Total Harvestable Area and Yield

Both harvestable area and yield of finger millet in Syangja showed steady increase between the periods 1980- 2016. Total harvested area of finger millet showed steady increase from 7000 ha in 1980 to 18000ha and 18770 ha in 2001 and 2012 respectively with growth rate of 288.1ha/year (Fig-2). The total yield of finger millet also showed fluctuations in various period with slight increase from 0.84 (t/ha) in 1980 to 1.2 (t/ha) in 1996 followed by decrease in yield of to 0.90 (t/ha) in 1997.

The yield showed some increase of 1.17 (t/ha) in 2003 and with not much variation following then (Fig-2). The correlation between harvestable area and finger millet yield showed high significance ($r=0.97$) i.e., increase in the yield of finger millet

along with the increase in harvestable area. Similarly, the linear regression coefficient analysis showed that time has significant ($P\text{-value} < 0.00$) effect on yield of finger millet in Syangja.

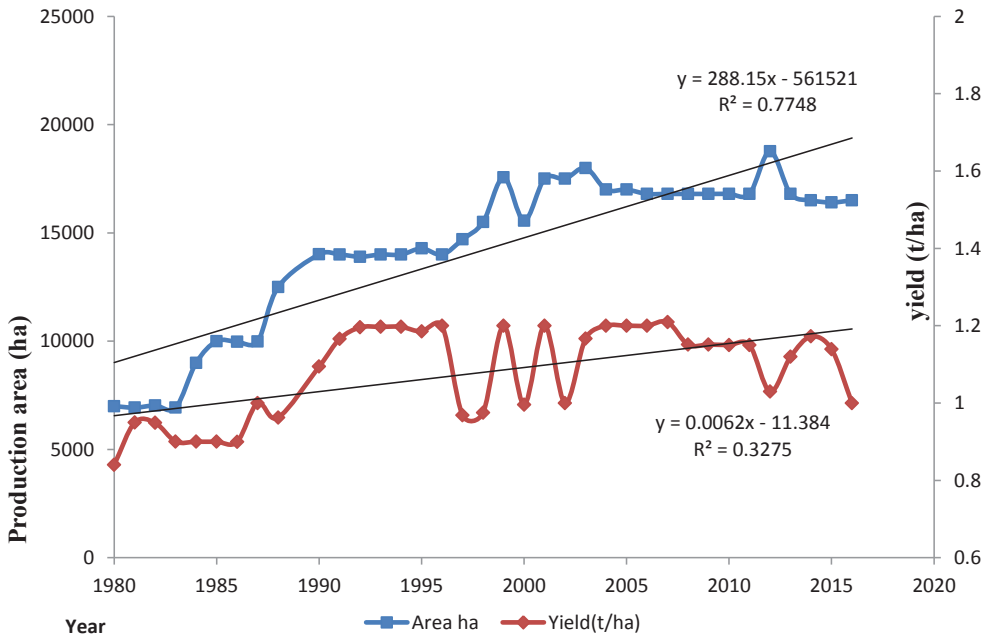


Figure 2: Relationship between Harvestable Area (ha) and Yield (t/ha) of Finger Millet(1980-2016)

Rainfall Trend

The growing season precipitation from 1980-2016 for three stations was analyzed using simple linear regression. The total growing season precipitation at Syangja station increased by 4.106mm/year whereas at the Chapakot and Waling stations decreased by 7.025mm/year and 9.722mm/year respectively (Figure 3). The total growing season rainfall was significance ($P\text{-value} < 0.01$) with the time. The total growing season rainfall was decreased by 362.13mm during the study periods within the district, which signified the erratic pattern of rainfall. Likewise,

minimum rainfall was experienced in the growing season during 1992, 1998, 2006 and 2008 and maximum in 1984, 1988, 1994 and 2000. Not limited to Syangja, similar erratic rainfall patterns was experienced throughout Nepal since 1980 (Malla 2008). This result is almost similar to the results obtained for the entire area of Kaligandaki basin (Syangja is a part of Kaligandaki basin) and precipitation pattern of Lamjung of central Nepal and Daldeldhura district of western Nepal (Mishra *et al.* 2014; Poudel and Shaw 2016; Bhandari 2013). Maximum rainfall in Nepal is experienced during June-September which is growing season

of finger millet. The rainfall in summer season becomes more intense (Joshi et al. 2011) but overall trend is decreasing. Rainfall frequencies, amount and intensity have increased in the higher altitude region including Nepal during summer (Shrestha et al. 2000; Eastering et al. 2000) however number of days with rain is declining in higher altitudinal region (IPCC 2007). Several other studies have showed that

precipitation trend in Nepal varies due to the interaction of heterogeneous topography with the monsoon and westerly wind system (Shrestha et al. 2012; Tiwari et al. 2015). Even decreasing trend of rainfall favors increase in the yield of finger millet in Syangja district may be due to the increase in amount of heavy rainfall events in summer, storing enough moisture in soil.

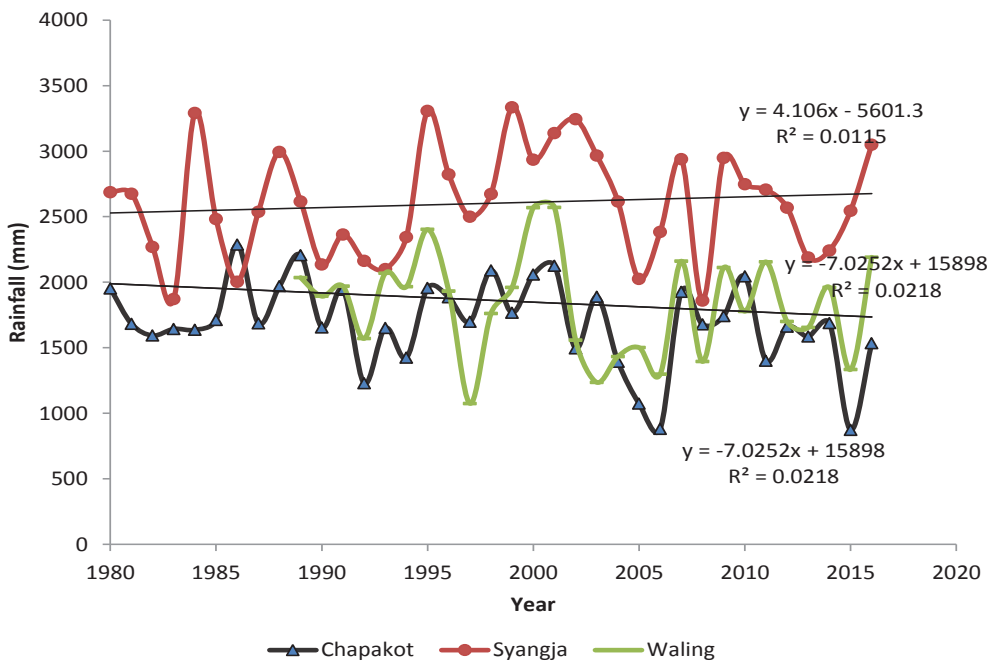


Figure-3: Trend of Growing Season Rainfall in Three Different Stations in Syangja

Growing Season Temperature Trend

The maximum, minimum and mean values of the growing season temperatures during 1980 – 2016 recorded at Syangja and Chapakot stations have been analyzed (Fig-4). To determine the significance trend, linear regression analysis was performed. Results show that temperature has a significant (P-value <0.05) association with time. The total growing season mean

temperature at Chapakot station neither increased nor decreased annually whereas records from Syangja station showed an increase by 0.009 °C/year between 1980-2016 (Fig-4a). Both maximum and minimum temperature at Syangja station showed similar increasing rate of 0.026°C, however that at Chapakot station showed maximum temperature increase at the rate of 0.017°C and minimum temperature decrease by 0.012°C annually. The results indicate that except the minimum

temperature at Chapakot station, both minimum and maximum temperature of finger millet growing period has increased over time, while the rate in increase of maximum temperature was higher than minimum temperature. The overall temperature analysis from 1977-1994

showed that the temperature of Nepal increased at the rate of 0.06°C (Shrestha et al. 1999; IPCC 2001; Shrestha et al. 2000; Ebi et al. 2007), which has also been the case for finger millet growing season temperature of Syangja district.

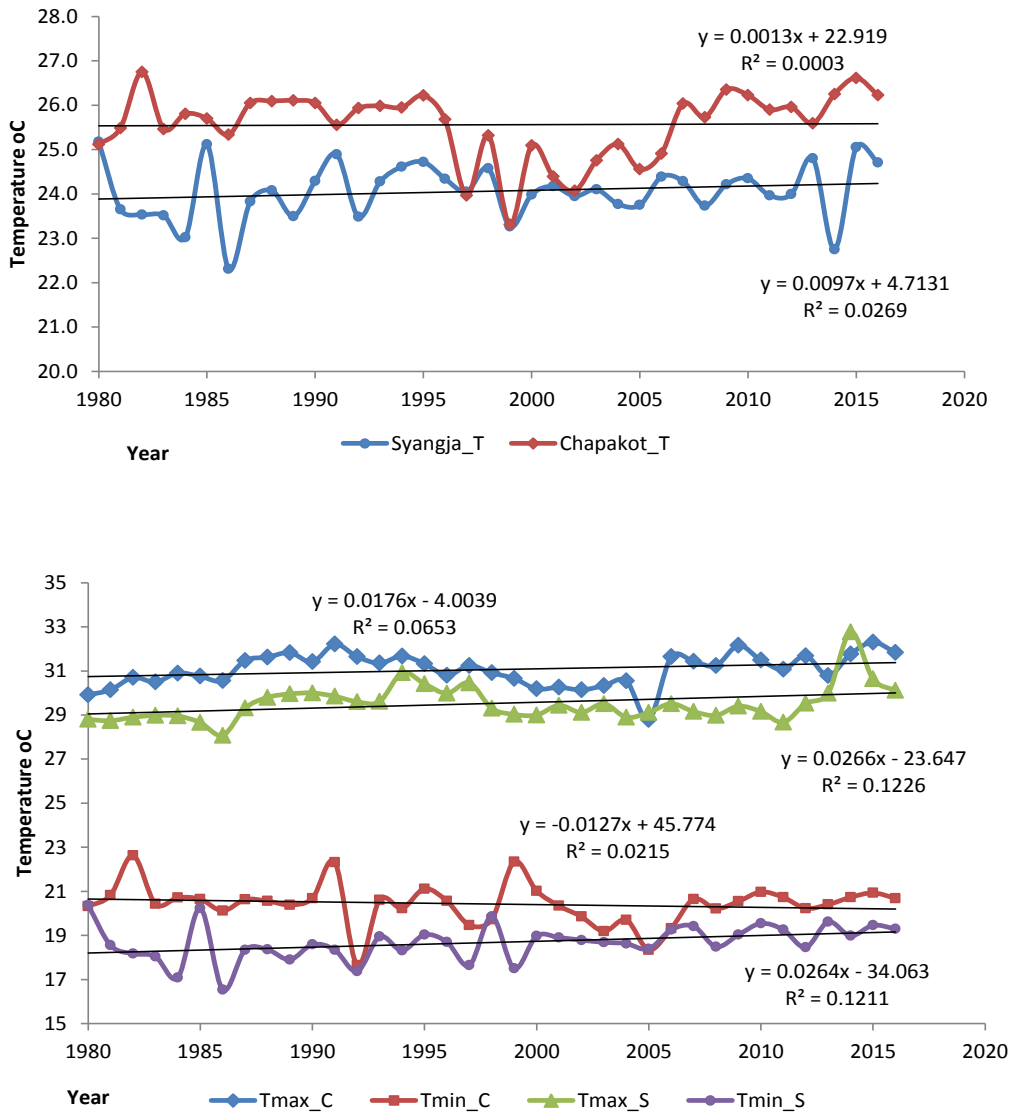
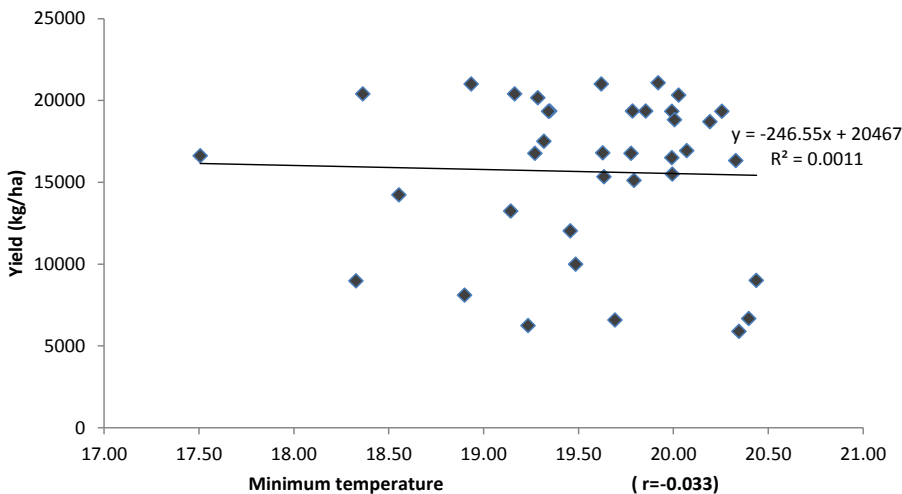
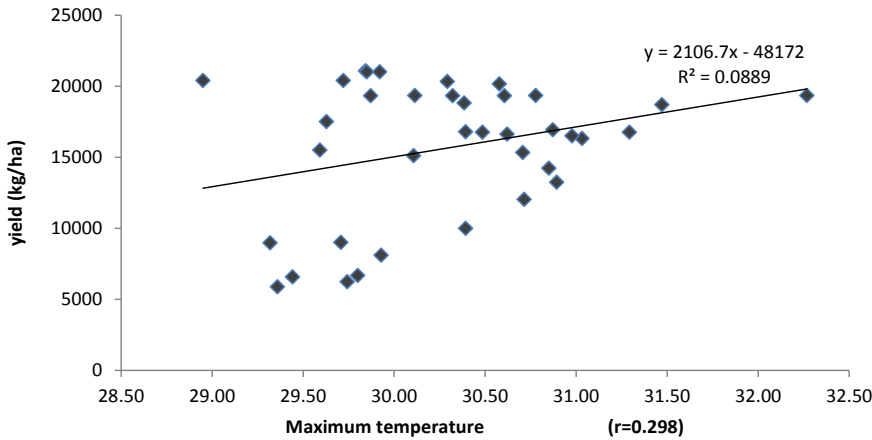


Figure 4: Growing Season Mean Temperature (a) and Minimum and Maximum Temperature Trend (b) in Chapakot and Syangja Stations of Syangja District 1980-2016.

Finger Millet Yield-Climate Relationship

In order to show the relationship between climatic variables and finger millet yield (Kg/ha) a correlation analysis and linear regression was carried out. The results showed that there was a positive and normal relationship between maximum temperature during growing season and

yield ($r=0.298$) whereas the relationship was negative between minimum temperature during growing season and rainfall with values $r=-0.033$ and $r=-0.145$ respectively (Figure5). The results of relationship between finger millet yield and maximum temperature of Syangja showed close resemblance with that of Lamjung district (Poudel and Shaw 2016).



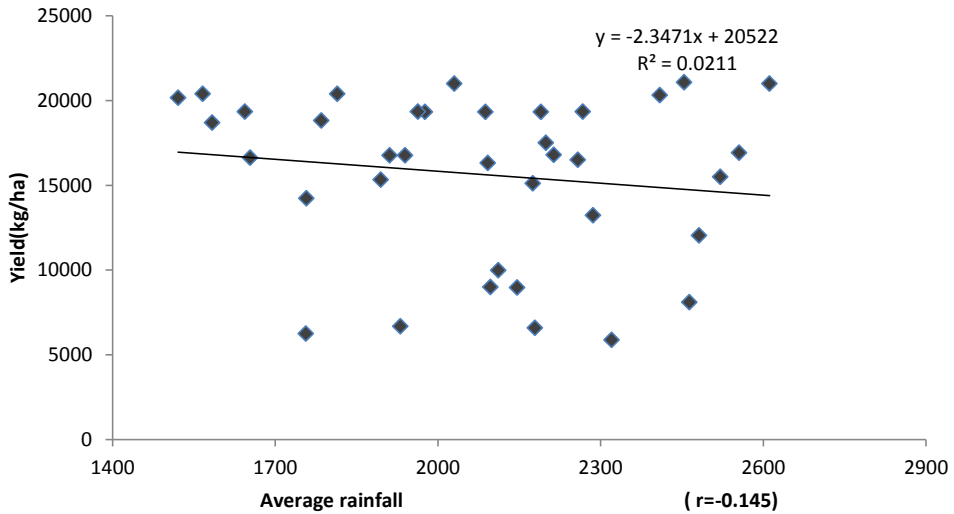


Figure 5: Relationship between Growing Season Climatic Variable and Finger Millet Yield

Climatic Trends and Changes in Finger Millet Yield

Multi-linear regression analysis between detrended finger millet yield (kg/ha) and climatic variables was performed to check the direct relationship between yield and climatic variables during the period

of 1980-2016. The detrended minimum & maximum temperature and rainfall and detrended yield of finger millet was calculated by using the differences of values from one year to the next. Figure 6 depicts the finger millet yield (yield anomalies) during 1980-2016 in Syangja.

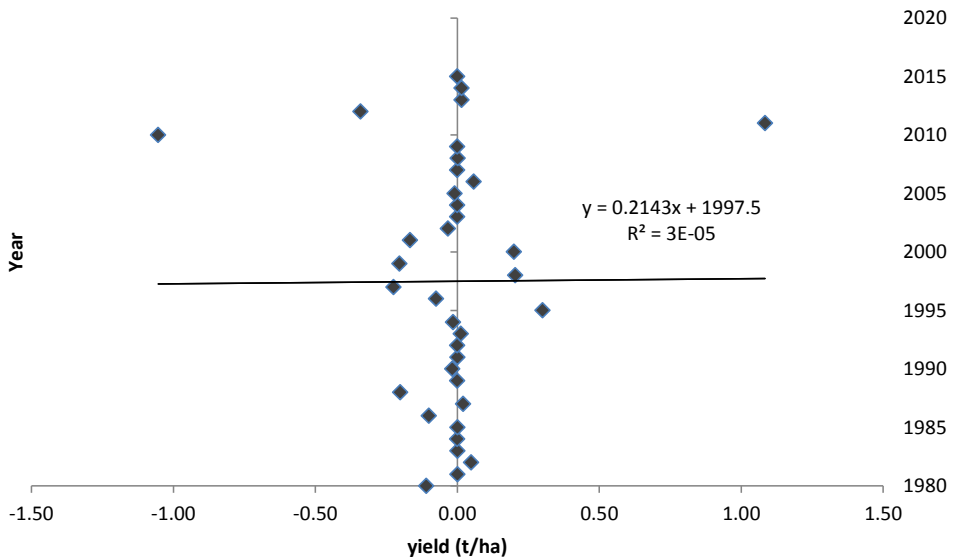


Fig-6: Detrended Finger Millet Yield

To prove the impact of climatic variables on crop yield a multi-linear regression model is widely used, however the detrended climatic variables were used in this study to quantify the relationship between climate change and crop yield, (Poudel and Shaw 2016; Bhatta *et al.* 2014). Though there are several parameters which influence the yield of crops like introduction of agro-technology, better seeds, better crop management, uses of fertilizers and pesticides, they were omitted during the analysis of detrended variables. Linear relationships between detrended finger-millet yield in Syangja, and detrended in climate variables were developed to determine the crop yield change due to changes in climate variables during the study period. These relationships was developed as

$$\Delta Y = \alpha + \beta_1 * \Delta P_{pt} + \beta_2 * \Delta T_{min} + \beta_3 * \Delta T_{max}$$

Where,

ΔY = Change in yield due to growing season temperature and rainfall.

α = constant

β_1, β_2 and β_3 = Coefficient of rainfall, minimum temperature and maximum temperature. ΔP_{pt} , ΔT_{min} and ΔT_{max} are observed change in growing season rainfall, minimum temperature and maximum temperature respectively during the study period.

The results of multi-linear regression are shown in Table-2. This model is able to describe that 42.8 percent of finger millet yield is controlled by climatic variables in Syangja. Although this analysis showed only significant relationship of growing season maximum temperature and finger millet yield in Syangja (Table-2) but yield of crops in mountain terrains majorly depends on climatic variables.

Table 2: Multivariate Regression Analysis of Detrended Finger Millet Yields in Syangja

SN	Climatic variables	Coefficient	P- Value	Multiple R ²	Sig
1	Rainfall	0.233887	0.859	0.428	No
2	Minimum temperature	234.0181	0.012		Yes
3	Maximum temperature	-323.834	0.640		No

CONCLUSION

This study analyzes the association of growing season temperature and rainfall on yields of finger millet in Syangja district of central Nepal depending upon historical climatic and yield data. The relationship between climatic variables and yield of finger millet was established with correlation and regression between detrended finger millet yield and precipitation as well as minimum and maximum temperature of three climatic stations of Syangja. Both harvestable

area and yield of finger millet in Syangja showed steady increase from 1980- 2016. The correlation between harvestable area and finger millet yield showed high significance ($r=0.97$) ie, along with increase in harvestable area the yield of finger millet also simultaneously increases. The total growing season precipitation at Syangja station increased by 4.106mm/year whereas at the Chapakot and Waling stations decreased by 7.025mm/year and 9.722mm/year respectively. Total growing season rainfall shows significant (P-value <0.01) with time period. The

total growing season mean temperature rises of Chapakot station was neither increased nor decreased annually whereas Syangja station has increased by 0.009 °C/year from 1980- 2016. Both maximum and minimum temperature of Syangja station showed same increasing rate of 0.026°C but that of Chapakot station showed maximum temperature increased at the rate of 0.017°C and minimum temperature decreased by 0.012°C annually. The multi-linear regression described that 42.8% of finger millet yield was controlled by climatic variables in Syangja. It was clearly identified that growing season temperature was increasing and total rainfall decreasing yearly. This changes on growing season temperature and rainfall induces several impacts which may be beneficial or harmful to finger millet depending upon season and altitude. In particular the yield of finger millet is being affected by higher temperature. Thus, it is recommended that any programs that are working to overcome the impact of climate change on food crops production should consider the crop like finger millet which is being affected by higher temperature as well as variety -specific adaptive strategies must be adopted to reduce impacts of climate change.

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