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EFFECTS OF RAINFALL VARIABILITY ON PRODUCTION OF FIVE MAJOR CEREAL CROPS IN SOUTHERN TIGRAY, NORTHERN ETHIOPIA

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Abstract: This study investigates the relationship between rainfall characteristics and production of five major cereal crops. Daily rainfall records and production data of five major crops were used for the analysis. A survey was carried out to supplement production data from 600 randomly selected farming households. A non-parametric correlation analysis and stepwise regression analysis were the statistical tools used in the study in addition to the descriptive statistics and coefficient of variations. Belg and Kiremt rainy seasons covered about 24% and 62.2% of annual total rainfall respectively; Belg rainy season was highly variable than the Kiremt one. Average onset of Belg rainy season arrived 59 days late than normal date; whereas Kiremt's was 35 days late than the normal, June 1. Mann-Kendall trend test indicated that annual and Kiremt rainy days were significantly decreasing. Very long dry spells were also found in both Kiremt and Belg rainy seasons, an average of 21 and 37 days respectively. Although, crop production was steadily increasing, the effects of some of the main rainfall characteristics on four of the five crop production were found significant. In a variable climate, the study found significant role of agricultural inputs in supporting farmers to increase their production. Findings of this study calls to intensify adaptation strategies, development of irrigation schemes and supply of more drought tolerant seeds.
Keywords: Climate variability; Crops production; Rainfall characteristics; Southern Tigray.
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INTRODUCTION

In a predominantly agricultural system, natural rainfall is the main source of water for agriculture sector in Ethiopia, and southern Tigray in particular. This rain-fed based agriculture system is highly sensitive to spatio-temporal variability of rainfall. In areas where rainfall is limited, variable and unpredictable in space and time, water is the major limiting factor for crop production (Stewarta and Hash, 1982; Sivakumar, 1992). According to Simane and Struick, (1993), in addition to the amount of rainfall, its distribution in a given season is critical in affecting crop growth and its production. Uneven seasonal distribution of rainfall can expose crops to different degrees of dry spells without significant reductions in total rainfall (Barron *et al.*, 2003). Northern Ethiopia is the area most affected by climate variability and series of droughts and famine in the country. More than a dozen localized and regional droughts happened in this area within the last three decades and affected agricultural productions negatively; and millions of rural poor farmers and their environment (Degefu, 1987; Camberlin, 1997; DPPC, 1997; Vste, *et al.*, 2013). Changes in annual and seasonal rainfalls have been analyzed by different studies using station based or aggregate meteorological records; although very few are made in southern Tigray. These works were focused on seasonal and annual rainfall averages to see the variability and changes in trends through time (Bewket and Conway, 2007; Cheung, *et al.*, 2008; Ayalew *et al.*, 2012; Hadgu, *et al.*, 2013). Some studies had also been made focusing on the characteristics of annual and seasonal rainfall, such as number of rainy days, length of dry-spells and onset and offset dates (Seleshi and Zanke, 2004; Seleshi and Camberlin, 2006; Hadgu, *et al.*, 2013). These studies were informative and worth a lot; however, like the former ones, they were more focused on made comparative studies over time to get changes in trend of the characteristics across Ethiopia. Although, some few other studies had tried to investigate the relationship between rainfall variability and crop production (Bewket, 2009) using time series data and correlation analyses in the neighboring Amhara regional state. Although informative, further studies are much required at lesser areal coverage and in a way that can show effects of rainfall characteristics on crop production.

This study aims at analyzing the relationship and effects of annual and seasonal rainfall characteristics (including rainfall amounts, number of rainy-days, length of dry-spells, growing periods, and onset and offset dates) on five major cereal crop productions in Southern Tigray in the period of 2000-2012.

EXPERIMENTAL

Study Area

Southern Tigray is one of the seven zones in Tigray regional state of Ethiopia located between $12^{0}14'53.9''$ - $13^{0}06'08''$ N and $39^{0}10'45.7''$ - $39^{0}53'41.7''$ E. Total area is 499,616.085 ha that comprises 5 rural districts and 3 town administrations, as in Figure 1. Rugged mountains, plateaus, valleys and gorges characterize the physical landscape of Southern Tigray. The topography contains four main traditional divisions of arable Ethiopia. Kola–lowlands (c1400 to 1800 m.a.s.l) with relatively low rainfall and high temperatures (40.4 %); Woina dega–middle highlands (c1800-2400 m.a.s.l.) with medium rainfall and medium temperatures (29.02%); Dega–highlands (c2400-3400 m.a.s.l.) with somewhat higher rainfall and cooler temperatures (30.1%) and Wurch–very-cold (>3400 m.a.s.l) with high rainfall and very cold temperatures (0.45%).

There are two agro-ecologic zones in general: Ofla-alaje highland agro-ecologic zone in the west and kola (lowland) agro-ecologic zone to the east. The two agro-ecological zones are agriculture-based mixed farming production systems. Food and cash crop cultivation is practiced along with livestock rearing (MARD, 2009). The area has mainly semi-arid climate with a bimodal rainfall type. The main rainy season which lasts from June to September (locally called *Kiremt*) follows the pre-monsoon hot season from February to May (locally called *Belg*) that adds a small rainy season to the area. Agricultur is rain-fed and dominated by small-scale farmers with an average land holding of less than one hectare per household. Almost every year the study area experiences localized droughts due to abnormally low and untimely rainfall causing crop failure to jeopardies rural livelihoods and food security (DPPC, 1997, 1998; DRMFSS, 2011; FAO, 2009, 2010,2012). Southern Tigray was selected for this study because recurrent drought and crop failures are common in this area. Total polulation of the study areas in 2013 was 717,420 with a population density of 144 persons per Km^2. Like the rest of country, agriculture is the mainstay of economy, where it directly supports for about 86.4% of the population for employment and livelihood (CSA, 2012).

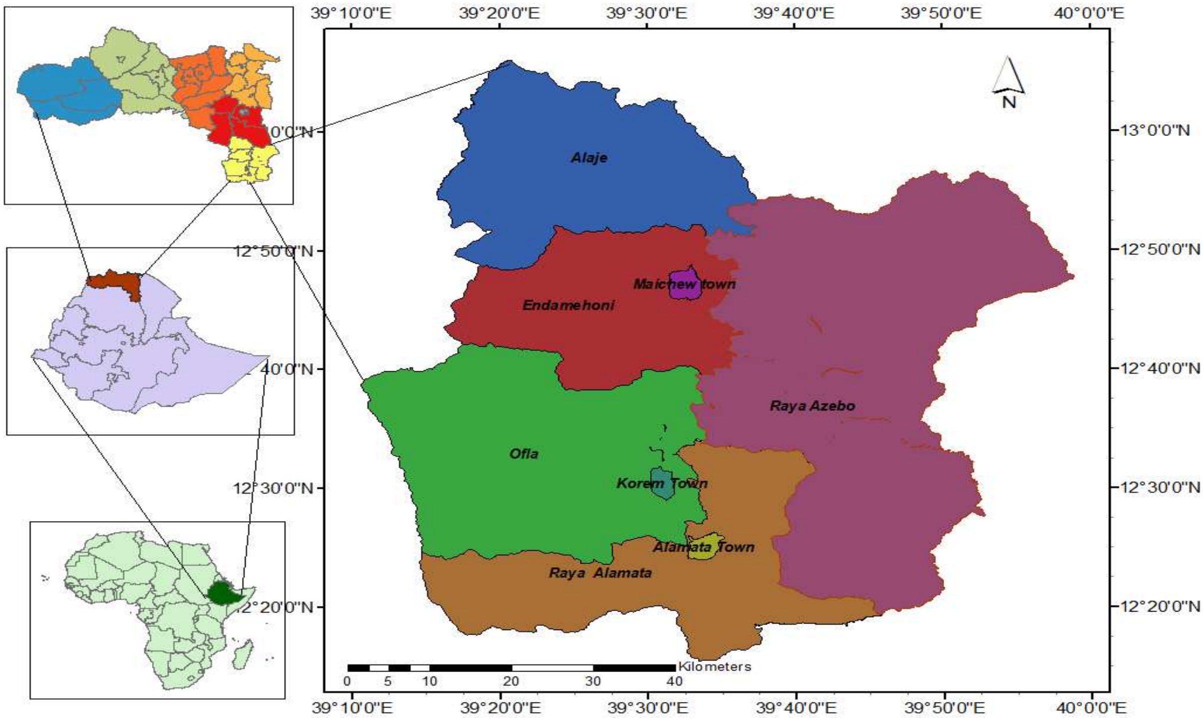

Figure 1. Location of Study Area [*Produced using ArcGIS 10.0 (ESRI ArcMap 10.0)]*

Data Sources

Both Secondary and primary data sources were used for this study. A survey using a multi-stage random sampling procedure was carried out in four districts (Endamehoni, Ofla, Raya Alamata and Raya Azebo) of southern Tigray in 2013. 600 households, 150 from each four districts were randomly asked about the amount of production they get from Belg and Kiremt seasons in the period 2008-2012. The other data used for this study were time series data on daily rainfall, production (Qt) and cultivated land (ha) of five major cereal crops (Teff, Barley, Wheat, Maize and Sorghum) between 2000 and 2012 in southern Tigray. Daily rainfall records (2000-2012) were gathered from the National Meteorological Services Agency (NMSA) of Ethiopia; whereas, production and cultivated land data were congregated from CSA Agricultural sample survey reports and statistical abstracts prepared by Tigray region Bureau of Finance and Economic Development (BoFED) for the year concerned. From the collected data, the following parameters were determined:

i. *Production in Quintal (Qt):* annual production of each of the five crops for the period 2000-2012.
ii. *Total rainfalls:* Annual rainfall total was rainfall total of all months in a year; Kiremt rainfall total was added rainfall of June, July, August and September; and Belg rainfall total contains February, March, April and May rainfalls.
iii. *Number of rainy days*: Using a definition from the National Meteorological Service Agency of Ethiopia, a rainy day is a day that accumulates 1 mm or more rainfall in its 24 hours (NMSA, 2001). Thus, rainy days for Kiremt season was counted starting from the first day of June to September 30 in each year; from first day of February to May 31 for Belg season; and January first to December 31 for annual total.
iv. *Maximum length of dry-spell in Kiremt and Belg seasons*: is the maximum number of consecutive dry days (a day that accumulate rainfall <1 mm); and the days were counted

to determine maximum dry spell length in Kiremt and Belg seasons.

v. *Date of Onset for Kiremt and Belg seasonal rainfalls*: Following Mesay (2006) approach for day of Onset, the criteria used to determine date of onset are rainfall of 10 mm or more with in 3 or more successive days; and there will be no dry spell of duration of nine days or more in the next 30 days. It should occur with an earliest starting days of June 1 for Kiremt and February 1 for Belg season.

vi. *Date of Off-set for Kiremt and Belg rainfalls*: different studies use different cessation periods for the two economically important rainfall types. This study considers the end of the Belg season, based on Mesay (2006), with an earliest possible day of May 1. Whereas, for the Kiremt season where different crops require different length of growing periods, farmers of the study area demand the rain to stay at least to half of September. Therefore, the earliest possible day of September 15 is considered as ending date where soil moisture can sustain for some time enough after the rain ceases.

vii. *Length of growing season for Kiremt and Belg season*: The length of growing period was designed as the difference between the onset date and offset date of Kiremt and Belg seasons.

Moreover, other production and early warning reports from DPPC and FAO/WFP were also be taken as secondary data sources to support the analysis.

Analysis Tools

Correlation and stepwise multivariate linear regression analysis were the statistical tools used to establish the association and effects of climatic characteristics on each of the five major crop productions. As Howitt and Cramer (2011) described it in detail, stepwise multiple regressions is a way of choosing predictors of a particular dependent variable on the basis of statistical criteria. Essentially the statistical procedure decides which independent variable is the best predictor, the second best predictor, etc. The emphasis is on finding the best predictors at each stage. When predictors are highly correlated with each other and with the dependent variable, often one variable becomes listed as a predictor and the other variable is not listed. This does not mean that the latter variable is not a predictor merely that it adds nothing to the prediction that the first predictor has not already done. Sometimes the best predictor is only marginally better than the second predictor and minor variations in the procedures may affect which of the two is chosen as the predictor. Generally, stepwise multiple regression is used when one wants to find out the best predictors, among a large number of variables, that make a significant contribution in explaining the maximum amount of variance in the criterion variable, what these predictors are and how much of the variance of the criterion variable they explain (Howitt and Cramer, 2011). The study also uses mean, standard deviation and coefficient of variability in analyzing the variations in the study variables over time.

Variability Analysis

Coefficient of variation (CV) was used as descriptors of rainfall variability as used in Bewket and Conway (2007) and Hadgu, *et al.* (2013). CV was adopted to evaluate the variability of the rainfall and its characteristics in addition to production indexes. It was calculated by dividing the standard deviation to the mean of variable considered;

$$CV = \left(\frac{\sigma}{\bar{x}}\right) \times 100$$

Where CV is coefficient of variation in percentage, σ is standard deviation and $\bar{x}$ is mean of the variable

Quality Control

Before the multivariate regression analysis was carried out for each crop, different tests were made to see data meet the assumptions required. Therefore, an analysis of standard residuals were carried out for each outcome variable, which showed that the data contained no outliers (Std. Residual Min = -1.063, Std. Residual Max = 1.514 for *Teff* production; Std. Residual Min = -1.063, Std. Residual Max = 1.980 for sorghum production). Tests to see if the data met the assumption of collinearity indicated that it was not a concern for each group (*teff*, Tolerance >.16, VIF <6.7; sorghum Tolerance >.583, VIF < 1.7). In addition, the data also met the assumption of independent errors (Durbin-Watson value of 2.03 for *teff*, and 2.395 for sorghum) and meet the assumption of non-zero variances.

Table 1: Annual and seasonal rainfall indices

Measurement	Indic Name
Annual number of rainy days (days)	ANRD
Kiremt number of rainy days (days)	KNRD
Belg number of rainy days (days)	BNRD
Belg Onset (days)	BOS
Kiremt Onset (days)	KOS
Belg maximum length dry-spells (days)	BMLDS
Kiremt maximum length dry-spell(days)	KMLDS
Belg length of growing season (days)	BMLGP
Kiremt length of growing season (days)	KMLGP
Kiremt Offset (days)	KOffS
Annual total rainfall (mm)	ARFT
Kiremt total rainfall (mm)	KRFT
Belg total rainfall (mm)	BRFT

Indices units are in parentheses

RESULTS AND DISCUSSION

For the last 13 years the coefficient of variability for all rainfall characteristics and crop production stated were larger than 20% except to annual rainfall and annual rainy days. This implies a large inter annual and inter-seasonal fluctuation in these variables in the study area, as can be seen from Table 2. Maize production is the most fluctuating crop types (CV = 128.6%) followed by Wheat (CV = 70%) and Barley (CV = 54.9%) productions every year. Moreover, the small rainy season was highly variable than the main one (Kiremt) considering every characteristics derived from the two, as seen from the. Belg season covers about 24% of the total annual, and it is extremely variable (CV = 42%). The average onset of Belg rainy season was 59 days after the assumed date (February 1), with standard deviation of 13 days. The date of onset is difficult to predict its pattern, as we can understand from the standard deviation value on average, Belg rainfall starts about April first week and ends averagely on May first week to result very short rainy and growing season, not more than 27 days. The Kiremt rainfall, on other hand, shares about 62.2% of the annual rainfall total in the study area. It is also more variable (24%) but less compared to the Belg rainfall. The average onset of rainfall in this season was 35 days after the supposed normal date (June 1); and its cessation date was mostly on the first week of September to result an average of less than 70 days length of growing season. Unlike to the Belg season, Kiremt onset has standard deviation of less than 10 days which implies its stability and predictability. Similarly Hadgu, *et al.* (2013) had revealed similar result on the onset of Kiremt rainfall that starts in the first dekad of July. The average number of annual, kiremt and Belg season rainy days over the period 2000-2012 were 70, 42 and 18 days respectively. Mann-Kendall's trend test for the number of rainy days indicated that annual and Kiremt rainy days were each decreasing an average of 2 days every year for the last two decades, significant at 0.01 level. The trend for Belg rainy days, although decreasing, was not significant.

Table 2: Descriptive statistics and Characteristics of rainfall and Production of five major crops in Southern Tigray, 2000-2012

Variable	Obs	Mean	Std. Dev.	Min	Max	CV %
Teff Production	13	250218.69	93232.73	78505.4	418084.18	37.3
Barley Production	13	308670.78	169375.08	113004.91	715561.11	54.9
Wheat Production	13	515211.87	362843.47	203645.62	1604811.4	70.4
Maize Production	13	126392.86	162570.82	28725.5	657342	128.6
Sorghum Production	13	409118.63	145295.54	96050.66	604026.52	35.5

ANRD	13	70.16	11.79	47.5	86.67	16.8
KNRD	13	41.87	8.94	28.75	57.67	21.4
BNRD	13	18.2	6.44	7.5	30.33	35.4
BOS	13	58.87	13.29	36.67	84.67	22.6
KOS	13	35.15	7.58	23.33	47.33	21.6
BMLDS	13	37.2	13.99	21	65.75	37.6
KMLDS	13	21.1	4.97	12.67	28.75	23.6
BMLGP	13	27	17.52	5	66	64.9
KMLGP	13	67.54	12.39	49	96	18.3
KOffS	13	-9.31	7.26	-22	2.67	78
ARFT	13	781.79	143.76	502.4	1025.4	18.4
KRFT	13	486.4	118.18	314.75	669.57	24.3
BRFT	13	186.69	78.48	65.98	314.67	42

Moreover, we have also found longer dry spells in both Kiremt and Belg rainy seasons in the study area, an average of 21 and 37 days respectively, with smaller value (<4 days) of standard deviation in Kiremt season. Longer dry-spells had also been reported by Seleshi and Camberlin (2005); and Hadgu, *et al.*, (2013) in northern Ethiopia. Mann-Kendall trend test for kiremt season also indicated an increasing trend of length of dry-spell (a day every year), significant at 0.05 level. This result was also in line with the findings of Hadgu, *et al.*, (2013).

Table 3: Correlation coefficients of 5 major crop productions with time (2000-2012)

Teff	Barley	Wheat	Maize	Sorghum
.179 (.393)	.590 (.005)**	.538 (.010)*	.154 (.464)	.256 (.222)

***,* significant at 0.01 and 0.05 level; Values in parenthesis are 2 tailed significant values; no value indicate weak association or less than .10 correlation coefficient*

Correlation Analysis

A non-parametric correlation analysis with Kendell's tau_b test was used to see how the different rainfall characteristics were associated with each of the five major cereal crops. Test of significance adopted for the correlation were at 0.01, and 0.05 levels. Before discussing the association between rainfall characteristics and production of each crop, presenting the correlation between each variable (both dependent and independent) and time would be worth a lot to see how they were across the study period. In the time frame of 2000-2012, all the five dependent variables (productions) have shown positive correlation with time; however, productions of barley and wheat had significant association. Mann-Kendall trend test for growth of production for barley and wheat also confirmed they are growing significantly. With regard to the independent variables (rainfall characteristics), only Belg rainfall have shown a positive association in the period. All the other independent variables have shown negative association with time (year). Although onset days and maximum length of dry spells (MLDS) have revealed positive results, their final implications is negative; saying maximum length of dry spells or onset dates positively correlated with time does not mean positive in the point of production of crops. Nevertheless, *ANRD* {T (13) = - .667, p =.002}, *KRD* {T (13) = - .615, p =.003}, *KoffS* {T (13) = - .487, p =.02}, *KTRF* {T (13) = - .385, p =.067} and *KLGS* {T (13) = - .359, p =.088} have significant negative association. *KMLDS* {T (13) = - .487, p =.02} has a positive and significant correlation coefficient implying that dry days are increasing overtime.

Table 4 shows the correlation coefficients between the dependent and independent variables. The table indicates *Teff* production was positively correlated with a number of rainfall characteristics; however the association with Belg rainy days, annual and Belg rainfall totals were statistically significant. Moreover, although negative, the correlation with Belg onset date was significant. Barley production had negative correlation with all the predictor variables except Kiremt onset and kiremt length of dry-spells; but only its association with number of Kiremt rainy days was statistically significant. Unlike to barley, wheat production had significant correlation coefficients with number of annual and kiremt rainy days, Kiremt onset and its total rainfall. While sorghum production had medium to strong association with some five predictor variables, its correlation with Belg onset, belg rainy days and Belg rainfall were significant. Maize production surprisingly did not show any significant correlation with at least one of the independent variables considered in the study. As can be seen in Table 4, all independent variables do not have significant correlation with each crop production. Therefore, we used stepwise multivariate regression analysis to produce the best possible equation that can describe the linear relationship between the dependent and independent variables; and predict effects of the most significant predictor variables in the study area for the period of 2000-2012. For the reason of addressing multi-collinearity different group of independent variables with less collinearity to each other were selected for the stepwise regression analysis.

Table 4. Correlation Coefficients for Dependent and Independent variables 2000-2012

Rainfall characteristics	Teff production	Barley production	Wheat production	Maize production	Sorghum production
ANRD	-	-.410(.051)	-.462(.028)*	-	-
KNRD	-	-.462(.028)*	-.564(.007)**	-	-.179(.393)
BNRD	.477(.024)*	-	-	-	.477(.024)*
BOS	-.487(.020)*	-	-	-.256(.22)	-.615(.003)**
KOS	-	.323(.126)	.426(.044)*	-.116(.58)	-
BMLDS	-.410(.051)	-	-	-	-.333(.11)
KMLDS	.179(.393)	.333(.113)	.333(.113)	.308(.143)	.154(.464)
BMLGP	.395(.065)	-	-.237(.268)	-	.237(.268)
KMLGP	-	-.359(.088)	-.410(.051)	-	-
KOffS	-	-.282(.18)	-.231(.27)	-	-.154(.46)
ARFT	.462 (.028)*	-.205(.33)	-.256(.22)	.385(.067)	.333(.11)
KRFT	.282(.18)	-.282(.18)	-.436(.038)*	.308(.14)	.103(.63)
BRFT	.462(.028)*	-	-	-	.538(.01)*

***,* significant at 0.01 and 0.05 level; Values in parenthesis are 2 tailed significant values; no value indicate weak associations*

Teff Production

Belg number of rainy days, Belg maximum length of dry spells, annual total rainfall, Belg total rainfall, *Belg* Onset, Kiremt maximum length of dry spells and *Kiremt* rainfall were used in a stepwise multiple regression analysis to predict *teff* production. As seen in Table 4, all correlations except between *teff* production and Belg maximum length of dry spells; between *teff* production and Kiremt rainfall total; and between *teff* production and Kiremt maximum length of dry spells were statistically significant. The prediction model contained three of the six predictors and was reached in three steps with three variables removed. The model was statistically significant, $F(3, 9) = 17.351$, $p < .001$, and accounted for approximately 85% of variance of *teff* production $(R^2 = .853, Adjusted R^2 = .803)$. *Teff* production was primarily predicted by a lower extent of dry-spells in *Belg* season; and to some extent of dry-spells during Kiremt season and higher volume of annual total rainfall of the area. The raw and standardized regression coefficients of the predictors are shown in Table 5.

Table 5. Stepwise regression results for *Teff* Production (2000-2012)

Model	Un-standardized Coefficients		Standardized Coefficients	sr^2	t	Sig.
	B	Std. Error	Beta			

(Constant)	-55721.33	89815.58	-	-	-.643	.536
BMLDS	-4713.82	905.93	-.707	0.444	-5.203	.001**
KMLDS	13787.30	2687.70	.726	0.432	5.130	.001**
KTRF	409.25	107.65	.59	0.237	3.802	.004**

Note: the dependent variable was teff production $R^2 = .853, Adjusted R^2 = .803$

$\mathbf{sr}^2$ *is the squared semi-partial correlation* *** Significant at 0.01 level*

Belg maximum length of dry-spells received the strongest weight in the model followed by kiremt maximum length of dry-spells and annual total rainfall. Generally with weak correlations between the predictors, the unique variance explained by each of the variables indexed by the squared semi-partial correlations, was relatively larger and statistically significant: BMLDS, KMLDS and KTRF accounted for approximately 44%, 43% and 24%, of the variance of *teff* production respectively. Generally, longer dry-spells have negative effects on crop production because they are periods of no water for crops for an abnormally longer time; but shorter and less severe than a drought. However, the success or failure of the crops, particularly under rainy conditions might be related with the distribution of dry spells (Mathugama and Peiris, 2011). BMLDS was found to affect *teff* production negatively for the season has short and small rainy days; however during the kiremt season the length of dry spell was positive effect. This might be because of the timing. *Teff* planted in Belg season is harvested in June, and second phase of planting the crop continues in July. In addition, harvest times for *teff* (June and September) obviously don't need rainfall for it would cause damage on the production. *This* time between harvest and planting periods, where dry spells happen, they probably may have less negative, if not positive, effect on production. Therefore, based on the results of the model, we can say the three rainfall characteristics were very strong indicators of *teff* production; also change in any of the seasonal rainfall characteristics especially of length of dry spells and rainfall amounts will cause significant effect on production of the crop.

Barley Production

Following their correlation coefficients they have with barley production and multi-colleaniarity issues in the predictor variables; *Kiremt* number of rainy-days, Kiremt maximum length of dry-spell, Kiremt total rainfall and Kiremt onset dates were used in the stepwise multivariate regression model to predict the production of barley crop in southern Tigray for the period 2000-2012. The correlations of these predictor variables with the outcome variable have shown in Table -4 and each predictor variable has moderate association with the outcome variable. However, the association between kiremt rainy-days and barley production was significant. The regression model contained only one of the four predictors delivered and was reached in first step with three variables removed. The model was statistically significant, F(1, 11) = 7.31, p = .021, and accounted for approximately 40% of the variance of *barley* production $(R^2 = .399, Adjusted R^2 = .345)$. The raw and standardized regression coefficients of the predictors are shown in Table 6.

Table 6. Stepwise regression results for Barley Production (2000-2012)

Model	Un-standardized Coefficients		Standardized Coefficients	$\mathbf{sr}^2$	t	Sig.
	B	Std. Error	Beta			
(Constant)	809571.68	189145.63	-	-	4.280	.001**
KNRD	-11964.56	4425.68	-.632	.399	-2.703	.021*

Note: the dependent variable was teff production $R^2 = .399, Adjusted R^2 = .345$

$\mathbf{sr}^2$ *is the squared semi-partial correlation; ** Significant at 0.01 level*

Wheat Production

Annual number of rainy days, *Kiremt* onset, *Kiremt rainfall total*, Kiremt maximum length of dry-spell and Kiremt length of growing period were used in the stepwise multivariate regression model to predict wheat production for the period 2000-2012. The correlations of these predictor variables with the outcome variable have been revealed in Table 4 and each predictor variable has moderate to strong association with the outcome variable. However, the association between annual number of rainy-days and wheat production; Kiremt onset dates and wheat production; and Kiremt rainfall total and wheat production were significant. Some other characteristics were also significantly correlated with production of wheat, but are not in the model because of multi-collinearity. The prediction model contained only one of the five predictors delivered and was reached in first step with four variables removed. The model, with only annual number of rainy-days total as predictor, was statistically significant, F(1, 11) = 8.91, p = .012, and accounted for approximately 45% of the variance of wheat production $(R^2 = .448, Adjusted R^2 = .397)$. The raw and standardized regression coefficients of the predictors are shown in Table 7.

Teff, Barley and wheat crops are generally crops of short growing period. For this main reason they have been cultivated twice a year following the short rainy season (*Belg*) and the main rainy season (*Kiremt*) in the study area (MoARD, 2007a; MoARD, 2007b). Although *teff* mainly follows early onset of *Belg* rains, all crops are usually planted in the time between February and March; and June is harvesting time. Similarly following the onset of kiremt rain, they generally will be sown in July and August and mostly harvested during October and November; *Teff* mostly is harvested earlier than the other (MoARD, 2007a). Although these three crops are among the major crops in the study area, *teff* is mainly dominant crop in the lowland areas which are warm and relatively drier. On the other side, wheat and barley are the main crop types of the highland environment where relatively higher rainfall is recorded than the lowlands. Although their production showed large variability (CV >37%), it was growing steadily in the last 13 years, with significant amount for the highland crops. However, the general trend of rainfall in the study period (2000-2012) was not promising in that annual and regional rainfall totals show sizeable decline and negative anomalies. The short rainy season, Belg; nevertheless show a slight recovery from the long term declining trend (1980-2012).

Table 7. Stepwise regression results for Wheat Production (2000-2012)

Model	Unstandardized Coefficients		Standardized Coefficients	sr^2	t	Sig.
	B	Std. Error	Beta			
(Constant)	1959649.37	490133.33	-	-	3.998	.002**
ANRD	-20589.34	6897.15	-.669	.448	-2.985	.012*

Note: the dependent variable was teff production $R^2 = .448, Adjusted R^2 = .397$

sr^2 *is the squared semi-partial correlation; **, * Significant at 0.01 and 0.05 level*

Sorghum Production

Some six independent variables such as; Belg total rainfall, Belg onset date, belg maximum length of dry-spells, kiremt onset date, kiremt maximum length of dry-spells and Kiremt total rainfall were moved in the stepwise multivariate regression model to predict the production of sorghum crop for the period 2000-2012 in the study area. Correlations of predictor variables with the outcome variable are shown in Table 4 and each predictor variable had moderate to strong association with the outcome variable. However, associations between Belg total rainfall and sorghum production; Belg onset dates and sorghum production; and Belg maximum length of dry-spells with sorghum production were significant. The step wise prediction model contained three of the six predictors and was reached in three steps with three variables removed. The model was statistically significant, F(3, 9) = 11.90, p = .002, and accounted for approximately 80% of the variance of sorghum production $(R^2 = .799, Adjusted R^2 = 731)$. Production of sorghum crop was largely predicted by the higher amount of rainfall; early onset and longer growing period of Belg season in the study area. The raw and standardized regression coefficients of the predictors are shown in Table 8.

Table 8. Stepwise regression results for Sorghum Production (2000-2012)

Model	Unstandardized Coefficients		Standardized Coefficients	sr^2	t	Sig.
	B	Std. Error	Beta			
(Constant)	788313.82	166572.03	-	-	4.733	.001**
BTRF	1205.76	313.00	.651	.332	3.852	.004**
BOS	-8550.85	2208.41	-.718	.335	-3.872	.004**
BMLGP	-4021.15	1624.37	-.485	.137	-2.476	.035*

Note: the dependent variable was sorghum production $R^2 = .799, Adjusted R^2 = 731$

sr^2 *is the squared semi-partial correlation* **,* *Significant at 0.01 and 0.05 level*

Belg rainfall total and Belg onset dates received strong weight in the model followed by Bel season length of growing period. Generally with sizeable correlations between the predictors, the unique variance explained by each of the variables indexed by the squared semi-partial correlations, was relatively moderate and statistically significant: BTRF, BOS and BMLGP accounted for approximately 33%, 34% and 14%, of the variance of production in sorghum crop respectively. Using the results of the model, thus, we may say the three rainfall characteristics were very strong indicators of Sorghum production in the study region. Unlike to Teff crop, the highland crops (Barley and wheat) relatively seemed to be limited to Kiremt rainfall characteristics. The production of barley and wheat was found to be predicted only by Kiremt number of rainy-days and annual number of rainy days respectively. Approximately about 40% of variances of production in barley crop were found to be accounted by the variation in Kiremt number of rainy-days. Moreover, about 45% of variances in production of wheat crop were accounted by variations in the annual number of rainy days. Perhaps because of the extreme variability and unpredictable nature of Belg rainfall and its characteristics, and the long time decline in trend of rainfall during the season; highland areas might have reduced their involvements in producing these two crops during the season. Inline to the above points, our survey results also indicate that about 60% of respondents from the highland areas did have less than one quintal of harvest from any of the highland crops raised in the last five years (2008-2012). Their reasons mainly were the gradual decline and unpredictability of the small rainy season. Maize and sorghum are crops demanding longer growing periods for which their planting to harvesting periods extend beyond one rainy season. After land preparation (January and February) following the condition of the rains, April is planting season; and after an average of six months would be the harvesting period, in November and December (MoARD, 2007a). the fact that they have longer growing period requirements mean the rainfall characteristics of both Belg and Kiremt seasons have greater influence on production of these crops.

Maize production had very extreme fluctuation (CV>128%) and moderate correlation (T>.30) with Kiremt length of dry-spells, annual and kiremt rainfall totals; but none of these characteristics were significant. In addition, comparing to the other crop type, maize production was the least growing in the study area. However, no rainfall characteristics considered in stepwise regression analysis was found to predict maize production significantly in the study period reflected. It is surprising to find out this type of results between rainfall and maize production with in a situation of predominantly rain-fed agriculture system in the study area. We suggest other studies to have further analysis between climate characteristics and maize production at spatio-temporal level. On the other hand, production of sorghum crop has been found to be affected by both Belg and Kiremt rainfall characteristics. About 80% of its production was accounted by Belg rainfall totals, Belg onset dates and Belg season growing periods significantly at 0.01 level. Survey results from the lowland areas, where *teff, Maize and Sorghum* predominantly grow, reveal that only 70% of the respondents did have less than one quintal of crop produced during the Belg season in the last five Belg rainy seasons (2008-2012). Moreover, production assessment and early warning reports from DPPC and FAO/WFP also indicated there were partial or total crop failures during Belg season in the study area due to factors related to spatio-temporal rainfall variability. From 1997 to 2012, it was only in four years (2001, 2002, 2005, and 2006) that Belg rainfall was found to be productive in southern Tigray. In the remaining years, the study area was suffering from the erratic and insufficient rain mostly dominated by dry spells which in-turn led in to partial or complete failure of production in the study area (DPPC, 1997b, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2008, 2009, 2011; FAO/WFP, 2007, 2008, 2009, 2010 and 2012). Our time series data also show supporting cases that those years with least cereal production since 1997 were during drought periods of 1997, 2002, 2008 and 2009 at local and areal level. Moreover, three wet periods; 2006, 2007 and 2010 were accompanied by very higher crop production. The fact implied here is that, with traditional agriculture system, poor coverage of irrigation and weak adaptation capacity, natural rainfall remains to signify productions and yields. In a state of climate change where rainfall is characterized by strong variability and irregularity, the contribution of irrigation development will help.

CONCLUSION

The hypothesis of this paper was that production of each of the five major crops is not affected by any of the rainfall characteristics discussed above. Except to maize production, we have found at least one major rainfall characteristics significantly affecting production in the study area for the period of 2000-2012. Findings of this study further suggests the intensification and extra expansion of agricultural technologies (especially irrigation and improved seeds) and environmental conservation practices at farm level which is supported by strong research and development works. Decreasing rainfall and growing length of dry-spell indicates the requirement of supplementary irrigation system to rescue failure of agricultural production. It also calls for supplying of more drought tolerant crops which can boost sufficient production in short rainy periods. Findings of this study revealed the need to increase our investment on development and reinforcement of R&D agencies to reach the growing demand gap. Strengthening local R&D capacities in all level not only help in producing and supplying improved seeds, it will also give farmers options for different crop preferences. Moreover, since other technologies and inputs are highly dependent on rainfall based irrigation systems, we are calling for investments in micro and medium level irrigation infrastructures where farmers can get guarantee for their crops during dry spells. Decreasing rainfall and growing length of dry-spell indicates the requirement of supplementary irrigation system to rescue failure of agricultural production.

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