Rainfall Variability and its Impact on Rice Productivity in Fogera Plain, Northwest Ethiopia

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ሩዝ በቅርብ ጊዜ ወደ ሀገራችን መግባቱ ይታወቃል ነገር ግን በዝናብ ተለዋዋጭ በሀሪ እና የዝናብ እጥረት በዋነኛነት በምርት ማነቆነት ይጠቀሳል ። ይህንን መስረት በማድረግ የናቱ ዋና ዓላማ የዝናቡን የረጅም ጊዜ ተለዋዋጭነት እና የዝናብ እጥረት ከሩዝ ምርታማነት ጋር ያለዉ ንግንኙነት ማጥናት ነዉ።። ይህንን ለማጥናት የ30 ዓመት የአራት ሜትሮሎጂ ጣቢወችን እና የምርታማንትን መረጃ ተጠቅሟል ። የዝናብ መጠን መረጃዉን ከብሄራዉይ ሜትሮሎጅ ኤጀንሲ እና የምርታማንትን መረጃ ከግብርና ቢሮ በመዉሰድ ለናቱ ተጠቅመናል።።ይህንን ጥናት የዝናቡን የረጅም ጊዜ ተለዋዋጭነትና እና የዝናብ እጥረት ከሩ ምርታማነት ጋር ያለዉን ግንኙነት lmtNተን የኮሬሌሽ፣ እርግሬሽን እና የማግኮብ ምዴሎች ተጠቅመናል።። የትንታኔዉ ዉጤትም የዝናቡ መጠን ቀንሷል የዝናቡ አጀማመር መዘግየት እና ተለዋዋጭነት ጨምሯል የእነገት ጊዘዉ አጥርዋል።። የዝናብ እጥረት እና ተለዋዋጭነት መጨመር በተለይ በዘር ወቅት እና ከኢንገት መጨረሻ ላይ ያለ ተጸእናዉ የጎላ ነበር።። የናቱ ዉጤት ትንታኔ እንደሚያሳየዉ የ5ቀን የ7ቀን የ10ቀን የ15ቀን የዝናብ እጥረት በዘር ወቅት እና አበባና ፍሬ በሚጠልፍበት ጊዜ በተለይ በናቱ ከተካተተ ወረዳወች ዉስ በወረታና በማክስኝት ጣቢያወች ከባህርዳር እና ከጎንደር ጋር ሲነጻጸር ችግሩ ጎለ ታይ ል ። የዉ ምርታማንት ከዝናብ መጠን ከዝናብ ቀናት እና ከኢገት ጊዘ መጨመር ጋር ቀጥተኛ እና የጎላ ግንኙነት ሲኖረዉ ነገርግን የዝናቡ አጀማመር መዘግየት እና የዝናብ እጠረት መጨመር ቀጥተኛ ያልሆነ የጎላ ግንኙነት እንዳላቸዉ በናቱ ተረጋግጧል ። በጥቅሉ የዝናቡ የረጅም ጊዜ ተለዋዋጭ ባሀሪየት 69% ለምርታማንት መቀነስ አስተዋጽአ እንዳላቸዉ ተረጋግጧል። ጥናቱ እንደሚያመለከተዉ ተለዋዋጭ የዝናብ ሁኔታ ማኔጅ በማደረግ የሩዝን ምርት ና ምርታማነት በፍጊራ እና አካባቢዉ መጨመር እንደሚቻል ጥናቱ አረጋግጦአል።።

Abstract

The objective of this study was to analyze rainfall variability and its impact on rice production in the Fogera Plain. The analysis used historical rainfall and yield data from four stations. Historical daily rainfall and yield data were obtained from the National Meteorology Agency (NMA) and Amhara Regional State Bureau of Agriculture, respectively. The rainfall data were subjected to trend and variability analysis. Partial correlation and multiple regression analyses were used to determine the relationship and impact of rainfall characteristics on rice yield. Results showed a decreasing trend of rainfall amount, shortening of the length of the growing period (LGP), increased the variability of rainfall onset date and dry spell length in the study area. The analysis revealed that dry spell lengths of 5 days (sp5), 7 days (sp7), 10 days (sp10) and 15 days (sp15) varied over the study areas with dry spells getting more prevalent in Woreta and Maksegnit compared to Bahir Dar and Gondar stations. Rice yield was positively and significantly correlated with annual rainfall amount (0.69**), LGP (0.61**), and a number of rainy days (0.59*). On the other hand, rice yield was negatively and significantly correlated with rainfall onset date (−0.693**) and length of a dry spell (-0.62**). Rainfall parameters explained 69% of the rice yield variability. The study indicated the need for managing rainfall variability to increase the productivity of rice in the Fogera Plain.

Introduction

Rain-fed crop production has a direct relationship with annual, inter-seasonal and seasonal rainfall which makes it the most vulnerable to seasonal climate variability. Therefore, the key challenge for lowland rice production is to reduce water-related risks posed by high rainfall variability rather than coping with an absolute lack of water (Rockström *et al.,* 2007). This is because seasonal climate variability is a major source of risk for crop production (Harwood *et al.,* 1999). Bewket (2009) has noted that in Sub Sahara Africa, rainfall is the most important climatic factor influencing the growth and development of crops.

In Ethiopia, crop production is dominantly rain-fed and its performance is dependent on rainfall and its erratic pattern which causes crop failures and food shortages (Devereux, 2000). The start and end of the rain, seasonal rainfall patterns of rainfall distribution, frequency, and the probability of the length of a dry spell in the growing season are key factors affecting the planning, establishment and management of crops in Ethiopia (Solomon *et al.,* 2015). Therefore, understanding the different the occurrence, seasonal and intra-seasonal distribution of the different features of rainfall such onset and end date of the seasonal rains, rainfall amount and distribution, number of rainy days and dry spell length and duration is crucial to manage the adverse effects while exploiting opportunities (Fitsume and Desalegn, 2013).

In many instances the rain-fed lowland rice production of Fogera Plain is affected by moisture stress at the late season due to early cessation of rainfall (Tilahun *et al.,* 2013; Tesfaye, 2014). In these Plain areas, however, much of rains in July and August do not help the crops much, as some of the water is lost as a run-off and deep percolation losses due to heavy rainstorms. Rainfall is below average during the early stage of the season in June and during the end of the season in September. Poor rainfall distribution, particularly in the early and late growth stages of the crop (after the mid of September) with the unsatisfactory amount of rainfall and the crop stressed during establishment, flowering and milking stages to affect the yield (Tesfaye, 2014).

Understanding the characteristics of seasonal and intra-seasonal rainfall in a given area has significant importance in rain-fed agriculture management, irrigation planning, and various decision-making processes related to climate change (Mathugama and Peiris, 2011). This also helps matching crops to their best-fit environments and thereby reduce the impact of rainfall variability on crop yields (Tesfaye and Walker, 2004).

Although rainfall variability is believed to be one of the most important rice production risks in the Fogera Plain, the impacts of rainfall variability on the productivity of rice has not been estimated. Therefore, this study was conducted to analyze rainfall characteristics of rainfall variability and estimate its impact on rice productivity in Fogera Plain.

Materials and Methods

The study area

The study was conducted in the major rice-growing areas of the Fogera Plain; mainly in four rice production districts (Bahir Dar, Woreta, Maksegnit, and Gondar) located around the eastern part of the Lake Tana in the western part of the Amhara Regional State. The geographical coordinates of the study areas are located between Latitude 11°40′N to 13°50′N and longitude 37°27′E to 38°10′E. The study area belongs to the moist tepid to cool agro-ecological zone and to the tepid to cool moist plains sub-agro-ecology (CEDEP, 1999). Monthly temperature and daily rainfall data from the four metrological stations were obtained from the national Meteorology Agency (NMA).

Analysis of rainfall variability

Rainfall variability analysis was conducted using daily long-term (1986 to 2017) rainfall data from the four stations selected for the study based on the level of rice production in the Fogera Plain. Rainfall variability was analyzed using onset date, cessation date, length of growing period (LGP), a number of rainy days and length of dry spells as major indicators of variability for the main rainfall season (June-September) by generating a long-term time series from the measured data using first-order Markov Chain Model. For this study, the onset of the rainy season was defined as the first occasion starting from the first of June that recorded at least 20 mm of rainfall over 3 days and was not followed by a period of more than 10 consecutive dry days in the following 30 days (Segale and Lamba, 2005). A period of 30 days is the average length for the initial growth stage of most crops (Allen *et al.,* 1998). Based on the evaporative demand and soil type of the study area, the end of the season was computed by considering a maximum daily evapotranspiration of 5 mm and soil available water holding capacity of 100 mm (Stern *et al.,* 2006). LGP was calculated as a difference between the onset and cessation dates of the main rain season. A day is considered as a rainy if it accumulates 1mm or more rainfall (NMSA, 2001). The number of rainy days was, therefore, counted starting from the first days of January to the end days of December in each year. A dry spell is defined as a sequence of dry days including the days with less than a 1mm value of rainfall (Stern, 2006). The Instant Statistical Program (Version 3.37) was used for processing data and analysis if the daily rainfall variables (Stern *et al.,* 2006). The rainfall variability was determined using the coefficient of variability (CV) which is calculated as the ratio of the standard deviation and mean of the long-term rainfall (Hare, 1983).

Partial correlation and multiple regression analyses were used to determine the relationship between rainfall characteristics and rice yield. The data distribution of each rice crop yield against time was checked by drawing histograms and normality tests before selecting the OLS (ordinary least squares) regression type. Therefore, based on the distribution of the yields (dependent variables) for the rice crop, the following regression model was employed

$$y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_nx_n + e$$

where; Y = the value of the dependent variable (rice yield/ha); a = Y-intercept ; b1, b2, b3, b4,b5 ⋯ bn = regression coefficients (the b values represent the amount of change in Y (rice yield/ha) for one unit of change in the corresponding x-value when the other x values are held constant; X1, X2, X3, X4, X5⋯ Xn = the independent variables (Xi= the independent variables x1 (annual rain days), X2 (onset), X3(LGP), X4 (annual rainfall totals) and X5 (length of dry spell) and e = the error of estimate or residuals of the regression. Y = Predicted yield of rice in the area. From the rainfall data, the following parameters were collected: annual number of rain days (in days), date(s) of onset of the rainy season (in days); cessation of the rainy season (in days); annual rainfall amounts (in mm) and maximum length of dry spells (days). The adjusted coefficient of multiple determinations (R^2) was used to determine the percentage explanation achieved jointly by the rainfall characteristics. The analysis of the correlation and regression was performed using XLSTAT- 2014 software (https://www.xlstat.com/en/).

Results and Discussion

Monthly rainfall and temperature distributions

Monthly rainfall and temperature data from the four metrological stations (Bahir Dar, Woreta, Maksegnit and Gondar) are summarized and presented in Figure 1. The study stations have a mean annual minimum and the maximum temperature of 11.9 °C and 28.84 °C, respectively with a mean temperature of 20.37 °C. The stations receive high rainfall in July and August. As the data over the last 32 years show (Fig. 2), the rainfall amount is relatively low in June (planting period) and September (grain filling period for most crops) indicating the precautions to be made to minimize crop establishment failures and yield reductions due to low moisture stress during the reproductive stage of rice, respectively.
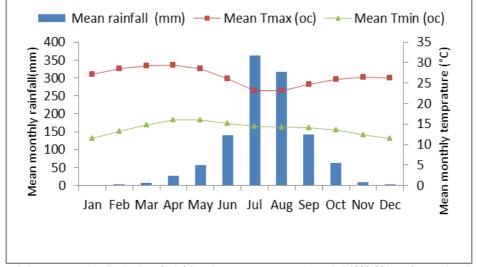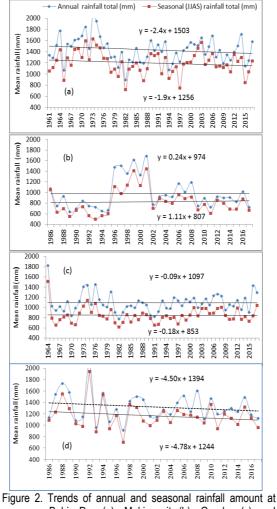

Figure 1. Average monthly distribution of rainfall and temperatures over the period 1986-2017 at four stations in the Fogera Plain**.**

Annual and seasonal rainfall trends

The result showed a decreasing trend of annual and seasonal rainfall at Bahir Dar, Woreta, and Gondar stations (Fig. 2a, c, and d) but an increasing trend at Maksegint station (Fig. 3b). The seasonal rainfall has been decreasing by 24, 1 and 45 mm per decade and also the annual rainfall has been decreasing by 19, 2 and 48 mm per decade at Bahir Dar, Gondar, and Woreta stations, receptively. The annual and seasonal rainfall at Maksegnit station shows an increasing trend which has to be interpreted with caution as there was an unusual increase in annual and seasonal rainfall total between the years 1996 and 2002. Although no evidence was available so far, this could be related to relocation of the recording station, change of instruments or recording errors (Ducré-Robitaille *et al*., 2003).

Figure 2. Trends of annual and seasonal rainfall amount at Bahir Dar (a), Makisegnit (b), Gondar (c) and Woreta (d) stations in the Fogera Plain.

Rainfall amount and variability in the Fogera Plain

The annual rainfall amount in the study areas ranged from 978 mm (Maksegnit) to 1403 mm (Bahir Dar) (Table 1). This indicated a wide variation of rainfall amount across the studied stations within the rice ecosystem in Fogera Plain suggesting the need for site-specific water and crop management practices based on the water supply conditions of the respective stations.

Table 1. Mean, standard deviation (SD) and coefficient of variation (CV) of rainfall parameters over the 1986-2017 period at four stations in Fogera Plain

Rainfall characteristics	Weather stations				
	Statistics	Bahir Dar	Woreta	Makisegnit	Gondar
Annual RF amount (mm)	Mean	1403	1320	978	1085
	SD	169.1	245.4	292.9	133.6
	CV (%)	12.5	18.6	30.0	18.6
Number of rainy days	Mean	112	98	89	110
	SD	8.1	11.0	15.3	10.6
	CV (%)	7.3	11.2	17.2	9.7
Rainfall onset date (DOY)	Mean	144	164	168	165
	SD	15.1	8.1	8.7	7.3
	CV (%)	10.5	4.9	5.2	4.4
Rainfall cessation date (DOY)	Mean	304	296	281	280
	SD	9.8	11.3	4.9	5.4
	CV (%)	3.2	3.8	1.6	1.9
Length of growing period (day)	Mean	160	132	113	115
	SD	19.7	13.1	10.7	8.3
	CV (%)	12.28	9.9	9.5	7.2
Maximum dry spell length (day)	Mean	20	26	29	17
	SD	10.3	11.8	12.1	5.5
	CV	51.4	46.2	41.2	31.8

The results indicate a wide range of annual rainfall variability among the studied stations with a CV ranging between 12.5% (Bahir Dar) to 30% (Maksegnit). The annual rainfall variability at Gondar and Woreta was 18.6% which made it intermediate as compared to Bahir Dar and Maksegint stations (Table 1). The mean number of annual rainy days across the four stations varied from 89 days (Maksegnit) to 112 days (Bahir Dar) over the study period. The annual variability of a number of rainy days followed the pattern of the annual total rainfall with the lowest and highest CV values observed at Bahir Dar and Maksegnit stations, respectively (Table 1).

The mean seasonal rainfall onset dates ranged from DOY 144 (May 24) at Bahir Dar to DOY 168 (June 17) at Maksegnit (Table 1). The onset dates at Woreta and Gondar (DOY 164 and 165 or June 13 and 14) are very close to the one at Maksegnit. The onset date variability was generally higher (CV >10%) at Bahir Dar station as compared to the one (CV <10%) at Woreta, Gondar and Maksegnit stations. The mean cessation date of the rainfall season showed a wide range among the studied stations. The season ended as early as DOY 280 (October 10) at Gondar and Maksegnit stations and extended as late as DOY 304 (October 31) at Bahir Dar station. As compared to

the onset date, the variability in cessation date was generally very low and remains below 10% at all the sites (Table 1).

The LGP also showed large variation among the stations studied with short (113-115 days), medium (132 days) and long (160 days) LGPs recorded at Gondar and Maksegnit, Woreta and Bahir Dar stations, respectively (Table 1). The CV in LGP was generally very low (<10%) at the studied stations except Bahir Dar indicating that crop growing season in the study region is relatively stable. However, the long (17 to 29 days) mean seasonal dry spell lengths recorded at the stations show the high risk of intra-seasonal water deficits in the Fogera Plain (Table 1). Moreover, the mean seasonal dry spell length was highly variable with the CV values ranging between 32% (Gondar) to 51% (Bahir Dar) indicating that the variabilities in dry spell lengths had both temporal and spatial dimensions (Table 1).

The findings of the rainfall variability analysis from this study are similar to those reported for Bahir Dar and Gondar stations by Ayalew et al. (2012). Similar to the findings of previous studies (Yilma and Camberlin, 2006; Hadgu *et al.*, 2013), the long and highly variable dry spells indicate the difficulty of managing in-season water deficits in the rice-growing areas of Fogera Plain. Understanding the events of the occurrence of rain features like onset and end dates and length of dry spells are crucial to manage the adverse effects of seasonal conditions and exploit opportunities (Fitsume and Desalegn, 2013).

Pattern of dry spells

The estimated probability of dry spell lengths based on the first-order Markov Chain Model is presented in Figure 4. The analysis result revealed that dry spell lengths of 5 days (sp5), 7 days (sp7), 10 days (sp10) and 15 days (sp15) varied over the study areas with dry spells more prevalent in Woreta and Maksegnit compared to Bahir Dar and Gondar (Figure 3). The probability of short dry spells (5-7 days) remain very low between DOY 160 to 240, 170 to 220, 160 to 250 and 160 to 240 at Woreta, Maksegnit, Bahir Dar and Gondar station, respectively. On the other hand, the risk of long dry spells (10-15 days) is relatively low between DOY 150 to 260, 160 to 240, 150 to 260 and 140-260 at Woreta, Maksegnit, Bahir Dar and Gondar station, respectively. Once the rainy seasons starts fully, the risk of short dry spells increases fast after DOY 240 at Woreta and Bahir Dar, DOY 220 at Maksegnit and DOY 230 at Gondar while a fast increase of long dry spells was observed after DOY 260 Woreta and Bahir Dar, 240 at Maksegnit and 260 at Gondar

Dry spells are important rainfall characteristics that determine the occurrence and length of intra-season droughts. Long dry spells because of significant yield loss if they coincide with drought-sensitive growth stages such as flowering and grain filling stages (Stern *and Coe,* 1984). The distribution of the dry spells presented in Fig.4, therefore, provides important information to plan site-specific rice planting, irrigation management and harvesting periods in the Fogera Plain.
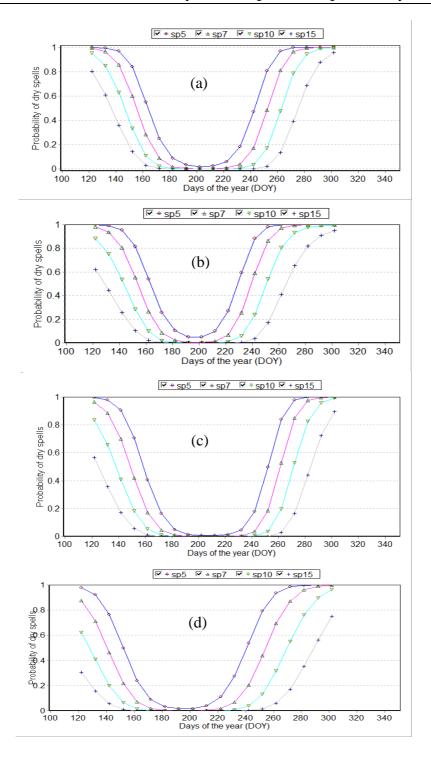
Figure 3. Probability of annual unconditional dry spell lengths at Woreta (a), Maksegnit (b), Bahir Dar (c), and Gondar (d) stations over the period 1986-2017.

Impact of rainfall characteristics on rice yield

The time series rice yield in the main rainy seasons showed high fluctuation over time with a significant negative association (r = -0.62**) with the length of dry spells (Figure 4; Table 2). Although dry spells are common in every season, the frequency and length of dry spells are relatively higher in some years than others. For example, the number of dry spells recorded in 2003, 2009, 1991 and 2004 was, 45, 46, 44 and 32, respectively. The years with a high number of dry spells had lower rice yields and vice versa. Therefore, the year to year variation in rice grain yields occurring in the region is partly attributed to the high dry spell frequencies. Since crop yield reduction is mainly due to the mismatch between a given crop and its growing environment (Tesfaye and Walkers, 2004), it is important to evaluate the type of rice varieties and the different growing environments in the Fogera Plain if one has to minimize rice yield losses in the region.
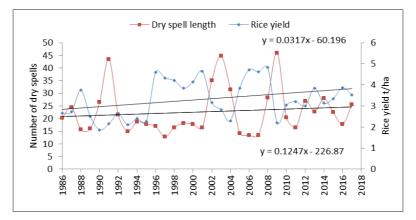

Figure 4. Rice yield and frequency of dry spell trends over the 1986-2017 period in Fogera Plain.

Explaining rice yield variations

Partial correlation and multiple regression statistical analyses were used to form the relationship between rainfall characteristics and rice yield. The correlations between rainfall characteristics and rice yield showed that annual rainfall amount (0.685**), LGP (0.613**) and an annual number of rainy days (0.591**) had a significant positive correlation with rice yield whereas rainfall cessation data had non-significant positive correlations (0.244ns) with rice yield. On the other hand, rainfall onset data (−0.693**) and seasonal dry spell length (-.618**) had significant negative correlations with rice yield (Table 2).

Table 2. Correlation matrix of rainfall characteristics and rice yield

	Rice yield	Number of rainy days	Onset date	Cessation date	LGP	Annual rainfall amount	Dry spell length
Rice crop yield	1						
Number of rainy days	0.591**	1					
Onset date	-0.693**	-0.499**	1				
Cessation date	0.244ns	0.173ns	-0.140ns	1			
LGP	0.613**	0.439*	-0.740**	0.769**	1		
Annual rainfall amount	0.685**	0.477**	-0.545**	0.602**	0.761**	1	
Dry spell length	-0.618**	-0.487**	0.414*	-0.214ns	-0.413*	-0.365*	1
**. Correlation is significant at the 0.01 P level (2-tailed); *Correlation is significant at 0.05 P level							

The extent to which the rainfall characteristics determined the variations in the yield of rice in the study areas is shown in Table 3. The five independent variables: annual rainy days, onset dates, LGP, annual rainfall amounts and frequency of the dry spell were regressed on rice yield (the dependent variables). Based on the regression coefficients shown in Table 3, a regression equation or predictor model wad developed which was presented as follows

$$Y=10159 +11.06x_1-55.13x_2-19.44x_3 + 3.40x_4 -27.46x_5 + 4961 + e$$

where Y = Predicted yield of rice; x_1 = annual number of rainy days); x_2 = rainfall onset date; x_3 = length of the growing period, x_4 = annual rainfall total; x_5 = maximum length of dry spell in a season; and e = the error of estimate or residuals of the regression.

The analysis indicated that dry spell length (x_5), onset date (x_2) and annual rainfall amount (x_4) had a significant ($P<0.05$) influence on rice yield among the rainfall characteristics (Table 3). In explaining the rice yield variation, rainfall onset date and seasonal total rainfall amount had the highest influence (47-48%) followed by a number of rainy days, dry spell lengths and LGP (35-38%). The rainfall characteristics listed in Table 3 together explained 69% of the rice yield variation. This means that 69% of the variations in the yield of rice were explained jointly by the rainfall variables while the remaining 31% of the variations could be attributed to other factors.

Table 3. Coefficients of the regression analysis of predictor variables

Predictor variables	The coefficient of determination (R^2)	Unstandardized coefficients		Standardized coefficients	T	P
		B	SE	Beta		
Constant	-	10158.826	4961	-	2.048	0.051
Number of rainy days	0.35	11.056	13.9	0.104	0.797	0.433
Onset date	0.48	-55.126	20.4	-0.432	-2.704	0.012
LGP	0.38	-19.437	16.3	-0.236	-1.195	0.243
Rainfall amount	0.47	3.39	1.19	0.464	2.846	0.009
Number of dry spells	0.38	-27.464	10.5	-0.317	-2.622	0.014
The adjusted coefficient of determination (R^2)					0.69	
*Coefficient: ** highly significant at 1% confidence level * significant at 5% confidence level*						

Yemenu *et al.,* (2013) reported that within variable seasonal rainfall patterns, understanding the different characteristics of rainfall is crucial to minimize the adverse effects of rainfall variability while exploiting opportunities that come with it. Moreover, several studies show that the productivity of many crops in smallholder farmers systems in developing countries could be significantly reduced by climate variability and change in the coming decades (Rahman and Rahman, 2015).

Conclusions

Rainfall variability was analyzed in terms of dry spell events, LGP, onset, and cessation of dates, number of rainy days, and rainfall amount over the last three decades. The results indicated considerable variation among the rainfall characteristics and stations studied. Among the rainfall characteristics, rainfall amount and number of dry spells were found to be the most variable. Among stations, variabilities of rainfall characteristics were generally higher at Maksegnit followed by Bahir Dar. The correlations between rainfall characteristics and rice yield showed that annual rainfall amounts, number of rainy days and LGP had a strong significant positive correlation with rice yield while the onset date and number of dry spells had strong negative correlations with rice yield. Rainfall amount, onset date, LGP, number of rainy days and dry spells explained about 69% of the rice yield variation. The study indicated that the need for seriously considering climate variability as a major determinant of rice yield in the Fogera Plain and designing site-specific crop management practices to minimize yield losses.

Acknowledgments

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