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# Analysis of Historical Rainfall Data and Associated Risks on Rain-Fed Tef Production at Debre Zeit, Central Ethiopia

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## Abstract

*As drought is the major bottleneck for the rain fed tef* ***(Eragrostis tef****) production, developing workable strategy that can mitigate its impacts is mandatory. To draw this strategy knowledge on how the rainfall behaves in the past decades is important. The central theme for this paper is studying the rainfall behavior over the past six decades in relation to the major rainfall induced risks for the rain-fed "tef" production system using 59 years of rainfall data. Risk of dry spell during germination and flowering is computed whereas crop water requirement satisfaction index is generated using water balance approach. The study shows strong intra annual variation but no trend on the annual and monthly mean rainfall totals, and number of rain days. The existence of this intra annual variation has enabled a wide range of possible planting dates that runs from late June to late August and there was no indication of trend that the planting date has a tendency to be either later or earlier in recent years. The result also depicts once in five years early and once in nine years late onset of the rain. Existence of these wide range of possible planting dates, early and late onset of the rain, high intra year variability in rainfall amount and number of rain days and absence of any apparent trend on the rainfall amount and number of rain days may shed some light how farmers are now facing frequent extremes that may consequence frequent crop failures. This signifies the need for every year rainfall forecasts and their appropriate analysis to have successful planting as well to minimize related risks and consequently to have better and consistent production system.*

Key words: Start of the rain, Planting dates, Dry spell, LGP, CWSI, End of the season

## Introduction

The study has targeted to supplement the "tef" research program which has been in place with the collaboration of Ethiopian Institute of Agricultural Research and McKnight foundation. In general crop production is largely determined by climatic and soil factors. The pattern and amount of rainfall are among the most important factors that affect agricultural systems. Rainfall is the most limiting factor in the rain-fed crop production system. It governs the crop yields and determines the choice of the crops that can be grown. Therefore, a detailed knowledge of rainfall characteristics is an important prerequisite for agricultural planning. The analysis of rainfall for agricultural purposes must include information concerning the trends or changes of precipitation, the start end and length of the rainy season, the distribution of rainfall amounts through the year, and the risk of dry and wet spells.

This study tries to examine presence of clear trend in rainfall amount and its distribution over the last six decades and tries to do a number of weather induced risk analysis in relation to different rainfall events that has special importance to the local farmers. Different type of rainfall events over the past six decades was assessed in relation to Ethiopian rain fed" tef" production.

Tef is an important cereal crop in Ethiopia. According to Central Statistical Agency in 2009/10 cropping season, cereal crops were grown on 9,233,025 of land of these 2, 588,661 ha was allocated for tef and the total production in Meher season was about 31, 793,743 quintals. Outside Ethiopia there is a growing interest in using tef. For example, small scale commercial production of tef has begun in a few areas of the wheat belts of the USA, Canada and Australia (Costanza et al., 1979). Tef has been introduced to South Africa and cultivated as a forage crop, and in recent years cultivated as a cereal crop in northern Kenya and the Netherlands.

Tef is endemic to Ethiopia and its major diversity is found only in that country. As with several other crops, the exact date and location for the domestication of tef is unknown. However, there is no doubt that it is a very ancient crop in Ethiopia, where domestication took place before the birth of Christ.

In Ethiopia, tef is traditionally grown as a cereal crop. The grain is ground to flour, which is mainly used for making popular pancake like local bread called "enjera" and sometimes for making porridge. The grain is also used to make local alcoholic drinks called "tela" and "katikala".

Tef straw, besides being the most appreciated feed for cattle, is also used to reinforce mud and plaster the walls of tukuls and local grain storage facilities called "gotera".

Tef grain, owing to its high mineral content has started to be used in mixtures with soybean, chickpea and other grains in the baby food industry. It is the most adapted crop in the diverse agro-ecologies of the country. Ethiopia is not only origin of Tef, but it is also the center of diversity. It is the most adapted autogamous crop in the diverse agro-ecologies of the country compared to other pulses.

## The Objectives of the study were

- To assess trend on annual and monthly rainfall amount, and number of rain days over the study period
- Examine the extent of variability of rainfall amount and the number of rain days across year over the study period
- To explore range of planting dates and analyze the extent of variability on onset and cessation of seasons
- To assess dry spell pattern in main season (JJAS) and to analyze the risk of dry spells on germination and flowering
- To analyze the crop water satisfaction condition across a range of possible planting dates and different soil types

# Material and Methods

## Study area

The study is conducted in Debrezeit area. The vicinity of Deberezeit is one of the major tef producing areas of the country situated in Ada Libon wereda of East Shoa zone.

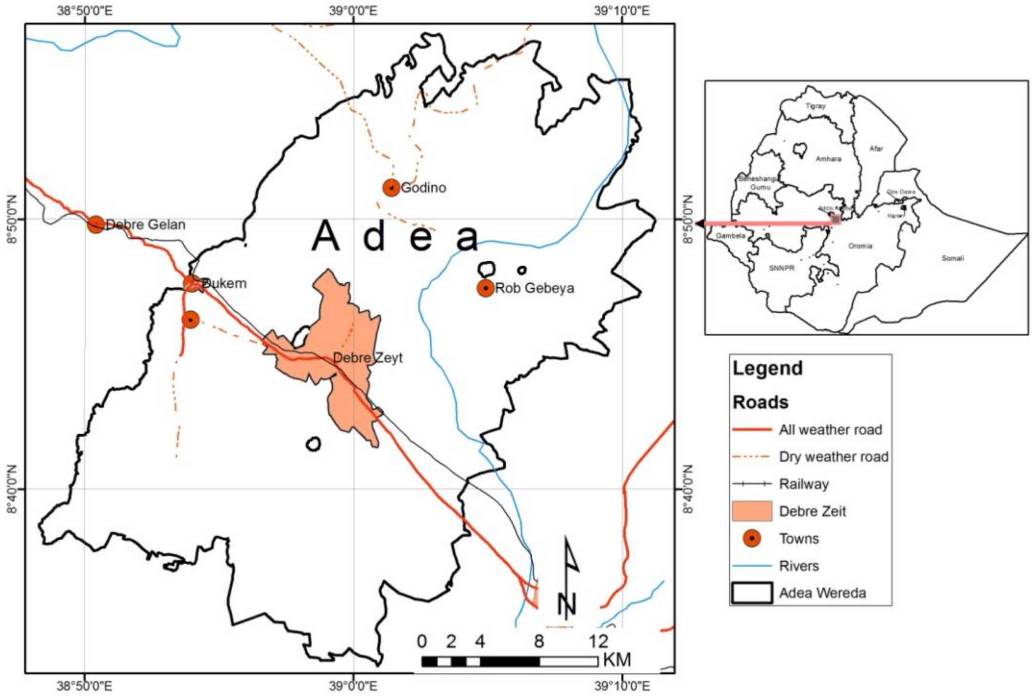



Figure 1: Location Map of the study area

## Source of Data

The study uses data from two adjacent stations at Debrezeit, Central Ethiopia located at 8°42'36N, 39°00'00"E, and altitude 1899masl and 8°45′58'N, 38°59'48E, and altitude 1891masl. The climate data is obtained from National Meteorological Agency (NMA) and Ethiopian Institute of Agricultural Research (EIAR) for the period of 1952 to 2010. Monthly missing values are replaced by the median value for that particular month.

## Annual rainfall totals and number of rain days

Annual rain fall totals and number of rain days (>=0.1 mm) are described using time series plots and descriptive statistics. Through this analysis possible trends as well as year to year variation on the annual rainfall amount and on number of rain days at Debrezeit is assessed. Cumulative frequency plots are constructed to analyze risk of getting annual minimum rainfall amounts and number of rain days.

## Monthly rainfall totals and number of rain days

The monthly rainfall totals and number of rain days at Debrezeit are assessed using summary values along with time series plots of the monthly values over the study period. Using the results from this analysis the existence of possible trend on monthly rainfall totals as well number of rain days is assessed. Also the extent of year to year seasonal variability is studied via this tool. Simple linear regression is fitted for the main season (JJAS) using years as an explanatory variable.

## Date of start of the rain

A range of possible planting dates are determined employing formally defined criteria using the information on the rainfall requirement for planting tef from farmer's experience, tef breeders and other researchers. For the analysis of the start of the rain two criteria's, the one with and the other without the consideration of dry spells during emergency, are used.

**Definition 1:** The 1st occasion from 22nd of June with 80mm or more within a 15-day period

**Definition 2:** The 1st occasion from 22nd of June with 80mm or more within a 15-day period and no dry spell exceeding 3 days in the next 7 days following planting (successful planting day)

The result from this analysis is further processed to see the possibility of early planting, the risk of waiting to get adequate amount of rainfall. Percent probability plots of planting dates are produced to explore range of possible planting dates with the extent of the associated risk.

## Dry spell during the main season (JJAS)

The maximum dry spell length for each months of the main rain season (JJAS) with an initial zero dry spell length and without this initial length is computed. Using these results the JJAS months dry spell condition are characterized. Unconditional maximum dry spell length during a 20 day period after a range of planting dates (germination and establishment) as well during flowering is computed across a range of different planting dates. These events are further processed to produce percentage of years with dry spell length exceeding 7, 10, 12 and 15 days.

## Crop water requirement

Water requirement and satisfaction of 90 and 110 day LGP tef varieties is analyzed via Crop Water Satisfaction Index (CWSI) computed using simple water balance model (Allen et al. 1998). This coefficient is computed for sand, clay and heavy clay soil types with 50 , 100 and 150 mm water holding capacity at 50 cm soil depth across six different planting dates (Jun 20, July 1, Jun 11, Jul 21, Aug 1, Aug 21) identified using the start of the rain definition. The result from this analysis is further processed so that it can depict the possible water stress the crop may have based the crop LGP, planting dates and the soil water holding capacity.

Decadal period is used for computing the CWSI values. Of the three parameters necessary for computing this Index the Kc value is adopted from similar activity conducted in Tigray (Araya et al. 2011), Ethiopia and monthly potential evapotranspiration (PET) value prepared by NMA and converted to decadal values is used.

The CWSI index computed using this method was further analyzed using group frequency tables, independent sample t-test.

### End of the season

End of the rain season is assessed using the water balance approach. As criteria for end of the season the first day after September 20 on which the water balance gets zero is considered as the day at which the season ends. A continuous evaporation rate of 5mm per day is used for this analysis. The NMA estimate for monthly potential evapotranspiration for Debrezeit is 118 mm and it is about 4 mm per day.

### Statistical packages

Instat is the software used for most of the analysis in this study. GenStat is used for trellis' plot production and SPSS is used for running independent sample t-test of CWSI values.

## Results and Discussion

### Trends in Annual rain fall amounts

The data described are the daily rainfall values from 1952 to 2010. The mean annual total rainfall over this period was 856.5 mm, with an average of about 103.1 rain days. The highest annual totals were 1436.0 in 1966 and 1302.6mm in 1964. The two lowest total records were 492.4 mm in 1994 and 421.1 in 1956. The minimum and the maximum number of rainy days were found to be 63 in 1956 and 130 in 1998 respectively.

Figure 1 and 2 underneath present time series plot of annual rainfall totals and number of rain days at Debrezeit from 1952 to 2010. The dotted lines show one and two standard devotions above and below the mean. The data depicts a slight increase from 1955 to 1965 and after that it shows a variation between years but no trend pattern perhaps up to 2010 with exceptional five years low record for the years 1991 to 1995. The low values for these years may be the result of El Nino rather a general decreasing trend on the rainfall amount. The time series plot for annual number of rain days (>= 0.1mm) doesn't show a clear increasing or decreasing pattern in any part of the study period. Considerable size of year to year variation is observed.

As Figure 3 and 4 clearly shows, one can expect annual rainfall of more than 1003mm and as well below 692mm only once in five year. Also about 851 mm is expected once in two years. On the average there will be 105 rain days once in two years as well once in five years there might be below 91 and above 115 rain days.

Figure 1. Annual rainfall totals (mm) at Debreziet, Ethiopia (1951-2010)

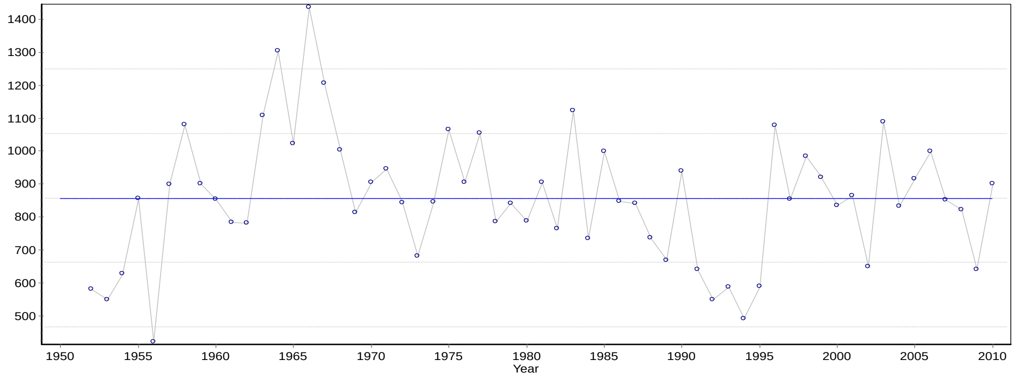



Figure 2. Annual total number of rain days at Debreziet, Ethiopia (1952-2010)

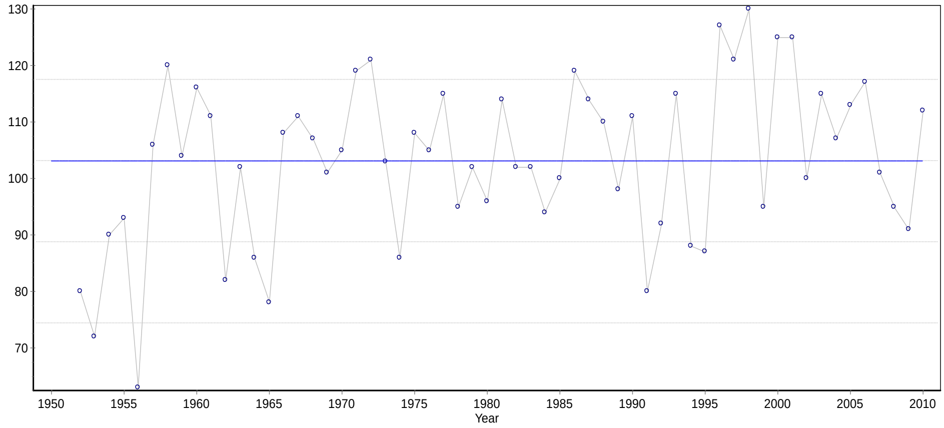


Figure 3: Cumulative frequancy plot  of annual total rainfall, at Debreziet, Ethiopia (1952-2010)

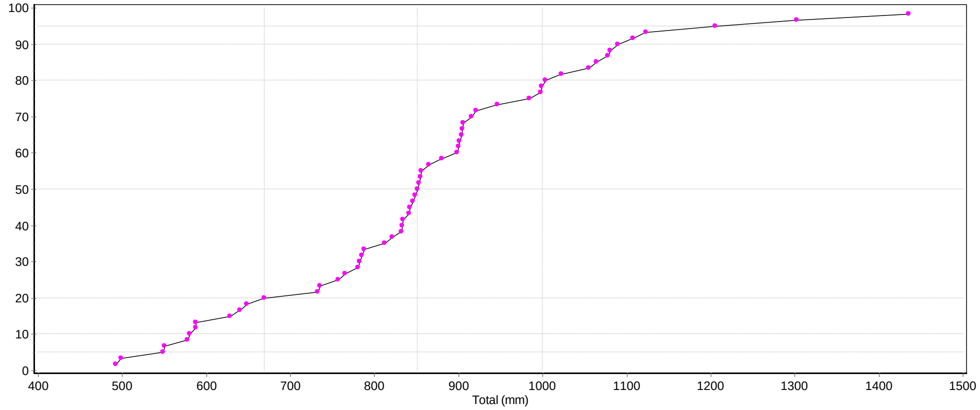
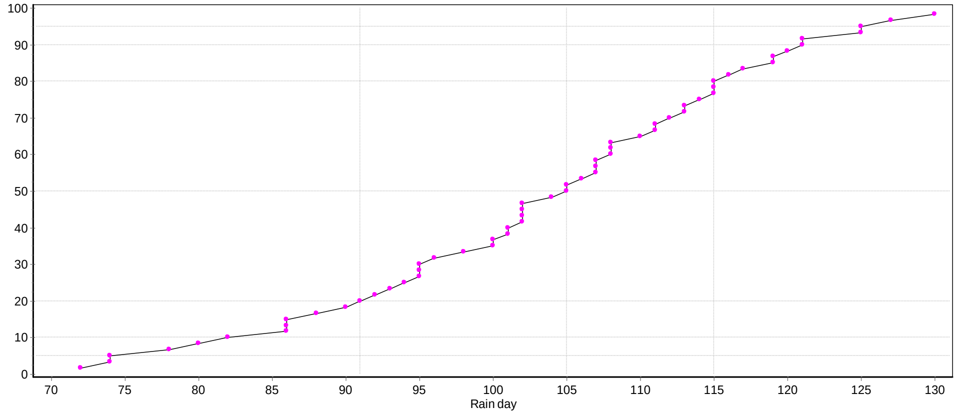



Figure 4. Cumulative frequancy plot fo rannual  number of rain days (0.1mm), at Debreziet, Ethiopia (1952-2010)




## Trends in monthly rain fall amounts

Debrezeit has two rainy seasons namely Belg (MAM), small rain season and Meher (JJAS) main rain season (Table 1, fig 6).  August and July are the only  two months every year at least with 78 and 83 mm of rainfall  and are the picks of the rain seasons with an average 220.6 and 218.79 mm respectively followed by September and June with 103.33 and 91.88 mm respectively. December and November are the least rainy if not dry at all months with less than 6 mm month. August has only 1 year (1.6%) with less than 100mm and two years (1963 and 1966) above 400mm. In the same way July has only 2 years (3.2%) with below 100mm and two years (1964 and 1965) above 400mm.

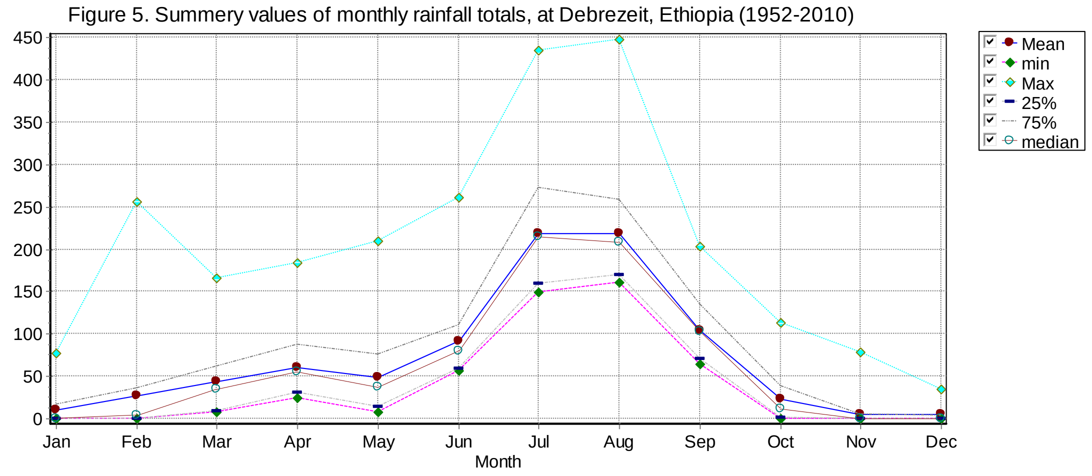


Figure 5. Summery values of monthly rainfall totals, at Debrezeit, Ethiopia (1952-2010)
450
400
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Mean
min
Max
25%
75%
median

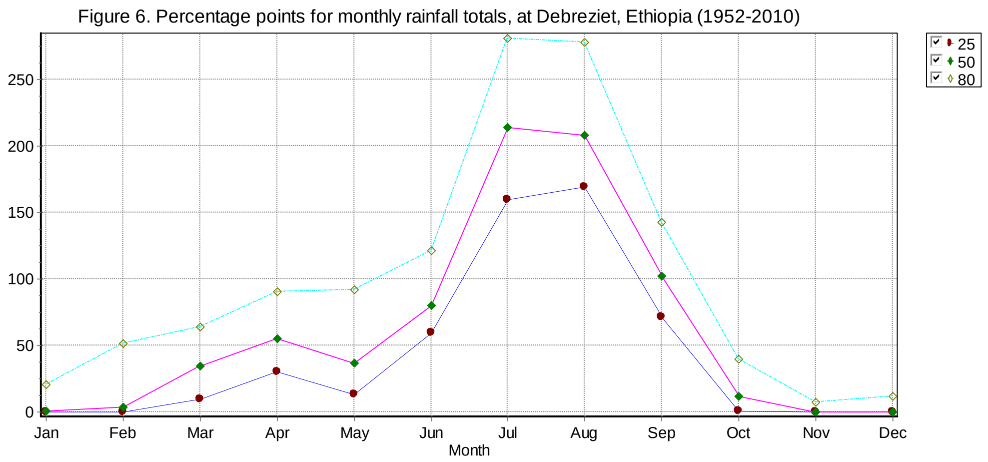


Figure 6. Percentage points for monthly rainfall totals, at Debreziet, Ethiopia (1952-2010)
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
25
50
80

Table 2. Summery values for monthly rainfall total (mm) at Debrezeit (1952-2010)

| | | | | | | Percentages | | | |
|---|---|---|---|---|---|---|---|---|---|
| Month | Minimum | Mean | Median | Maximum | S.d. | 25 | 50 | 75 | 80 |
| Jan | 0 | 10 | 0 | 78 | 17 | 0 | 1 | 15 | 21 |
| Feb | 0 | 26 | 3 | 256 | 48 | 0 | 3 | 36 | 51 |
| Mar | 0 | 44 | 35 | 166 | 42 | 8 | 35 | 61 | 64 |
| Apr | 0 | 61 | 52 | 184 | 40 | 25 | 55 | 89 | 90 |
| May | 0 | 49 | 37 | 210 | 46 | 7 | 37 | 75 | 92 |
| Jun | 0 | 92 | 81 | 262 | 43 | 56 | 80 | 110 | 122 |
| Jul | 83 | 219 | 214 | 435 | 79 | 150 | 214 | 273 | 281 |
| Aug | 78 | 221 | 215 | 448 | 70 | 161 | 208 | 258 | 279 |
| Sep | 0 | 103 | 102 | 203 | 45 | 64 | 102 | 133 | 143 |
| Oct | 0 | 22 | 12 | 113 | 29 | 0 | 12 | 36 | 40 |
| Nov | 0 | 5 | 0 | 79 | 13 | 0 | 0 | 5 | 7 |
| Dec | 0 | 4 | 0 | 35 | 8 | 0 | 0 | 3 | 12 |

Table 3. Summery values for monthly rain days, at Debrezeit (1952-2010)

| | | | | | | Percentage | | | |
|---|---|---|---|---|---|---|---|---|---|
| Month | Mean | Minimum | Maximum | Median | S.d. | 25 | 50 | 75 | 80 |
| Jan | 2 | 0 | 10 | 1 | 2 | 0 | 1 | 3 | 3 |
| Feb | 3 | 0 | 17 | 2 | 4 | 0 | 2 | 5 | 6 |
| Mar | 5 | 0 | 21 | 5 | 5 | 2 | 5 | 8 | 9 |
| Apr | 8 | 0 | 18 | 8 | 4 | 5 | 8 | 10 | 11 |
| May | 7 | 0 | 20 | 6 | 5 | 3 | 6 | 10 | 12 |
| Jun | 14 | 0 | 22 | 14 | 4 | 11 | 14 | 17 | 17 |
| Jul | 22 | 11 | 29 | 23 | 4 | 19 | 23 | 25 | 25 |
| Aug | 22 | 7 | 28 | 23 | 4 | 20 | 23 | 24 | 25 |
| Sep | 15 | 1 | 24 | 16 | 5 | 12 | 16 | 18 | 19 |
| Oct | 3 | 0 | 13 | 2 | 3 | 1 | 2 | 4 | 5 |
| Nov | 1 | 0 | 9 | 0 | 2 | 0 | 0 | 2 | 2 |
| Dec | 1 | 0 | 7 | 0 | 2 | 0 | 0 | 1 | 2 |

Figure 7. Summery values for monthly number of rain days, at Debreziet, Ethiopia (1952-2010)

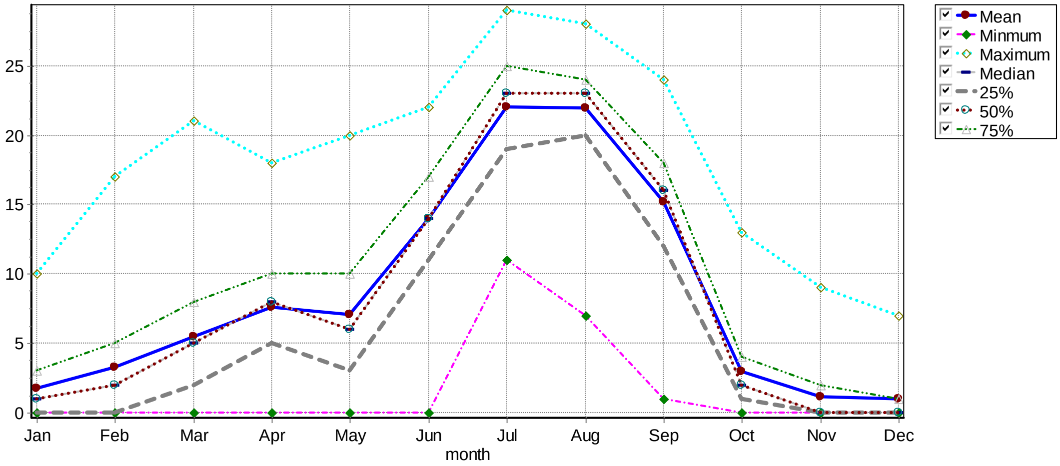



Figure 8. Percentage points for monthly number of rain days, at Debreziet, Ethiopia (1952-2010)

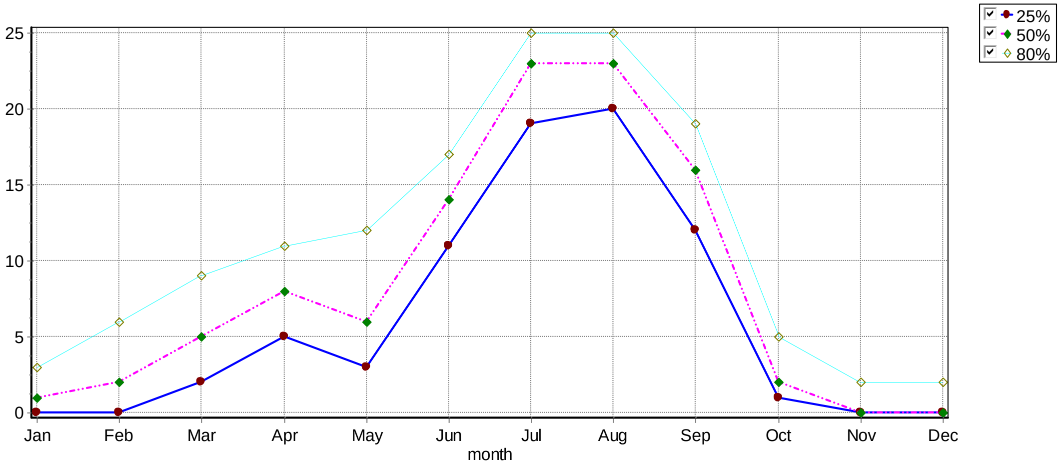
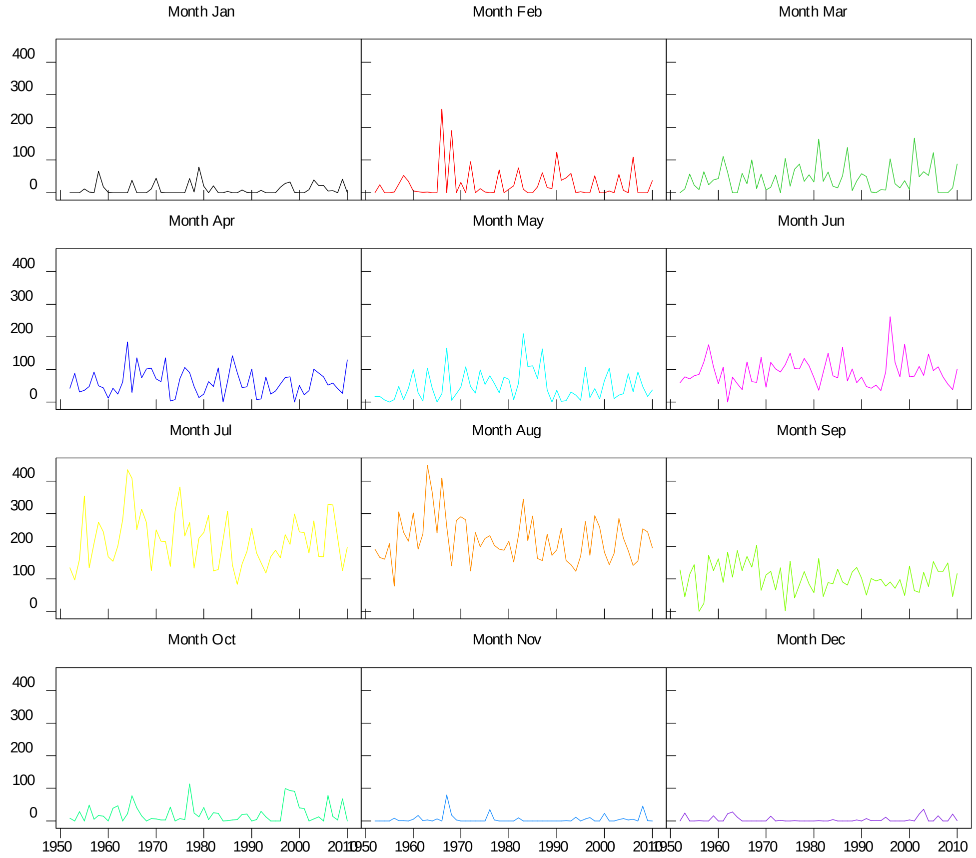



Figure 7 and Table 3 above depicts that August and July are the only two months every year at least with 7 and 11 rain days respectively. These months are the picks of the rain seasons each with 22, 23 and 23 rain days as an average, median and 2nd quintile values. The minimum number of rain days recorded for August is 7 in 1956 while for July 11 in 1953. September and June are the next two rainy months with an average of 15 and 14 rain days respectively. December and November can be considered as dry months each with monthly average of 1 rain day per month. In the main season (JJAS) once in 5 years it is expected to get a monthly total rain days below 11, 19, 19, 12 and above 17,25,25 19 days respectively.

Figure 9. Monthly total rainfall amount, at Debreziet, Ethiopia (1952-2010)




Inspection of the above (Figure 9 and 10) time series plots of monthly total rainfall and number of rainy days do not depict any possible decreasing and increasing trend. To give further strength for this result an ordinary linear regression is fitted using year as an independent variable. The result from the regression analysis also doesn't show trend both on the monthly rainfalls totals and number of rainy days (Table 3).

Table 4. P-values for monthly rainfall totals for Debrezeit Ethiopia (1952-2010)

| Feb | Mar | Apr | May | Jun | July | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|
| 0.44 | 0.61 | 0.73 | 0.59 | 0.57 | 0.56 | 0.14 | 0.33 | 0.34 | 0.95 | 0.77 |

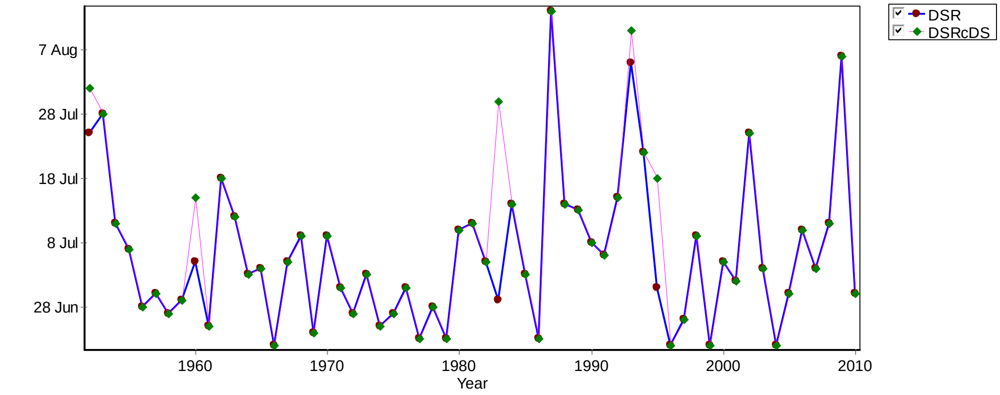
Empirical analysis of risks for rain-fed tef production

## The start of the season

Table 5. Summery values for start of the rain

| Definition | Earliest | 25% | Mean | Median | 75% | Late | S.d |
|---|---|---|---|---|---|---|---|
| Definition1 | 22-Jun | 28-Jun | 6-Jul | 4-Jul | 13-Jul | 13-Aug | 12 |
| Definition2 | 22-Jun | 28-Jun | 7-Jul | 5-Jul | 15-Jul | 13-Aug | 13 |

Figure 11. Date of start of the rain, at Debreziet, Ethiopia (1952-2010)




DSR: date of start of the season, DSRcDS: date of start of the season considering dry spell

Figure 11 shows the date of the start of the rains for the above two possible definitions of the start of the rains. The value for DSR differs from the values of DSRcDS for 5 years out of the 59 study years. This means if the farmers use DSR they will be forced to re-plant about 1 year in every 12 years because of dry spell during germination that kills seedlings. The possible planting date in both definitions is from June 22 to August 13 (Table 4, Fig.11). For 25 percent of the years it was possible to planet before June 28 while in one fourth of the cases onset delays until August 13. Median and the average planting dates are July 06 and July 04 for definition 1 and July 07 and July 05 respectively. From Inspection of Figure 11 and as well from simple regression analysis, there was no indication of trend in the data, i.e. the planting date has a tendency to be either later or earlier, in recent years though considerable amount of year to year variation is noticed.

Planting before the end of June is possible once in every 5 years and for half of the cases the first week of July is the ideal planting week. Only once in 9 years the framers may be forced to wait until August.

Figure 12. Percent Probability Plot of DSR, at Debrezeit, Ethiopia (1952-2010 )

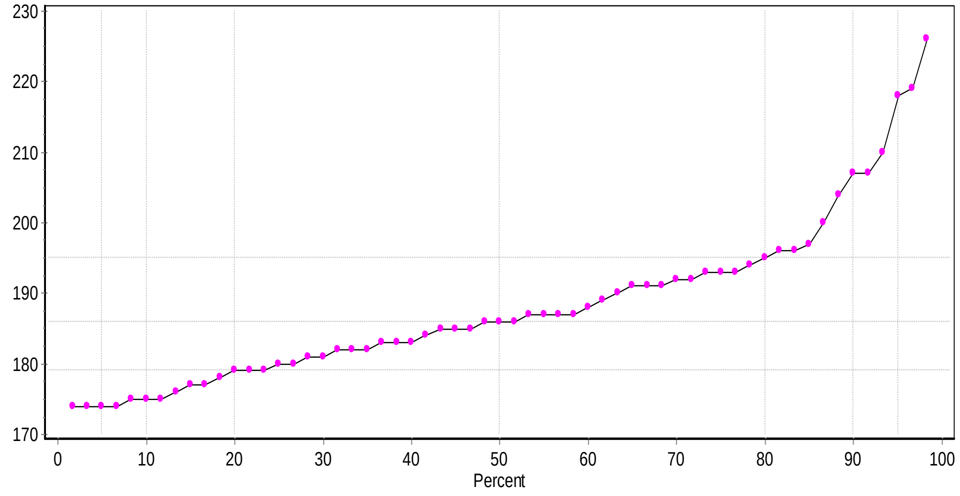
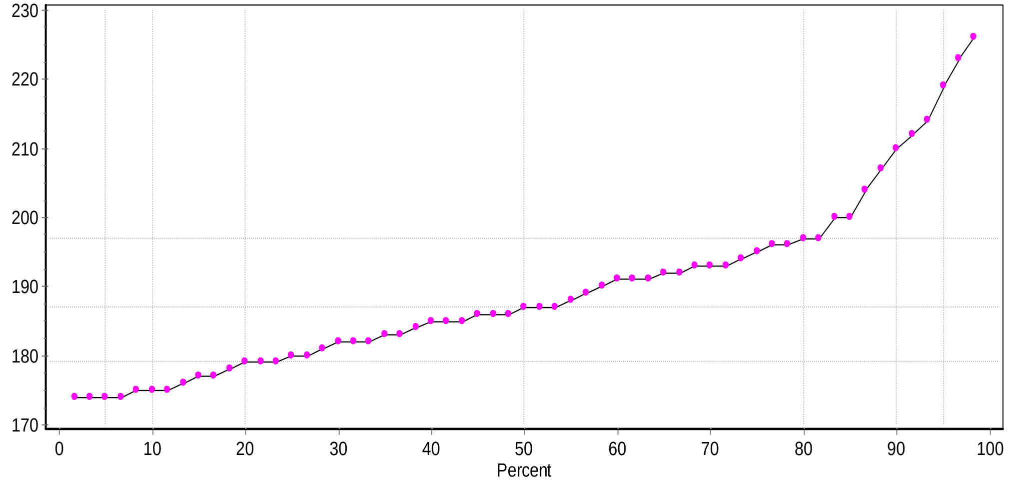



Figure 13. Percent Probability Plot of DSRcDS, at Debreziet, Ethioia (1952:2010)



## Dry spells

In general, crops are more sensitive to water deficit during emergence, flowering and early yield formation than other stages. The dry spell condition across the growing season mainly at sensitive growth stages needs to be understood to minimize yield reduction.

## Maximum dry spell in main Season (JJAS)

For this study dry day is defined as a day with below 0.85 mm of rainfall. The maximum dry spell in main season is computed with a condition that the initial day in each month being rainy and without this condition. When the initial day conditioned being rainy, the average number of dry days during the main season (JJAS) varies from 7.5 to 3.3 days per month (Table 5). June and September were completely dry for some years. The maximum dry spells for July and August were 15 and 12 days respectively. Not conditioning the initial day to be rainy significantly affects the dry spell condition in June but not the rest of JJAS month. In 80% of the years the minimum dry spell length in June is 11 with condition that the first day is rain and 19 without this condition. For the rest of the months (JAS) the dry spell length is 5, 4 and 9. From this fact it can be said that, planting in early June will have strong risk of seedling death due to dry spell post planting.

Table 5. Summary of dry spells during the main season (JJAS), at Debrezeit, Ethiopia (1952-2010)

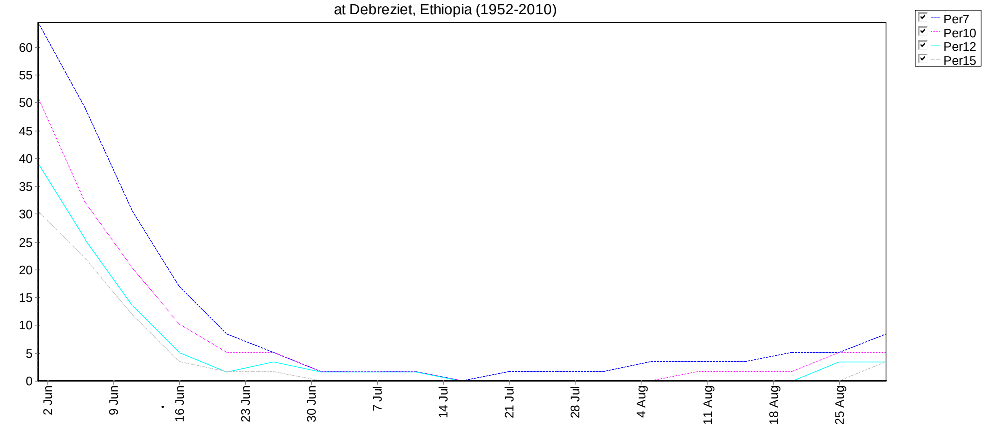
| | | | | | percentage point | | |
|---|---|---|---|---|---|---|---|
| Month | Mean | Minimum | Maximum | Median | 25% | 50% | 80% |
| Jun | 13.41 | 3 | 42 | 11 | 5 | 11 | 19 |
| Jul | 3.542 | 1 | 15 | 3 | 2 | 3 | 5 |
| Aug | 3.23 | 1 | 12 | 3 | 2 | 3 | 5 |
| Sep | 7.305 | 2 | 31 | 6 | 4 | 6 | 9 |
| Jun_0 | 7.508 | 2 | 30 | 7 | 4 | 7 | 11 |
| Jul_0 | 3.31 | 1 | 15 | 3 | 2 | 3 | 5 |
| Aug_0 | 3.39 | 1 | 12 | 3 | 2 | 3 | 4 |
| Sep_0 | 7.2 | 2 | 30 | 6 | 4 | 6 | 9 |

## Length of dry spells during germination and establishment

For tef dry spells at initial stage (germination and establishment) and flowering (Tillering) are critical. Continuous dry spell on the first seven days post planting will kill seedlings and a dry spell in the next 10 days also will hinder the plant establishment.

The result in Figure 14 provides the risk of seedlings death from a given planting strategy across a range of potential planting dates. The result is computed for the range of planting dates starting from June 1 to August 31 with step of five days. A risk of dry spells exceeding 7, 10, 12 and 15 days in the 20 days post planting is computed (Figure 14). The risk of longest dry spell decreases monotonically in June and for the first two decades of July it gets its minimum value and after that starts picking up slowly. Planting in early June is almost unsuccessful while planting late in June is possible but has considerable risk of seedling death.

Figure 14. Percentage of years with dry spell exceeding 7, 10, 12 and 15 during 20 days period after a range of planting dates at Debreziet, Ethiopia (1952-2010)

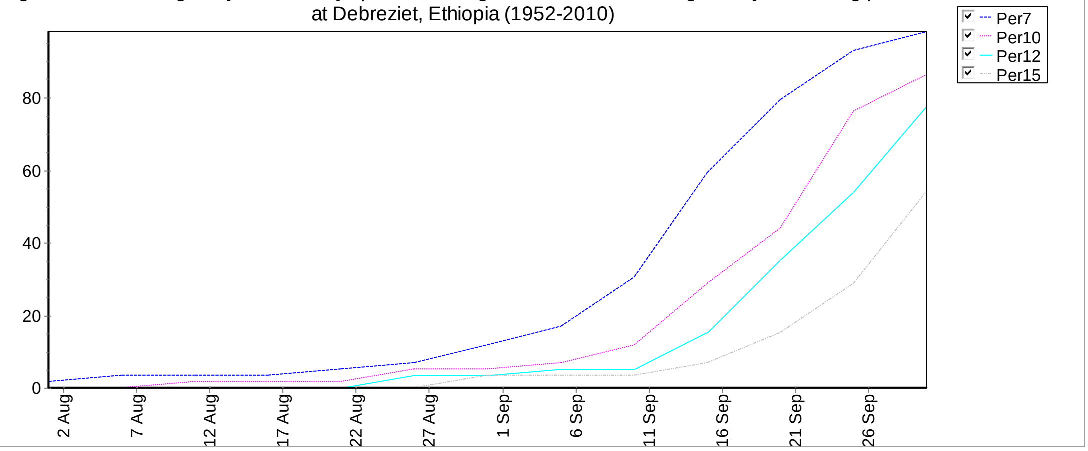



## Length of dry spells during flowering

For tef dry spell during flowering is critical. Extended dry spell during flowering will affect the tillering and grain formation process and consequently the yield. The flowering in tef usually starts from mid August to early September depending on the planting date and growing period of the planted variety. The results in Figure 15 show the risk of dry spell exceeding 7, 10, 12 and 15 days during a 20 day flowering period.

In general, the dry spell conditions during flowering continuously decreases from 1st of August to the end of September. We cannot neglect this risk as it exists throughout the flowering period. For instance the risk of dry spells exceeding 10 days remains throughout this period with a constant rate of s about 1 once in every ten years.

Figure 15. Percentage of years with dry spell exceeding 7, 10, 12 and 15 during 20 days flowering period at Debreziet, Ethiopia (1952-2010)




## Crop Water Satisfaction Index (CWSI)

The index has a maximum value of 100 and is reduced through the season if the crop is under stress. Stress, which results in a decrement in the index, can be caused by a water deficit or surplus. Rainfall, potential evapotranspiration and crop coefficients must be supplied together with a sowing date (or a criterion for sowing) and the soil water holding capacity. In this study decadal period is used for computing the CWSI values. Of the three parameters necessary for computing this Index CWSI the Kc value used is adopted from similar activity conducted in Tigray, Ethiopia and monthly potential evapo-transpiration (PET) values prepared by IMA and converted to decadal values are also used.

Table 6: LGP and Kc used for calculating water balance for cropping periods

| | Developmental period (days) and Kc value by variety types | | | | |
|---|---|---|---|---|---|
| Developmental Stage | Quncho | Dukum | Magna | Tsedey | Single crop coefficient values (k(c)) |
| Emergency and establishment | 20 | 20 | 20 | 20 | 0.9 |
| Vegetative development | 30 | 30 | 30 | 20 | |
| Mid-season (Flowering) | 40 | 40 | 40 | 30 | 1 |
| Late season (grain filling maturity) | 20 | 20 | 20 | 20 | 0.45 |
| Length of growing period (LPG) | 110 | 110 | 110 | 90 | |
| The first decade for the LGP start from | | | | | |
| D3-Jun | D1-Jul | D2-Jul | D3-Jul | D1-Aug | D2-Aug |

Table 7. Frequencies of the final CWSI at Debrezeit, Ethiopia for 90-day variety (1952-2010**)**

| Final CWSI | Planting date | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | June 21 | | | July 1 | | | July 11 | | | July 21 | | | August 1 | | | August 11 | | |
| | Availability of water in the soil profile in mm | | | | | | | | | | | | | | | | | |
| | 50 | 100 | 150 | 50 | 100 | 150 | 50 | 100 | 150 | 50 | 100 | 150 | 50 | 100 | 150 | 50 | 100 | 150 |
| Less than 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 2 | 2 |
| 60-70 | 2 | 2 | 2 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 5 | 3 | 3 |
| 70-80 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 18 | 7 | 6 |
| 80-90 | 15 | 15 | 15 | 11 | 11 | 11 | 3 | 3 | 3 | 5 | 2 | 2 | 13 | 5 | 4 | 21 | 12 | 6 |
| 90-95 | 21 | 21 | 20 | 10 | 9 | 8 | 9 | 8 | 8 | 4 | 3 | 3 | 16 | 3 | 2 | 7 | 9 | 6 |
| 95-99.9 | 14 | 14 | 14 | 16 | 17 | 18 | 14 | 13 | 11 | 16 | 11 | 7 | 15 | 12 | 7 | 3 | 9 | 8 |
| 100 | 4 | 4 | 5 | 22 | 22 | 22 | 32 | 34 | 36 | 33 | 42 | 46 | 11 | 38 | 45 | 1 | 17 | 28 |
| Total | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 |

The result in Table 8 shows, for the 90-day variety in all the three soil types the CWSI increase consistently across planting dates that ranges from June 21 to July 21 and it decrease after that. For planting date duration which ranges from Jun 21 to July 11 CWSI increases independent of soil water holding capacity. If one plans to plant starting from the third decade of July, the CWSI strongly depends on the soil water holding capacity. For instance the numbers of years with CWSI value of 100 ranges from 33-46, 11-45 and 1-28 depending on the soil types for planting dates of July 21, August 1and August 11 respectively. From this result one can infer, importance of planting on soil type with high water holding capacity when the planting gets as late as July 21. As farmers may lack diversity in soil types, planting drought tolerant variety or even anther crop when onset is let.

As Table 8, for the 110-day variety in all the three soil types the CWSI increase consistently if planting is in the first two decades. For soil with water holding capacity of 50 mm after July 11 CWSI consistently decrease. CWSI for the soils with 100 and 150 mm holding capacity CWSI consistently decrease after July 21. It seems whenever the rain get let up to August that year is drought year for this variety even with soil with 150 mm of water capacity. Only the soil type with 150mm has only 3 years CWSI value of above 90 when planting gets late until second decade of August. In general the 90-day variety has comparative high CWSI value almost across all the planting ranges and soil types. If it was not for the long LGP varieties high yielding potential, it is better to plant the 90 day variety as it has relatively wide planting range, better CWSI values and relative short LGP.

Table 8. Frequencies of the final CWSI at Debrezeit, Ethiopia for 110-day tef (1952-2010)

| Final CWSI | Planting date | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 21- June | | | 1- July | | | 11-Jul | | | July 21 | | | 1-August | | | 11-August | | |
| | Availability of water in the soil profile | | | | | | | | | | | | | | | | | |
| | 50 | 100 | 150 | 50 | 100 | 150 | 50 | 100 | 150 | 50 | 100 | 150 | 50 | 100 | 150 | 50 | 100 | 150 |
| Less than 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 4 | 1 | 1 | 20 | 11 | 10 |
| 60-70 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 1 | 3 | 0 | 0 | 11 | 4 | 3 | 23 | 10 | 5 |
| 70-80 | 4 | 4 | 4 | 2 | 1 | 1 | 1 | 1 | 1 | 12 | 3 | 2 | 29 | 13 | 7 | 11 | 24 | 15 |
| 80-90 | 15 | 15 | 14 | 4 | 4 | 4 | 13 | 3 | 2 | 29 | 11 | 5 | 12 | 23 | 10 | 5 | 9 | 17 |
| 90-95 | 19 | 18 | 18 | 13 | 11 | 11 | 17 | 5 | 4 | 8 | 10 | 7 | 2 | 8 | 9 | 0 | 5 | 6 |
| 95-99.9 | 17 | 18 | 18 | 22 | 21 | 20 | 19 | 19 | 16 | 5 | 18 | 9 | 1 | 7 | 8 | 0 | 0 | 3 |
| 100 | 4 | 4 | 5 | 18 | 22 | 23 | 7 | 30 | 35 | 1 | 16 | 35 | 0 | 3 | 21 | 0 | 0 | 3 |
| Total | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 | 59 |

## Independent Sample t-test

As Table 10 depicts, the variability in CWSI values for the two varieties across the different soil types in each of the planting dates is found to be homogeneous and consequently the independent sample t-test is applied to compare the CWSI values of the 90-day variety with 110-day variety for the three soil types in each of the planting dates. The test indicate that for early plantings both varieties perform at the same level for all soil types but for late plantings in all soil types the 90-day variety performs significantly superior (P<0.01) than that of 110-day variety.

Table 9. Independent Sample T-test

| Planting date | Levene's Test for Equality of Variances | t-test for Equality of Means | | | | | |
|---|---|---|---|---|---|---|---|
| | | Sig. | T | df | Sig. | Mean Diff | S.e |
| 21-Jun | 0.94 | 0.33 | -1.17 | 116 | 0.25 | -1.51 | 1.29 |
| 21-Jun | 0.85 | 0.36 | -1.24 | 116 | 0.22 | -1.60 | 1.29 |
| 21-Jun | 0.98 | 0.33 | -1.23 | 116 | 0.22 | -1.60 | 1.30 |
| 1-Jul | 0.11 | 0.74 | -0.03 | 116 | 0.97 | -0.04 | 1.06 |
| *1-Jul* | *0.66* | *0.42* | *-0.75* | *116* | *0.45* | *-0.76* | *1.01* |
| 1-Jul | 0.62 | 0.43 | -0.69 | 116 | 0.49 | -0.70 | 1.02 |
| 11-Jul | 5.94 | 0.02 | 4.05 | 116 | 0.00 | 4.86 | 1.20 |
| 11-Jul | 0.23 | 0.63 | 0.44 | 116 | 0.66 | 0.48 | 1.08 |
| 11-Jul | 0.04 | 0.85 | 0.10 | 116 | 0.92 | 0.10 | 1.07 |
| 21-Jul | 5.37 | 0.02 | 8.09 | 116 | 0.00 | 12.71 | 1.57 |
| 21-Jul | 7.14 | 0.01 | 3.14 | 116 | 0.00 | 4.74 | 1.51 |
| 21-Jul | 3.75 | 0.06 | 1.43 | 116 | 0.16 | 2.12 | 1.48 |
| 1-Aug | 0.28 | 0.60 | 9.38 | 116 | 0.00 | 16.98 | 1.81 |
| 1-Aug | 8.79 | 0.00 | 7.08 | 116 | 0.00 | 12.91 | 1.82 |
| 1-Aug | 16.91 | 0.00 | 3.90 | 116 | 0.00 | 7.58 | 1.94 |
| 11-Aug | 0.51 | 0.48 | 7.87 | 116 | 0.00 | 16.19 | 2.06 |
| 11-Aug | 0.06 | 0.80 | 7.38 | 116 | 0.00 | 17.14 | 2.32 |
| 11-Aug | 1.28 | 0.26 | 5.48 | 116 | 0.00 | 14.26 | 2.60 |

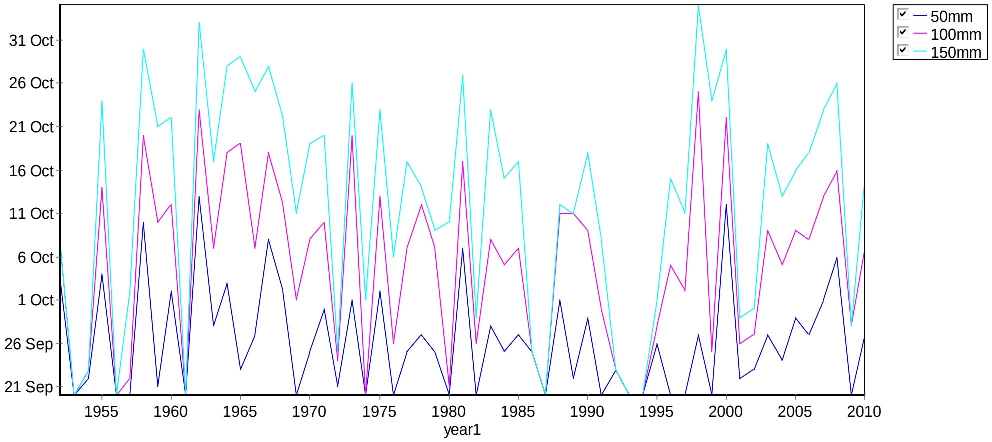
## End of the season

As criteria for end of the season the first day after September 20 at which the water balance gets 0 is considered as the day at which the season ends. A continuous evaporation rate of 5mm per day is used for this analysis. The monthly potential evapotranspiration rate NMA estimate for Debrezeit is 118 mm and it about 4 mm per day. As Table 10 and Figure 17 depicts, the end of the season ranges from September 20 to November 4. The range for end of the season directly depends on the soil water holding capacity. Once in two years the season will end on Sep-25 for 50 mm soil, Oct-07 for 100 mm soil and Oct-15 for 150 mm soil type.

Table 10. Summery values for end of the season

| Min | Mean | Median | Max | S.d | 20% | 50% | 75% |
|---|---|---|---|---|---|---|---|
| Sep-20 | Sep-26 | Sep-25 | Oct-13 | 6 | Sep-21 | Sep-25 | Oct-02 |
| Sep-20 | Oct-05 | Oct-07 | Oct-25 | 10 | Sep-24 | Oct-7 | Oct-12 |
| Sep-20 | Oct-12 | Oct-15 | Nov-04 | 13 | Sep-29 | Oct-15 | Oct-23 |

Figure 17. End of the rain season at Debreziet, Ethiopia (1952-2010)




Debrezeit receives mean annual total rainfall of 856 mm, within average of 103 rain days. The annual total rainfall amount varies from 421 to 1436 mm and the number of rain days ranges from 63 to 130. Debrezeit benefits from bimodal rain season namely, Belg (MAM), small rain season and Meher (JJAS) main rain season. July and August are the picks of JJAS months with at least 7 rain days every year while November and December are dry at all months the year.

There is no any clear trend both on the annual rainfall totals and number of rain days. Significant amount of year to year variation exists both on the rainfall amount and on the number of rain days. This result may shed some light that farmers are now facing frequent extremes that may consequence frequent crop failures.

The possible planting date for tef ranges from mid June to mid August. Once in five years it is possible to plant before the end of June. The first week of July is an ideal planting time for tef. About one in nine years it is not possible to plant before the second week of August. There is no trend in the data that shows the planting date has a tendency to be either later or earlier in recent years but considerable amount of intra year variation is observed.

The risk of longest dry spell during germination and establishments decreases monotonically in June and for the first two decades of July it gets its minimum and after that starts picking up slowly. This means planting in early June and late August is almost unsuccessful. Planting late in June and early in August is possible but planting in late June has considerable risk of seedling death while planting in early August has the risk of early cessation of season which may affect flowering or grain filling. Under normal circumstance planting in early July will significantly minimize the risk of seedling death due to dry spell during germination and establishment. In general, the dry spell conditions during flowering continuously decreases from 1st of August to the end of September. This risk cannot be neglected as it exists throughout the flowering period. The result from the dry spell analyses strongly supports the findings of the analyses for possible planting dates. This signifies the need for every year rainfall forecasts and their appropriate analysis to have successful planting as well to minimize related risks.

The CWSI performance of the 90-day variety is almost the same and consistently increasing in all the three soil types if planting is from Jun 21 to July 21 and if planting is later then it decreases. If planting starts from the third decade of July, the CWSI value strongly depends on the soil water holding capacity. From this result one can infer, importance of planting on soil type with high water holding capacity when the planting gets as late as July 21.

For planting in late June or in first decade of July the CWSI performance of 110-day variety is the same and increasing in all the three soil types and CWSI consistently decreases if planting is in August. Whenever onset is let up to August that year is drought year for this variety. In general the 90-day variety has comparative high CWSI value almost across all the planting ranges. If it is not for long LGP verities high yielding potential, it is better to plant the 90 day variety as it has relatively wide planting range, better CWSI values and relative short LGP.

The within planting date and as soil type variability in CWSI values is the same for the two varieties. If planting is early, both varieties can be planted across any of the soil types but for late plantings 90-day variety is more appropriate as it performs superiorly across all the soil types.

The end of the season ranges from September 20 to November 4 while it depends on the soil water holding capacity. The water balance in the soil will remain above 0 on the average for 3 to 4 months depending on the soil water holding capacity. Once in two years the season will end up on Sep-25, Oct-07, and Oct-15 for the 50, 100 and 150 mm water holding capacity soil types respectively.

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