In: ***Proceedings of the 16th International Conference of Ethiopian Studies,*** **ed. by Svein Ege, Harald Aspen, Birhanu Teferra and Shiferaw Bekele, Trondheim 2009**

Rainfall variability and crop production in Ethiopia Case study in the Amhara region

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Ethiopian agriculture is mostly rainfed, whereas inter-annual and seasonal rainfall variability is high and droughts are frequent in many parts of the country. Rainfall variability has historically been a major cause of food insecurity and famines in the country. Surprisingly, however, the relationships between rainfall variability and fluctuations in agricultural production at regional and sub-regional scales have not been studied in detail. The objective of this study was to analyze rainfall variability and trends, and examine vulnerability of food grain production to rainfall variability in the Amhara region of Ethiopia.

1. Introduction

Agriculture is the source of livelihood to the overwhelming majority of Ethiopia's population. It employs over 80% of the labour force and contributes ~45% to the national GDP, on average. The Ethiopian agriculture is characterized by extreme dependence on rainfall, low use of modern agricultural inputs and low output levels. For instance, the use of chemical fertilizers in 1999/2000 was only ~35 kg ha^{-1} on average (Tadesse, 2002), irrigated land accounts for < 2% of the total cultivated land of the country and crop yields oscillate around 1.2 t ha^{-1} (Befekadu and Berhanu, 2000). The amount and temporal distribution of rainfall is generally the single most important determinant of interannual fluctuations in national crop production levels (Mulat et al., 2004). According to von Braun (1991), for instance, a 10% decrease in seasonal rainfall from the long-term average generally translates into a 4.4% decrease in the country's food production. Rainfall in much of the country is, on the other hand, often erratic and unreliable; and rainfall variability and associated droughts have historically been major causes of food shortages and famines (Wood, 1977; Pankhurst and Johnson, 1988). Even though rainfall variability and drought are not new a phenomenon in Ethiopia, its frequency of occurrence has reportedly increased during the past a few decades (Ketema, 1999). Yet in Ethiopia, very few studies have considered in detail the relationships between crop yields and rainfall characteristics. At the national scale the link between drought and crop production has been documented (e.g. von Braun, 1991), but the detail of specific events at regional and sub-regional scales, however, remains contested with debate about the interactions and importance of confounding factors such as the civil war, land tenure, poverty and long-term environmental change (Desalegn, 1991; de Waal, 1994). Indeed, statistical associations between rainfall and crop production at sub-regional scales have not been studied in any detail.

The impact of rainfall on crop production can be related to its total seasonal amount or its intra-seasonal distribution. In the extreme case of droughts, with very low total

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seasonal amounts, crop production suffers the most. But more subtle intra-seasonal variations in rainfall distribution during crop growing periods, without a change in total seasonal amount, can also cause substantial reductions in yields. This means that the number of rainy days during the growing period is as important, if not more, as that of the seasonal total. Jackson (1989) notes that even in wet locations rainfall variability at the daily time scale is critical to plant growth, particularly in the early part of the rainy season before soil moisture reserves have been built up. Generally, the effect of rainfall variability on crop production varies with types of crops cultivated, types and properties of soils and climatic conditions of a given area.

The aim of this study was to analyze rainfall variability at annual and seasonal time scales and examine vulnerability of food grain production to rainfall variability by using the Amhara region as a case study site. The specific objectives were to: i) examine local scale rainfall variability and trend by using data from a relatively dense network of stations, and ii) assess the magnitude of relationships between rainfall and crop production in the region. The following section presents a brief description of the study area and the data sources and methods of analysis employed in the study. This is followed by the results and discussions, and conclusions sections, respectively.

2. Materials and methods

2.1. The Amhara National Regional State (ANRS): a brief description of study area

The ANRS is located in the north-western and north-central parts of Ethiopia (fig. 1). It has a total area of ~170,000 km^2, which is divided into 11 administrative zones (provinces) and 105 w*oredas* (districts). Subsistence agriculture is the principal economic activity in the ANRS. The subsistence agriculture in the region is characterised by a mixed farming system where crop production and livestock rearing are practised concurrently by farming households. Crop production accounts for the lion's share in annual incomes of households. Owing to the variegated agroecological conditions prevailing in the region, different types of crops are produced: cereals, pulses, oil seeds, and horticultural crops. Cereals occupy the largest area under the crops. CSA (2001) estimated that 81% of the total cultivated land, which is estimated at 4.2-4.3 million ha (BoRD, 2003), was under cereals in the 2000/01 cropping year. During the same year, the shares of pulses and oil seeds were 12.5% and 6.5% of the total area under crops, respectively. *Tef* and sorghum are predominant among the cereals, whilst faba bean, chickpea and field pea are the pulses extensively grown. There are two cropping seasons in the region- the *meher* season (by using the *kiremt* rains) and the *belg* season (by using the *belg* rains). The *meher* season is the main cropping season and it accounts for the overwhelming proportion of the total area cultivated and annual crop production. For instance, 91% of the total cultivated area was cropped during the *meher* season in 2000/01 cropping year (CSA, 2001).

Land degradation and drought are the major physical challenges to agriculture in the ANRS. The rugged topography, expansion of cultivation into steeplands owing to increasing population pressure, intense grazing pressure, and torrential rains are linked with land degradation mainly due to soil erosion by water. According to Lakew et al. (2000), 10% of the total area of the ANRS suffers from annual soil loss rates of >200 t/ha, and 29% of the total area experiences soil loss of 51-200 t/ha per year. In the remaining area, annual soil loss rates are 16-50 t/ha (in 31% of total area) and <16 t/ha (in 30% of total area). These estimates are, however, based on plot scale measurements and should be interpreted with caution as there are methodological problems associated with their scaling-up to larger areas. Agricultural drought is the other major problem in the Amhara region. Out of the 105 *woredas* in the region, 48 are drought-prone and food-deficit; crop production in these *woredas* on average meets only 62% of the requirements for food assuming a daily food requirement of 2100 Kcal per capita (~225 kg of cereals per person per annum) (BoRD, 2003). The eastern parts of the region are particularly affected by recurrent droughts. According to USAID (2000:3), "there has been no single year since 1950 where there was no drought in this part of the region". This statement is however not based on analysis of climatological records; it probably refers to the persistent problem of food insecurity in the area. Droughts often translate into food shortages and famines in the region because of the heavy dependence of agricultural production on natural rainfall. Irrigated agriculture is negligible in the ANRS, although 500,000 ha of land are considered to be suitable for irrigation agriculture (IWMI, 2004).

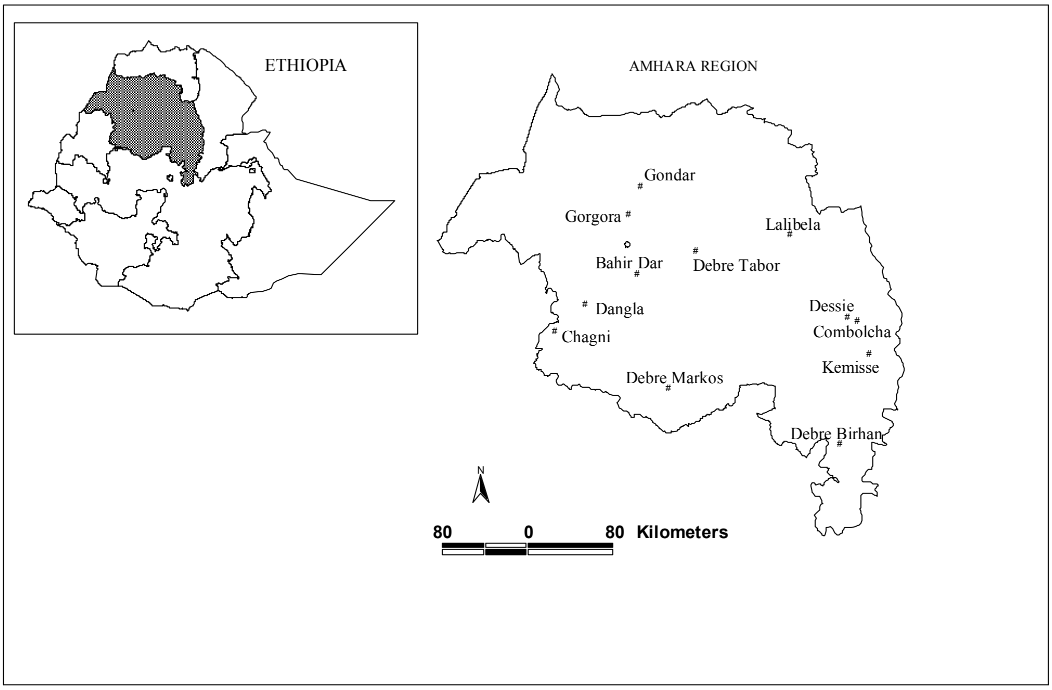

Figure 1. The ANRS and location of the 12 stations used in the study.

2.2. Data sources and methods of analysis

The data used for the study were historical rainfall records and time series data on area coverage, production and yield of cereals during the *meher* season. The rainfall data were collected from the Ethiopian National Meteorological Services Agency. Relatively long rainfall records were obtained for 12 stations, with a reasonably good geographic distribution to cover the study area (fig. 1). Station records span from 1975 to 2003, and years with missing data were not included in the analysis. The agricultural statistics, aggregated at the level of Administrative Zones, were collected from the Central Statistical Authority for the 1994-2003 decade. The study considered only the *meher* season because well over 90% of the total cultivated land of the region is cropped during this season.

Various methods of data analysis were employed in the study. Analysis of the rainfall data involved characterizing long-term mean values, and calculation of indices of variability and trends at monthly, seasonal and annual time steps. The coefficient of variation and the Precipitation Concentration Index (PCI) were used as statistical descriptors of rainfall variability. The PCI values were calculated as given by Oliver (1980);

$$PCI = 100*[\Sigma P_i^2 / (\Sigma P_i)^2]$$

Where P_i is the rainfall amount of the ith month; and Σ = summation over the 12 months.

According to Oliver (1980), PCI values of less than 10 indicate uniform monthly distribution of rainfall, values between 11 and 20 indicate high concentration, and values of 21 and above indicate very high concentration.

The least squares regression technique was used to quantify trend in annual and seasonal rainfall and the Spearman's *rho* test was used to test statistical significance of trend. Standardized anomalies of rainfall were calculated and used to assess frequency and severity of droughts, as in Agnew and Chappel (1999);

$$S = [P_t - P_m] / \sigma$$

Where, S = standardized rainfall anomaly.

P_t = annual rainfall in year t.

P_m = long-term mean annual rainfall, over a given period of observation.

σ = standard deviation of rainfall over the period of observation.

The drought severity classes are extreme drought ($S < -1.65$), severe drought ($-1.28 > S > -1.65$), moderate drought ($-0.84 > S > -1.28$), and no drought ($S > -0.84$). The class intervals correspond with the 95, 90, and 80 percentiles assuming that annual rainfall data are normally distributed.

The monthly rainfall series of all the stations were used to calculate an areal average rainfall for the region as follows (Nicholson, 1985);

$$R_j = I_j^{-1} \Sigma X_{ij}$$

Where R_j is areally integrated rainfall for year j; X_{ij} is rainfall at station i for year j and I_j is the number of stations available for year j. Variability and trend in the areal rainfall were also examined using the same methods.

Correlation and regression were used to examine relationships between monthly and seasonal rainfall and crop production. The patterns of inter-annual rainfall variability and fluctuations in cereal production are also presented graphically to gain a better insight into rainfall-crop production relationships in the region. It is important to note here that consideration of production of cereals will be more appropriate than yield in investigating the influence of rainfall variability, because the latter can miss out impacts of extreme climatic conditions involving severe droughts that might lead to abandonment of planted areas prior to harvest. In other words, total production aggregates impacts of climate on both production and yields and harvested areas and thus has greater economic relevance than yield. Further, amount and temporal distribution of rainfall also has influence on area cultivated in a given year.

3. Results and Discussion

3.1. Rainfall variability and trends

3.1.1. Seasonal patterns of rainfall

The annual total rainfall in the highlands of the ANRS varies from slightly over 770 mm in Lalibela to more than 1660 mm in Chagni (Table 1). Only three stations (Debre-Birhan, Gorgora and Lalibela) experience annual rainfall amounts of less than 1000 mm. Three stations (Chagni, Dangla and Debre Tabor) receive more than 1500 mm of rainfall per year. Rainfall is unimodal in most of the region; and bimodal in the Wello highlands. Much of the rainfall is concentrated in the four months of the *kiremt* season. The rainfall shows moderate interannual variability as shown by the coefficients of variations (Table 1). Generally the *belg* (small rainy season, March-May) and the *bega* (dry season, October-February) rainfalls are much more variable than the *kiremt* (main rainy season, June-September) rainfall. A similar conclusion - that *belg* and *bega* rainfalls are more variable than *kiremt* rainfall- was arrived at by Engida (1999) in his study that analyzed rainfall data from 419 stations throughout the country. Engida (1999) also reported that rainfall variability is higher in areas of low annual rainfall.

The contribution of *kiremt* rainfall to the annual total ranges from 64% in Combolcha (in the eastern part of the ANRS) to nearly 85% in Gorgora (in the north-western part). *Belg* rainfall makes a considerable contribution to the annual total in the more easterly stations of Combolcha, Dessie, Kemissie and Lalibela. The extreme concentration of rainfall can also be seen from the contribution of the single largest monthly total to annual total rainfall at each of the stations. The highest monthly totals generally account for a very high proportion of the annual totals and range from 23% in Chagni to nearly 40% in Lalibela. The calculated PCI shows that rainfall in the ANRS is generally characterized by high to very high monthly concentration (PCI values ranged from 17% in Chagni, Dangla and Debre Markos to 27% in Lalibela).

Table 1. Annual and seasonal rainfall (mm), coefficient of variation the Precipitation Concentration Index (PCI), 1975-2003.

Station	Annual		*Kiremt*		*Belg*		*Bega*		PCI
	mean	CV	mean	CV	mean	CV	mean	CV	(%)
Bahr Dar	1445	0.17	1214	0.18	115	0.68	121	0.55	22
Chagni	1665	0.12	1252	0.11	174	0.50	252	0.34	17
Combolcha	1045	0.17	669	0.23	230	0.40	143	0.53	18
Dangla	1542	0.14	1165	0.14	183	0.50	178	0.46	17
Debre Birhan	893	0.13	691	0.17	139	0.35	60	0.61	24
Dessie	1193	0.16	787	0.23	251	0.44	163	0.50	18
Debre Markos	1349	0.12	978	0.12	208	0.41	162	0.55	17
Debre Tabor	1580	0.18	1253	0.19	156	0.54	160	0.67	20
Gondar	1110	0.17	876	0.22	140	0.48	109	0.49	20
Gorgora	959	0.21	815	0.25	93	0.60	68	1.47	22
Kemissie	1063	0.23	675	0.27	219	0.56	150	0.63	20
Lalibela	772	0.22	594	0.29	136	0.58	53	0.97	27

3.1.2. Annual and seasonal rainfall trend and variability

For the period 1975-2003, annual rainfall shows negative trend in four out of the 12 stations and positive trend in eight of the stations (Table 2). The positive trends at Dessie (128 mm/decade) and at Lalibela (101 mm/decade) are statistically significant at less than 0.01 and 0.05 levels, respectively. The positive trends in annual rainfall at Bahir Dar, Combolcha, Debre Birhan, Debre Markos and Kemissie are also high, though not statistically significant due to large inter-annual fluctuations. For the *kiremt* rainfall, increasing trends at Dessie and Lalibela are statistically significant. The other significant trends are the decreasing *kiremt* rainfall at Debre Tabor and the decreasing *belg* rainfall at Dangla (both to < 0.1 significance level).

Table 2. Annual and seasonal rainfall trend during 1975-2003.

Station	Annual		*Kiremt*		*Belg*	
	Trend	*rho*	Trend	*rho*	Trend	*rho*
B-Dar	45	0.17	42	0.16	8	0.09
Chagni	-24	-0.17	-12	-0.12	-4	-0.12
Combolcha	51	0.26	60	0.27	-15	-0.16
Dangla	-22	-0.03	12	0.36	-19	-0.56*
D-Birhan	62	0.20	73	0.23	-23	-0.16
Dessie	128	0.62***	107	0.48***	2	-0.04
D-Markos	55	0.26	33	0.26	6	0.04
D-Tabor	-103	-0.28	-101	-0.40*	25	0.23
Gondar	-36	-0.02	-29	-0.04	-19	-0.28
Gorgora	29	0.12	11	0.13	-10	-0.01
Kemissie	34	0.21	30	0.11	5	0.04
Lalibela	101	0.47**	104	0.45**	-19	0.09

*Significant at 0.1 level; **Significant at 0.05 level; ***Significant at 0.01 level
Trend: in mm /10 years
Rho: Spearman's *rho*

3.1.3. Areal rainfall indices for the region

The annual average areal rainfall in the Amhara region is 1194 mm, with a standard deviation of 124 mm and coefficient of variability of 10.4%. The anomalies in the annual and seasonal areal rainfalls are shown in figure 2. The rainfall in the region is characterized by alternation of wet years and dry years in a periodic pattern. Of the 29 years of observation, 17 years (59%) recorded below the long-term average annual rainfall amount while 12 years recorded above average. Most of the negative anomalies have occurred during the 1980s (8 of 17). Between 1978 and 1992 the annual rainfall has been below the long-term mean, excepting the years of 1980 and 1988 when rainfall was slightly above the mean, and 1991 for which no records were available at many of the stations because of the political instability in the country in that year. The 1984 rainfall amount emerges as the lowest on record in the region, showing the worst drought year in the country's modern history. It was a culmination of droughts that started in 1978. Rainfall has shown some recovery since the 1990s, from the low values of the 1980s, but drier conditions have been experienced in 2002 and 2003. According to drought assessment method by Agnew and Chappel (1999), there have been four drought years during 1975-2003 in the Amhara region, with varying severity. There were two extreme (1984 and 1987), one severe (1990) and one moderate (1992) drought years, which together represent 14% of the total number of observations. Once again, the year 1984 stands out as the worst year, with a standardized rainfall anomaly of -2.75. In contrast, 1996 was the wettest year in the region over the period of record followed by the year 2000.

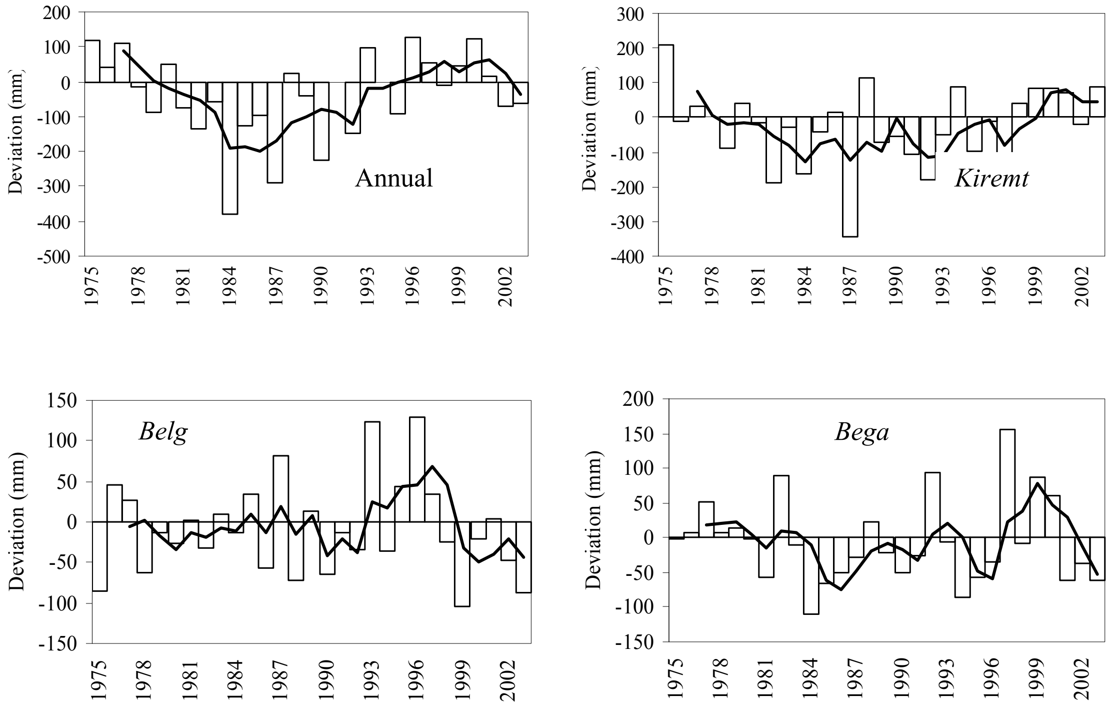

Figure 2. Deviations of annual and seasonal rainfalls from long-term averages (bold line- 3-yrs moving average)

3.2. Rainfall-crop production relationships

Table 3 presents summary statistics on cereal production in the ANRS during the period 1994-2003. *Tef* (*Eragrostis tef*), the staple food crop in many parts of the region, is the most important cereal in terms of area cultivated as well as total production, followed by sorghum. In terms of yield, maize has the largest one. Sorghum exhibits the largest year-to-year variability in terms of area cultivated, total production and yield compared to the other cereals. This high inter-annual variability is caused mainly by inter-annual variability in rainfall. As sorghum is cultivated in semiarid and arid parts of the region, it is particularly vulnerable to the vagaries of weather. During agro-meteorologically drier years, both area planted (and thus production) and yield per unit of cultivated land become lower than average.

Table 3. Summary statistics on area cultivated (000 ha), production ('000 Qt) and yield (Qtha^{-1}) of cereals in the ANRS, 1994-2003.

	Tef	Barley	Wheat	Maize	Sorghum	Millet	Total
Area							
Minimum	744.4	220.7	185.8	226.5	303.4	136.4	1899.7
Maximum	949.3	357.2	332.6	377.8	626.2	273.8	2632.0
Mean	852.2	285.0	268.0	285.5	428.2	177.5	2296.4
CV (%)	7.5	14.2	17.7	16.2	22.2	21.8	9.3
Production							
Minimum	5190.0	1997.5	2071.9	3148.8	2533.0	898.6	18180.7
Maximum	7685.4	3671.1	4145.7	6488.8	8021.2	2180.2	27385.1
Mean	6795.3	2583.7	2896.3	4945.1	4946.1	1626.9	23793.4
CV (%)	12.9	21.2	23.7	23.4	31.7	20.4	15.4
Yield							
Minimum	6.9	7.4	8.9	13.9	6.9	6.6	-
Maximum	9.0	11.4	13.4	21.5	13.2	10.8	-
Mean	8.0	9.0	10.8	17.2	11.4	9.2	-
CV (%)	9.2	13.5	14.2	12.8	16.9	14.5	-

Results of correlation analysis between monthly, seasonal and annual areal average rainfalls and cereal production are given in Table 4. *Tef*, barley and wheat production show considerably high correlations with the *kiremt* rainfall, while sorghum production shows a stronger correlation with the *belg* rains. Except for sorghum, correlations between cereal production and *belg* rainfall are low and some negative; mainly because of the significant inverse relationship between the *belg* and *kiremt* rainfalls ($r = -0.661$, $p = 0.038$). Annual rainfall is weakly correlated with production of cereals, and hence it is a poor predictor of yields as well as total outputs. In statistical terms, only the correlation between wheat production and *kiremt* rainfall is significant. At the monthly time scale, correlations between areal rainfalls during May to September and cereal production are all positive. May to September covers the period from preparation of fields and sowing to maturity stage of crops. The production of *tef* shows high correlations with August and September rainfalls. Barley and sorghum production shows stronger correlations with May and June rainfalls than with the others. For millet production, rainfall during May appears to be particularly important. The production of wheat shows high correlations with rainfalls in all of the five months.

Table 4. Correlations between production of cereals and areal monthly, seasonal and annual rainfalls in the ANRS

	Tef	Barley	Wheat	Maize	Sorghum	Millet
May	0.137	0.444	0.506*	0.309	0.492	0.503
June	0.189	0.421	0.414	0.188	0.503	0.176
July	0.199	0.049	0.612*	0.345	0.079	0.224
August	0.623*	0.273	0.564*	0.349	0.260	0.236
September	0.493	0.348	0.733**	0.149	0.212	0.127
Belg	-0.001	-0.24	-0.17	0.19	0.57	0.21
Kiremt	0.47	0.43	0.80***	0.23	0.10	-0.005
Annual	0.26	-0.35	-0.17	0.33	0.37	0.23

*Significant at the 0.1 level; **Significant at the 0.05 level, ***Significant at the 0.01 level

Even though correlation coefficients are positive, most are not significant in statistical terms. This is not unexpected given the short length of the production data used and the non-linear nature of relationships between crop production and rainfall amount. As noted above, temporal distribution of rainfall at sub-monthly time scales is also important in affecting yield of crops. Correlation coefficients between production and monthly and seasonal total rainfalls are, in other words, inadequate to capture the essence of impacts of rainfall variability on crop production. In recognition to this, the general patterns of inter-annual rainfall variability and fluctuations in cereal production are presented graphically (fig. 3) to gain a better insight into rainfall-production relationships in the region.

Tef (Eragrostis tef)

As shown in Table 4, *tef* production is more strongly correlated with the *kiremt* rainfall than with the *belg* and annual rainfalls. *Tef* is generally sown between mid-June and July, and hence the influence of the *kiremt* rains is as expected. Fluctuations in *tef* production generally follow the patterns of inter-annual variability of the *kiremt* rainfall (fig. 3). Over the 10-yr period, *tef* production has been above average in five years following above-average *kiremt* rains. Likewise, in two years out of ten, tef production fell below the decadal average following below-average *kiremt* rains. In 1997, both *tef* production and *kiremt* rainfall were at their lowest levels for the decade 1994-2003. *Tef* production was substantially below the 10-yr mean in 1994 whilst the *kiremt* rainfall was above average. The primary reason for the very low *tef* production in 1994 was the very low yield level obtained in the same year (6.9 Qt/ ha), which is the lowest on record for the period 1994-2003. The latter is to be explained by several factors, one of which is likely to be intra-seasonal distribution of the *kiremt* rainfall during that specific year. In 1995 and 1996, *tef* production was above the 10-yr mean, while the *kiremt* rainfall was below its mean; and it is partly due to the above-average *belg* rainfall during those years which contributes to increased soil moisture availability. The highest *belg* rainfall was recorded in 1996 over the period 1994-2003.

Barley and Wheat

Barley and wheat are sown in June, usually earlier than *tef*. Like that of *tef*, barely and wheat production show higher correlations with the *kiremt* rainfall. The production of barley was below the 10-yr mean in four years out of ten, as was the *kiremt* rainfall. In three of the ten years, both barley production and *kiremt* rainfall were above their respective decadal averages. Between 1998 and 2000, for three years, barley production has been below its 10-year mean while the *kiremt* rainfall has been slightly above its 10-yr mean. A partial explanation to this discrepancy can be related to the *belg* rainfall which was below its 10-yr mean during those three years. In fact, the lowest *belg* rainfall for the period 1994-2003 occurred in 1999. The production of wheat showed positive anomaly during five of the ten years, as did the *kiremt* rainfall. Similarly, negative anomalies in wheat production during four years were along with four years of negative anomalies in the *kiremt* rains. In 1996 and 1997, when wheat production fell by 28% from its 10-yr mean, area cultivated with wheat was also considerably below its 10-yr average.

Maize and Sorghum

Maize appears to require a more even distribution of rainfall throughout the *belg* and *kiremt* seasons, as it can be seen from patterns of anomalies in maze production and the *belg* and *kiremt* rainfalls and from the high correlation between maize production and annual total rainfall. The production of maize recorded positive anomalies in six out of the ten years, four of which are accompanied by positive anomalies in the *kiremt* rainfall and two are accompanied by positive anomalies in the belg rainfall. Likewise, out of four negative maize production anomalies, two are accompanied by negative anomalies in the *kiremt* rainfall and two by negative anomalies in the *belg* rainfall. The production of maize was 36% and 29% below its 10-yr mean in 1994 and 2002, respectively. In 1994, both area under maize and yield of maize (13.9 Qt/ ha) were at their lowest levels on record for the period 1994-2003. The low maize production in 2002 was apparently because of the below-average *belg* as well as *kiremt* rainfalls.

Sorghum production is particularly related to the *belg* rains. This is because of the fact that sorghum is sown in early May or even late April, which makes the *belg* rainfall critically important. Sorghum production reached its highest decadal mark in 1996; and this is the year with the highest amount of *belg* rainfall for the decade under study. In 1996, the area coverage of sorghum was at its highest and its yield the second highest. Thus, in 1996 favorable *belg* rainfall condition had allowed cropping of a larger area and improved sorghum yield per ha of cultivated land.

In general, for the production of both sorghum and maize, which are long-cycle crops sown early from the *kiremt* rains, the significance of *belg* rainfall is quite obvious. By the beginning of the *belg* season, which follows the long dry season of *bega* (October to February), soil moisture is virtually nil. Hence, occurrence of adequate rainfall in the early periods of the season (*belg* season) is important for maize and sorghum production. During the *kiremt* season, not only that rainfall occurrence is likely to become more common, but also that soil moisture reserves will be sufficient to support plant growth during any dry spells. Sorghum in particular has a good tolerance for water stress caused by dry spell occurrences. Similarly, sorghum tolerates end-of- season dry spells (rainfall shortage in September) than maize, so it is more sensitive to rainfall in *belg*, while maize is more sensitive to dry spells throughout its growing period beginning in *belg* and until end of *kiremt*.

Millet

Anomalies in millet production show influences from the *belg* and annual total rainfalls, with a slightly higher correlation with anomalies in annual total rainfall. Over the 10-yr period, millet production recorded positive anomalies in five cases, of which two are accompanied by positive anomalies in annual rainfall, two by positive anomalies in *belg* rainfall and one by positive anomalies in both *belg* and *annual* rainfalls. Negative anomalies in both *belg* and annual rainfalls in 2002 and 2003 contributed to negative anomalies in millet production. In 1994, millet production was 45% below the 10-yr average; and both area under millet and millet yield were at their lowest for the decade 1994-2003. During the same year, *belg* rainfall was 15% below its 10-yr mean.

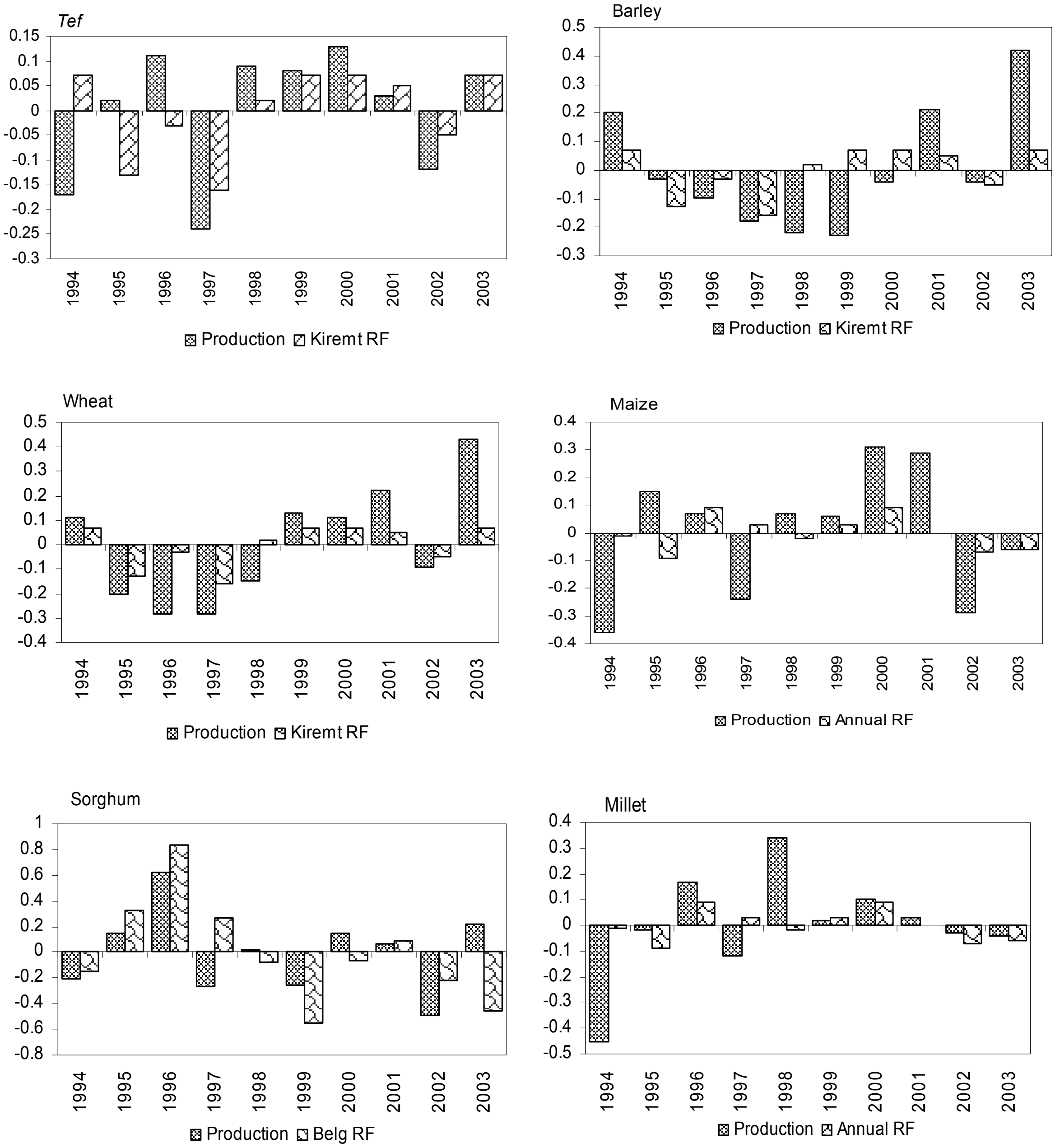

Figure 3. Standardized anomalies of production of cereals and seasonal and annual rainfall amounts in the ANRS (1994-2003)

As it can be seen from Figure 3, production of each cereal crop has shown negative anomaly in 1997 and 2002. This was due to high negative anomalies in seasonal rainfalls. The *kiremt* rainfall in 1997 was at its lowest for the period 1994-2003 (16% below the 10-yr mean). In consequence, total cereal production reached its lowest record for the decade (24% below its 10-yr mean) in the same year (1997). In 2002, both *kiremt* and *belg* rainfalls were below their respective decadal averages; and correspondingly total cereal production in the same year was 21% below its 10-yr average. In addition to these two years (1997 and 2002), the production of *tef*, maize, sorghum and millet recorded negative anomalies in 1994 as well, which contributed to the below-average total cereal production in the region (16% below the 10-yr mean). The number of relief food assisted population in the region was around 2.02 million, 3.12 million and 1.20 million in 1997-98, 2002-03 and 1994-95, respectively (Woldeamlak, 2006).

4. Conclusions

This study has presented analyses of recent rainfall behavior and relationships between rainfall variability and fluctuations in crop production in the drought-prone ANRS of Ethiopia. Historical rainfall records from 12 stations and time series data on area coverage, production and yield of cereals during the *meher* season were used as inputs. The findings of the study show that there are significant intra-regional differences in rainfall amount, variability and trend. Annual rainfall varies from about 770 mm in the eastern part (Lalibela) to more than 1660 mm in the western part (Chagni) of the region. Rainfall amount is higher and its variability lower in the western part of the region than in the eastern. Recovery of rainfall during the 1990s from the low values of the 1980s obscures decadal scale trends in annual and seasonal rainfall at some stations. Many stations show drier conditions in 2002 and 2003. Examination of trends in annual and seasonal rainfall generally shows absence of any systematic patterns of change across the region. The observed trends in some of the indices are thus mainly dependent on local scale climatic controls, rather than large scale climatic forcing.

Inter-annual and seasonal variability of rainfall is a major cause of fluctuations in production of cereals in the region. Over the 1994-2003 decade, for which crop production data are available, the patterns of inter-annual variability in productions of the six major cereals (*tef*, barley, wheat, maize, sorghum and millet) cultivated in the region show similar patterns of inter-annual variability in the seasonal or annual rainfall amounts. Productions of *tef*, barley and wheat show stronger correlations with the *kiremt* rainfall while sorghum production is more strongly correlated with *belg* rainfall. Maize appears to require a more even distribution of rainfall throughout the *belg* and *kiremt* seasons. Sorghum shows the largest year-to-year variability as it is cultivated in semi-arid and arid parts of the region where rainfall variability is high. Productions of the cereals also showed statistically significant correlations with each other, suggesting that rainfall is the common yield-limiting factor as use of chemical fertilizers and other agricultural inputs is limited. The fact that there are high correlations between cereal production and rainfall in the region suggest that farmers are vulnerable to food-insecurity related to rainfall variability. Thus there is a need for water resources development including household level rainwater harvesting for crop production. According to Woldeamlak (2006), household level rainwater harvesting, with appropriate management and utilization, has a potential to serve as an adaptation strategy to current rainfall variability and supplement rainfed crop production by enabling production of high market value crops such as vegetables and fruits, with implications for adaptation to future climate change as well.

Acknowledgements

I am grateful to the Ethiopian National Meteorological Services Agency and the Central Statistical Authority for kindly providing me with the rainfall and crop production data, respectively.

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