Moisture availability, cropping period and the prospects for early warning of famine in Ethiopia

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Summary

DROUGHT AND FAMINE *occur regularly throughout sub-Saharan Africa, and their effects are particularly severe in heavily populated countries such as Ethiopia. Over the last 30 years, four major drought periods and associated famines of varying degrees of severity have been recorded in Ethiopia.*

Relatively simple models are available to predict the moisture available for plant growth using standard meteorological data. Since moisture availability is directly related to crop production, such models may make

it possible to give an early warning of crop shortfalls and the onset of famine.

In this paper, a moisture availability model developed by the Food and Agricultural Organization (FAO) of the United Nations is used to estimate the periods since 1953 when there has been sufficient moisture available for satisfactory crop growth at different locations in Ethiopia. The preliminary results of an analysis using existing meteorological data show that short length of growing periods correlate well with the recorded incidence of drought and famine in the country.

Across the drought- and famine-prone areas of northern and central Ethiopia there is a bimodal distribution of rainfall and cropping is usually restricted to the period of the main rains which occur during June to September. Although the short rains falling between February and May generally do not provide enough moisture to support a crop, they are important because it is during this period that much of the land preparation and cultivation takes place. If land preparation is largely completed during the short rains, the farmer can take full advantage of the main rains.

If the short rains fail, most land preparation can only begin after the start of the main rains, and this preparation time cuts into the period available for crop growth. Historically, severe famine periods have been associated with a sequence of 2 or more years in which the short rains failed and the resultant main-season growing periods were either marginal or so short that crop failure was inevitable.

Introduction

Plant growth and crop yield are closely related to the amount of moisture available during the growing season. Relatively simple models are available that can quantify this relationship and, when fed appropriate data, can be used not only to predict but also to partially explain past crop failures. The opportunity to analyse data on moisture availability, and to develop a predictive model for application in Ethiopia, arose in August 1984 through cooperation between ILCA, FAO and the Land Use Planning and Regulatory Department of the Ethiopian Ministry of Agriculture.

Methods

A computer program originally developed by FAO for an agro-ecological study of crop suitability in Africa (FAO, 1978) was installed on the Hewlett Packard 3000 computing system at ILCA headquarters in Addis Ababa. The FAO program estimates the moisture available for crop growth in individual months of the year, using data of the type described in Table 1. The length of growing period (LGP) is calculated through a simple water balance model that relates precipitation (P) and moisture stored in the soil (S) to the potential evapotranspiration (ETp) of the crop, the latter being assessed using the Penman formula (Penman, 1948). Crop production can then be estimated, at least qualitatively, in terms of the time during which plant growth can proceed without serious restriction due to moisture stress.

Table 1. *Parameters used in the calculation of LGPs*.

Abbreviation	Parameter
P	Monthly precipitation (mm)
T	Daily average temperature for the month (°C)
T_x	Average maximum temperature for the month (°C)
T_n	Average minimum temperature for the month (°C)
e	Average vapour pressure (mb)
RH	Relative humidity (%)
U	Average wind speed at 2 m above ground (m.sec^{-1})
n	Monthly average number of sunshine hours per day
n/N	Percentage of possible sunshine hours
R_g	Total radiation (cal. cm^{-2} day^{-1})
R_n	Net radiation (cal. cm^{-2} day $^{-1}$)
ET_p	Potential evapotranspiration (mm. Month^{-1})
S	Stored soil moisture (mm)

Monthly ET_P varies little between years, and the LGP can be estimated with reasonable precision from rainfall data once the mean ET_p has been calculated from long-term records. Fortunately precipitation, and to a lesser extent temperature, are both widely recorded in Ethiopia. A number of other parameters required in the original calculation of ET_P were estimated from nearby locations (FAO, 1984).

For the purposes of the following analysis the LGP is defined as the period in days when moisture supply from precipitation exceeds half the potential evapotranspiration (from Penman, 1948), plus that period during which plants evapotranspire stored soil moisture resulting from excess precipitation (definition modified after FAO, 1978). The stored soil moisture assumed to be available can be varied in the computer program from 0 to 200 mm in intervals of 50 mm. This allows factors such as soil texture and depth to be taken into account. Any time interval when water is available but the temperature is too low for crop growth is excluded from the calculation of LGP.

A typical growing period includes a 'humid period' when P exceeds ET_P, enabling the soil profile to accumulate a moisture reserve and plant growth to proceed without restriction from moisture stress. Such a growing period is termed a 'normal growing period'. Growing periods where P remains between 0.5 and 1.0 ET_p are referred to as `intermediate'. No soil moisture reserve accumulates under these circumstances, since P remains less than ET_P. The choice of 0.5 ET_p as the threshold value for moisture availability is based on considerable experimental evidence that important physiological changes are induced in many crops below 0.5 ET_p (Doorenbos and Kassam, 1979). Germination also proceeds in most crops when P exceeds 0.5 ET_P.

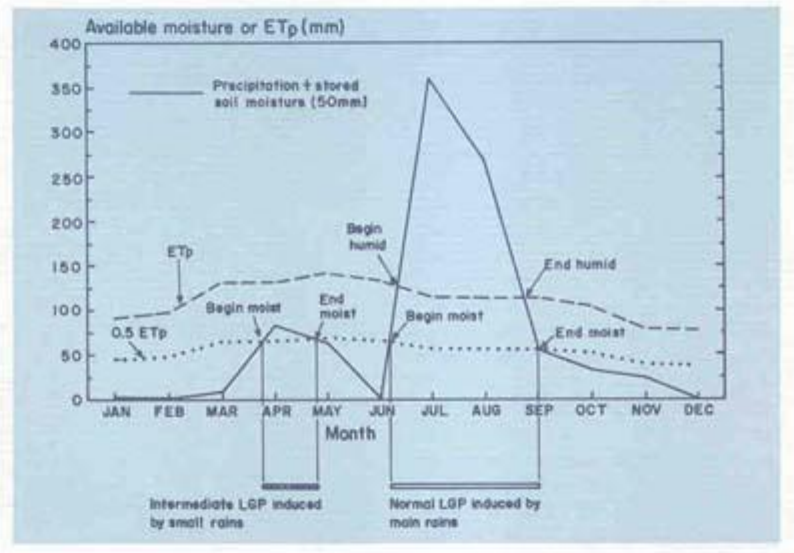
Results and discussion

Rainfall distribution patterns in central and northern Ethiopia

The annual rainfall distribution in the central and northern highlands of Ethiopia, including those areas periodically affected by drought, is generally bimodal (FAO, 1984). The first period of rainfall, usually in the months of February to May, provides a growing period of between 5 and 100 days, depending on the location. The longer growing periods during this short rainy season are more likely to occur along the northeastern escarpment running from southern Tigray through Wello to northern and central Shewa. The variability in the length and frequency of these rains is much greater than that of the main rains occurring from June/July to September.

Figure 1 gives a typical example of moisture availability during 1981 in areas surrounding the northern highlands town of Asmara. An intermediate growing period of approximately 30 days occurred around April, followed by a dry period of about 45 days, after which the onset of the main rainy season quickly raised soil moisture above 0.5 ET_p. In the example given the LGP from June to September was 85 days.

Figure 1. *Precipitation and evapotranspiration at Asmara, 1981.*



Generally, the short rains are insufficient for producing all but the most rapidly maturing crops; they may fail altogether or occasionally merge with the long rains. The dry period between the short rainy season and the onset of the main rains is usually too long to allow the planting of long-season crops before the start of the main rains. Highland sorghum may be planted during the short rains in areas where these are more reliable and substantial, but only at the risk of severe yield reduction or complete crop failure in a bad year.

The importance of soil depth in reducing moisture stress

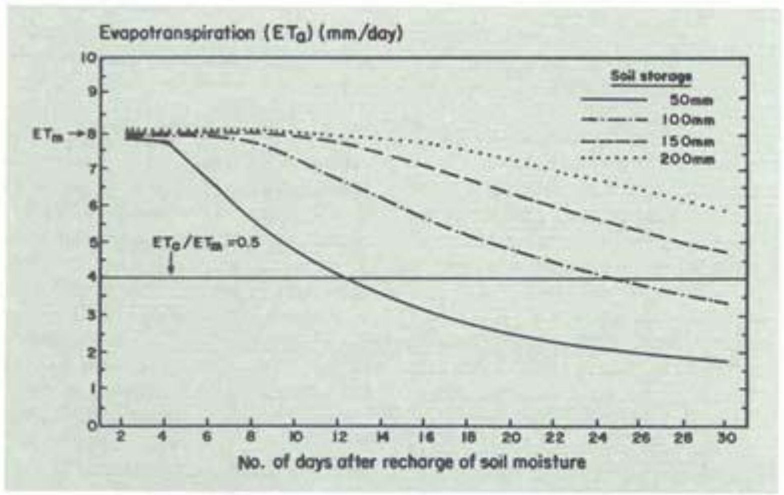
Stocking and Pain (1983) have examined in some detail the concept of available soil moisture and the minimum soil depth necessary for crop production. Assuming that a 50% yield reduction is tolerable, surprisingly shallow soils appear capable of supporting the production of crops such as sorghum.

Rainfall patterns in northern and central Ethiopia during the main rainy season are characterised by heavy monthly falls of between 150 and 350 mm in July and August. This rainy season begins and ends rather abruptly. The moisture index (P/ET_p) for July and August normally exceeds 1, and may in fact exceed 2 or 3 even in relatively dry years. However, little additional rain falls after the second week of September. Consequently crops must draw on stored soil moisture after only about 60 to 80 days, and considerably sooner if late land preparation delays planting.

The ability of soils to store water from the 2 previous wet months is thus a critical factor in the final crop yield. Much depends on the growing season requirements of the crop itself, but Stocking and Pain's assumption that soil moisture recharge occurs 10 times during the growing season is probably not applicable to Ethiopia, making minimum soil depth requirements somewhat greater if acceptable yields are to be achieved.

Figure 2, derived from Doorenbos and Kassam (1979), shows the reduction in actual evapotranspiration (ETa) over time from the point of last recharge, for four different soil storage capacities. Assuming that the maximum evapotranspiration of the crop (Et_m) is 8 mm/day, then for a soil storage capacity of 50 mm ETa/ET_m it is reduced below 0.5 after 12 days. Beyond this point yields are assumed to fall to less than 50% of their potential. For a storage capacity of 100 mm it is 24 days before the same degree of yield reduction occurs. This emphasises the importance of soil moisture storage after the rainy season has ended.

Figure 2. *Reduction in evapotranspiration over time.*



Because of the shallow soils that are found over much of the famine-prone areas of Ethiopia (FAO, 1984[x]), a substantial proportion of the precipitation falling during the heavy main rains is lost as runoff. For Asmara and Mekele the assumed storage capacity is 50 mm, since at both locations the medium-textured soils are generally less than 50 cm deep. Medium-textured soils are assumed to have available soil water capacities of about 140 mm/m (Doorenbos and Kassam, 1979), and this is consistent with a storage of about 50 mm in a soil less than 50 cm deep.

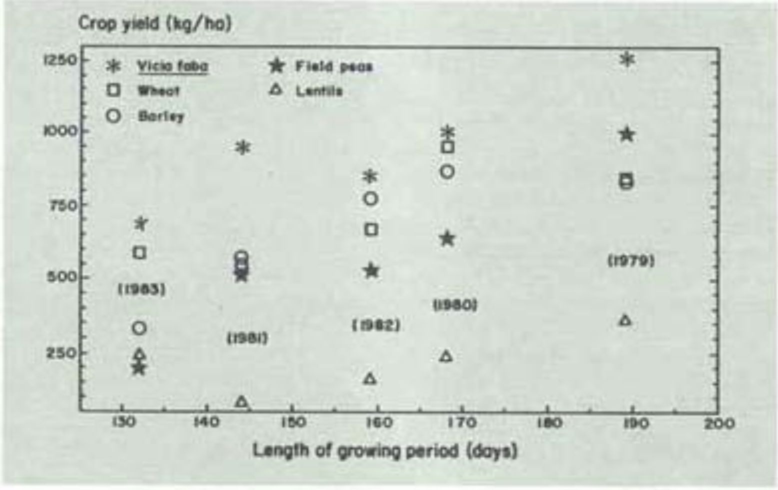
In Asmara, for example, P/ET_p in 1981 exceeded 3 in July and 2 in August (see Figure 1), yet the main-season LGP was still only 85 days because most of the rain would have run off the land. Despite an apparently favourable total rainfall, the LGP during 1981 extended only into September.

Annual variability of LGP in drought-prone areas of Ethiopia

The effect of moisture stress was investigated by estimating the LGP in cases where severe yield reductions or total crop failures are reported to have occurred in drought-prone areas of Ethiopia. The preceding climatic events and the moisture available from the short rains were also examined to gain a more complete understanding of the famine cycle.

Some empirical data on the effect of LGP on crop yield were obtained from research reports of the Ethiopian Institute of Agricultural Research (TAR). Unfortunately, the limited nature of the data meant that no firm conclusions could be reached. Data from ILCA's Debre Berhan research station were also examined for five different crops, for the years 1979 to 1983. The results of this analysis are shown in Figure 3 where each point represents the weighted mean yield from 42 cooperating farmers growing traditional crop cultivars.

Figure 3. *Effect of length of growing period on crop yields, ILCA, Debre Berhan, 1979–1983.*



Yields of all crops show a generally upward trend with increasing LGP, except those of wheat and barley at an LGP of 190 days when an excess of moisture may have influenced the results. However, for the purpose of studying the effects of serious moisture stress, Debre Berhan is not a suitable station, as the minimum LGP was more than 130 days in the years for which data are available. Further research into the effects of moisture availability on crop yields in Ethiopia is clearly needed before firm conclusions can be reached.

Figure 4 shows the year-to-year variation in the main-season LGP for three meteorological stations in traditional grain-producing areas of Ethiopia, spanning the period from 1953 to 1983. Table 2 gives the location and altitude of each station.

Figure 4. *Crop growing period at three Ethiopian sites, 1953–1983.*

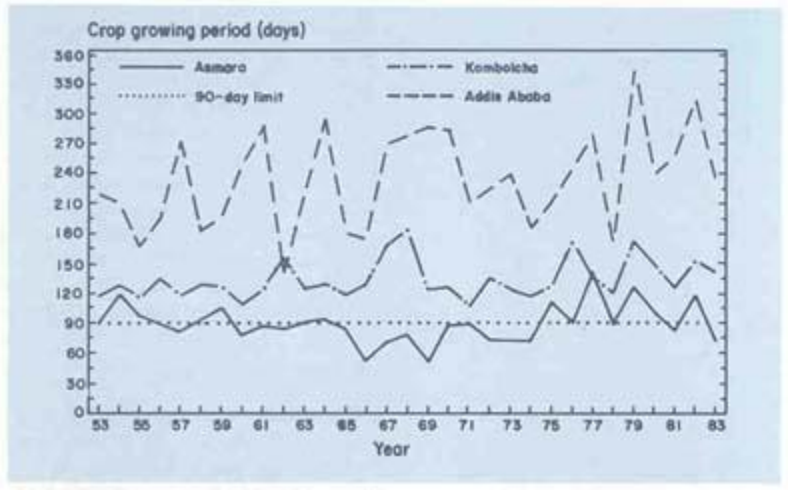


Table 2. *Variation in main-season LGP at three Ethiopian sites, 1953–1983*.

Site	Location	Altitude (m.a.s.l.)	Mean main-season LGP (days)	Standard deviation	Coefficient of variation (%)
Addis Ababa	9° 02'N, 38° 45'E	2408	235	50	21
Kombolcha	11° 05'N, 39° 45'E	1903	133	20	15
Asmara	15° 17'N, 38° 55'E	2355	89	20	22

Most crops grown in Ethiopia, with the exception of some pulses and very low-yielding varieties of teff and wheat, require a growing season of at least 90 days. This generalisation is of course dependent on temperature and, as altitude increases and temperatures fall, a crop requires a progressively longer LGP if it is to yield successfully. Above 2000 m a.s.l. in Ethiopia, highland varieties of sorghum and maize commonly require between 150 and 180 days to reach maturity; on the other hand, at lower altitudes these crops mature in only 90 to 120 days. Thus short growing periods in the highlands can be a serious problem for such crops.

The data for Asmara show that the longest LGPs over a 31-year period rarely exceeded 90 days, and particularly low values were recorded in the years 1966–69 and 1972–74, which were both famine periods in northern Ethiopia. While the identification of drought years is not quite as simple as estimating the LGP in a given year, it is worth noting that Asmara had rather short main-season LGPs in most years of the period under study. This in turn must have severely limited the range of suitable crops for the region since, at such a high altitude, the optimal growing period for barley, for example, probably exceeds 90 days.

Addis Ababa and Kombolcha both have much longer LGPs, but these varied substantially. Farmers planting late-maturing crops in the vicinity of Addis Ababa will undoubtedly have poor yields in some years. However, the shortest LGP recorded for the main growing season in both

Addis Ababa and Kombolcha still exceeded the maximum for Asmara. The average LGP for Kombolcha (133 days) is lower than that for Addis Ababa (235 days) but 120 days was exceeded in most years and, as will be noted later, rainfall in Kombolcha tends to be more bimodal in its distribution, from which crop production can benefit substantially.

Role of the short rains in crop production

There is a relationship between reported drought periods and the failure of the short rains in those years when the main-season LGP was less than 90 days. Crops can be grown successfully if the short rains are sufficiently prolonged, but for much of the highlands, including the drought-prone areas of Wello, Tigray and Eritrea, these rains are so unreliable that farmers cannot regularly take advantage of them for cropping. Unreliable as they are, the short rains are still very important because they facilitate land preparation prior to the main cropping season.

Land preparation in Ethiopia with the traditional ox-drawn plough is extremely difficult if the soil is either very dry or excessively wet. Thus, ideally, land preparation begins at the end of each harvest before soils dry out, and starts again during the short rains when the soil is easily worked. Such a practice enables farmers to plant early in the main rainy season and takes full advantage of the available LGP. If the short rains fail, however, land preparation can only begin after the onset of the main rains. Consequently, planting is delayed well beyond the start of the main growing season and crops may be subjected to moisture stress if the rains end early. At higher altitudes, generally above 2300 m a.s.l., the risk of frost damage to late-season crops must also be considered.

The total time needed for land preparation varies with the crop and the soil, but is generally between 10 and 30 days. If this time is subtracted from the main-season LGP in a year when little or no land preparation is possible because of the failure of the short rains, then the likelihood of crop failure is greatly increased.

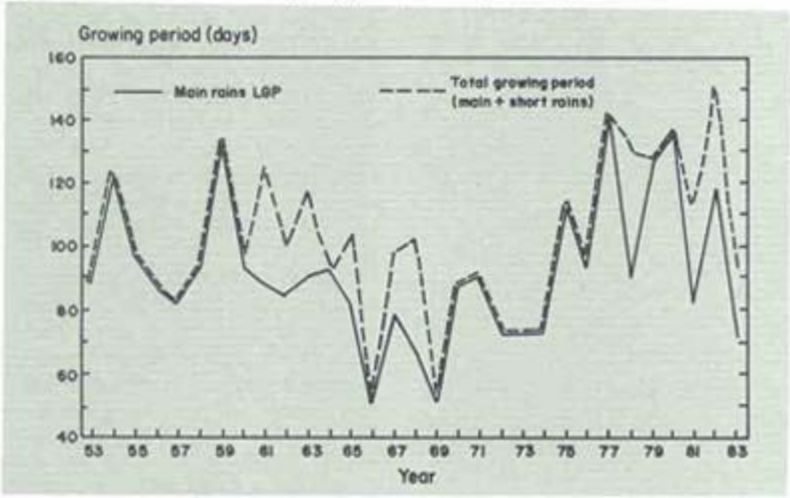
Case studies

Figures 5, 6 and 7 support the suggestion that the combination of a failure in the short rains and a shortened main-season LGP has, historically, coincided with serious drought and famine years in northern Ethiopia.

Asmara, 1953–1983

In Figure 5 the main-season LGP for Asmara from 1953 to 1983 is shown by a solid black line. The dotted line represents the total number of growing days in the same years, thus highlighting the contribution from the small rains. Between 1953 and 1960 the total LGP and the main-season LGP were the same, indicating that effectively no short rains fell in those years.

Figure 5. *Main rains LGP and total growing period, Asmara, 1953–1983.*



Growing periods of 95 days or less, with a minimum of 80 days in 1957, occurred between 1955 and 1958. Assuming that land preparation had to take place during the main cropping season, the total LGP probably varied between 50 and 85 days, indicating a substantial cumulative loss in both grain supplies and the seed available for planting. Draught animals and the human population in the Asmara area must have been in poor condition by 1957 and 1958, and substantial numbers of people died in Wello and Tigray during the period following the 1957/58 drought, although a locust infestation exacerbated the problems caused by the low rainfall (Tafesse Olkeba, 1984).

In 1966 a serious drought appears to have occurred around Asmara. The short rains failed totally and the main-season LGP fell to around 50 days, indicating that most crops probably failed. In the following 3 years the main-season LGP was less than 90 days, although in 1967 and 1968 the total number of days suitable for crop growth exceeded 100. Another serious failure occurred in 1969 with no short rains evident and an LGP of less than 60 days.

From 1969 to 1974 a period of extreme drought occurred in the Asmara area. In 1971 and 1972 some crops may have been successful, but a shortage of seed carried over from the preceding years probably limited plantings. Substantial crop failure is again indicated for Asmara from 1972 to 1974 with no short rains and an LGP of about 75 days in each of these years. This period coincides with the widely reported famine of 1971–74.

Although there were no short rains from 1969 to 1977, in 1975 and 1977 the main season LGPs were very favourable for crop production. In 1981 the main-season LGP again fell below 90 days although the short rains in that year were favourable. In 1982 good short rains and a very favourable July-to-September rainfall distribution again assisted crop production.

In 1983 the short rains were limited and the main-season LGP fell to about 70 days, almost certainly resulting in crop shortfalls. However, because of the relatively good season in 1982, reserves were probably available to farmers in 1983.

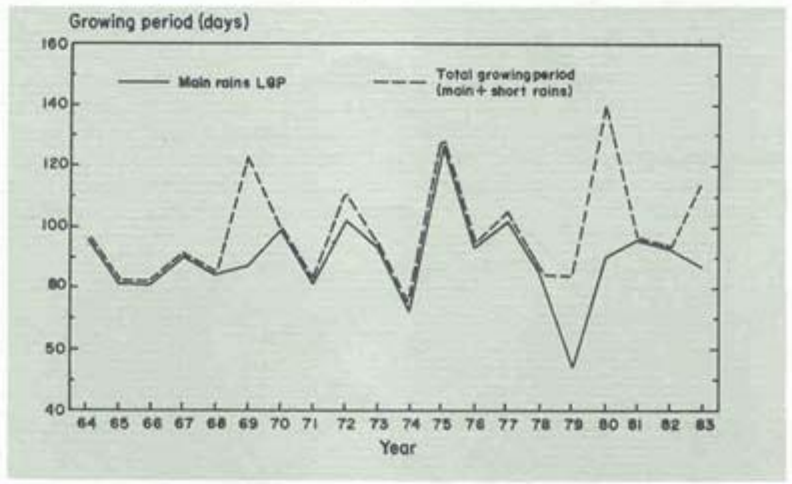
Figures for the first half of 1984 for Asmara suggest that while the short rains did fall, the July rainfall was poor and the prospects for successful crops depended on the August and

September rainfall. In the past, 2 successive years of crop shortfalls have been associated with famine. The year 1984 was therefore a crucial year in this respect.

Mekele, 1964–1983

Unfortunately, the meteorological data available for Mekele do not allow as comprehensive an analysis as for Asmara, but the 20-year period does span three reported drought periods in northern Ethiopia (Figure 6). Historically, Mekele is one of the hardest-hit famine areas in the country, and its recent climatic history warrants close inspection.

Figure 6. *Main rains LGP and total growing period, Mekele, 1964–1983.*



The years 1964 and 1965 are reported as drought years in Ethiopia (Tafesse Olkeba, 1984), but little regional documentation is available. In view of the marginal LGPs, particularly in 1965 and 1966, food reserves around Mekele in 1966 and 1967 must have been low. The inadequate 1967 rainfall and poor harvests must have contributed to an accumulating shortfall in grain supplies, and animal and human condition in the region during 1967 and 1968 will have been poor.

Although the main-season LGP in 1969 was not very long, the considerable short rains would have assisted land preparation and provided good forage for livestock. In 1970 the short rains failed and the main season LGP was less than 100 days, with land preparation cutting into this period. The year 1971 was a poor year with no short rains to assist land preparation and only 80 days of moisture available for crop growth. In 1972 the combination of some short rains and a growing season longer than 100 days provided a slight respite, but cumulative effects on the seed supply and on the condition of both draught animals and the human population were probably being felt.

The 2 years which followed led to the widely reported famine of 1974. No effective short rains fell in either 1973 or 1974, and the main-season LGPs of just over 90 and 70 days respectively resulted in yield reductions in 1973 and almost total crop failure in 1974. The build-up to the famine in 1974 around Mekele is less obvious than for Asmara. However, warning signs were certainly apparent by 1973, and perhaps even by 1971, when a possible poor seed supply and the deteriorating condition of both draught animals and the human population meant that farmers were unable to take advantage of the somewhat improved farming conditions in 1972.

As in Asmara, conditions around Mekele in 1975 improved greatly with a total LGP of almost 130 days. Conditions in 1976 and 1977 were marginal with LGPs of between 90 and 100 days. No short rains in 1978, and an LGP of less than 90 days, must have again put food production at risk in the region. A serious problem is indicated in 1979, both from the total rainfall figures and from the unusual rainfall distribution. The total LGP for 1979 was less than 90 days, which in itself would have limited production, but the longest component of the total LGP recorded was less than 60 days. Fortunately, considerable short rains fell in 1980, followed by a main season LGP of 90 days. To what extent farmers were in a position to take advantage of this improved situation is unknown.

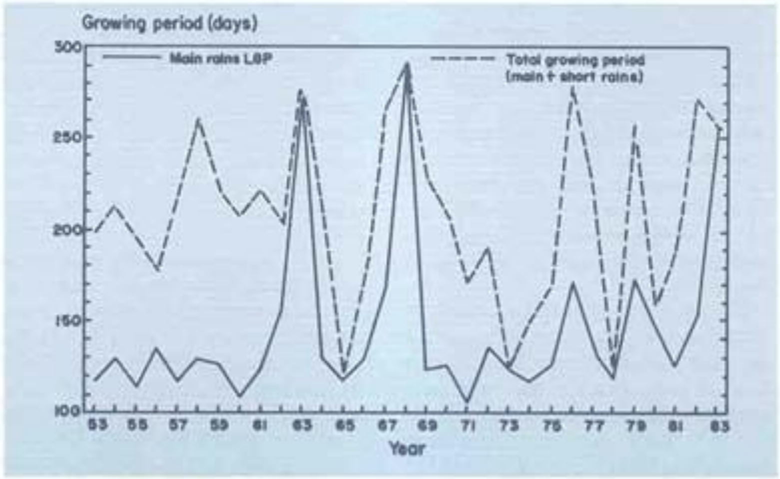
LGPs of between 90 and 100 days, with no short rains, were recorded in 1981 and 1982. Total rainfall improved in 1983, but this was mainly due to reasonable short rains. The main-season LGP was again less than 90 days.

Thus 3 consecutive years in which the main-season LGPs were barely 90 days, and only 1 year in which the short rains fell, indicate that problems were accumulating. If the short rains were to fail in 1984, famine would be the likely consequence, especially if the main-season rains did not begin until late June or early July. Although no reliable meteorological data were available at the time of writing, indications were that this unfortunate scenario did indeed take place.

Kombolcha, 1953–1983

Figure 7 indicates a more favourable situation in Kombolcha. LGPs were generally much longer than those in Mekele or Asmara, although serious departures from the norm are likely to disrupt agricultural production since plantings in any one year are influenced by the farmers' anticipation of the growing season.

Figure 7. *Main rains LGP and total growing period, Kombolcha. 1953–1983*.



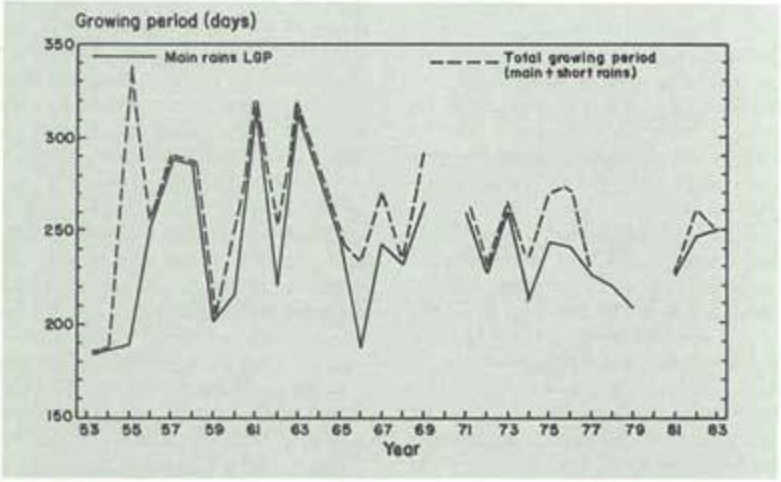
For several periods over the 30 years studied the main-season LGPs for Kombolcha remained between 100 and 130 days, as in the period 1953–1961. The clearer bimodality of rainfall however ensures more time for land preparation and even allows two cropping seasons in some years. A combination of a failure of the short rains and a main-season LGP of less than 130 days occurred in 1965, 1973 and 1978. In fact this situation in 1965 coincided with reported drought elsewhere in the country, as did that for the 1973 cropping season. It is interesting to note that substantial short rains fell in 1971, but that the main-season LGP in that year was the shortest recorded in the period studied. Crop production around Kombolcha was probably lower than usual during 1971 and 1973, and this may have reduced the grain surpluses available for distribution to nearby famine areas in those years.

The failure of the short rains and the low main-season LGP in 1978 was followed by a considerably better season in 1979. Sufficient short rains fell in 1977 and the carry-over production from a very favourable year in 1976 would have buffered any production shortfall in 1978.

Debre Markos, 1953–1983

Data from Debre Markos (Figure 8) are included to permit comparison with one of the most productive grain-growing areas of the country. No data are available for 1970 and 1980, but the remaining data are sufficiently clear to show that reliable production was to be expected. It is notable that the shortest main-season LGP recorded in this 30-year time span was 185 days. The probability of total crop failure due to moisture stress in the region is thus negligible.

Figure 8. *Main rains LGP and total growing period, Debre Markos, 1954–1983.*



Conclusions and recommendations

LGP and the development of an effective early warning system

The argument developed above underlines the fact that if soil moisture levels are less than those required by crops for uninhibited growth, then yield reductions, and in the most severe cases total crop failures, are inevitable. Low annual rainfall, poor rainfall distribution throughout the year, high evapotranspiration and shallow soils all contribute to a moisture deficit. Since the calculation of LGP encompasses all these factors, an analysis of LGP on a year-to-year basis gives some insight into the reasons for repeated famine over much of the country.

The present study indicates that the serious famine periods recorded at Mekele and Asmara over the past 20 to 30 years were preceded by 2 or more consecutive years in which the main-season LGP was less than 90 days, and in which the short rains failed. Up-to-date analyses of

LGP could therefore constitute the basis of an early warning system to indicate the likelihood of serious famine in drought-prone areas of the country.

Danger signals based on these criteria were apparent at Mekele after the 1981 and 1982 seasons. Small but significant short rains in 1983, although followed by a main season LGP of less than 90 days, may have bridged the gap in production until 1984. Preliminary rainfall figures obtained from the Relief and Rehabilitation Commission (RRC) in September 1984 indicate that no effective short rains fell until April, after which data were not available. It is clear from the widespread famine in the region that the main rains were insufficient and did not extend significantly into September; the 1984 crops failed and the preceding years had left no reserves.

For Asmara, danger signals were less apparent until 1983. This could explain the present lack of famine reports from further north in Eritrea, the region surrounding Asmara. However, based on the analysis for Asmara presented above, shortfalls in crop production seemed inevitable in 1984 unless the long rains persisted into September. A crucial indicator for Asmara will be whether or not substantial short rains occur before the end of April 1985. Alternatively, a long main-season LGP in 1985, from May/June until September, may enable land preparation to begin sufficiently early in the season to ensure good crop growth without moisture stress. If neither occurs, severe shortages of locally produced food reserves must be expected, extending the famine much further north during 1985.

Obviously, Asmara and Mekele represent only a small sample of the famine-stricken areas of Ethiopia. Historical analysis of as many additional locations as possible is desirable in order to develop a more generally applicable early warning system. Using the LGP computer programs installed at ILCA, it is now possible to review moisture conditions on a monthly or yearly basis for any location in the country for which suitable monthly climatic data are available. Periods of extreme moisture stress and probable crop failures in drought-prone areas can thus be identified. This suggests that patterns leading to famine, similar to those detected in Asmara and Mekele, might be identified in other areas after more extensive analysis. It is possible that patterns of moisture conditions and famine are very location specific, but this can only be confirmed by additional data collection and analysis.

Regardless of the detailed nature of such patterns, an index of the moisture conditions preceding former famine periods for each new location could be built up in a manner similar to that discussed for Asmara and Mekele. When historically unfavourable patterns begin to emerge, a close watch on the current season's rainfall would provide, by late July, an early warning of crop failures for most of the central and northern highlands of the country. However, such an early warning system can only be effective if meteorological data are recorded and transmitted rapidly to a centre equipped to analyse them. Such analyses could be carried out by ILCA's Computer Unit.

Calibration of satellite early warning systems using LGPs

Information from the NOAA series of satellites has been used in West Africa to estimate vegetative biomass production (Tucker et al, 1982). The use of such satellite imagery has also been proposed to monitor, and to give early warning of, drought conditions throughout Africa.

When compared with the spectral responses of vegetation recorded on NOAH imagery, a time sequence of moisture indices calculated from the LGP computer-program opens up the possibility of calibrating satellite data with moisture availability and LGP. If this proves feasible, the LGP in a given year could be monitored directly using NOAA data, eliminating the need for monthly meteorological inputs.

Long-term agronomic limitations in drought-prone areas

A striking feature of the agro-climatic analysis for both Mekele and Asmara is the limited duration and the high degree of variability of the crop growing periods. This inevitably leads to marginal crop yields in many years, and because of increasing population, famine can be expected to recur with increasing frequency in the future. This is borne out to some extent by the relatively short period of unfavourable agricultural conditions preceding the current famine in northern Ethiopia, compared with the longer build-up to the 1974 famine. To what extent other factors such as disruption of traditional supply routes and cultivation patterns, due to civil unrest, contributed to the rapid onset and severity of the current famine is unknown.

An effective early warning system is, unfortunately, only a means of detection; it does not solve the problems associated with drought and famine. Over the longer term fundamental changes will need to be made to existing production systems: land use will have to be rationalised so that erosion-prone soils are conserved by sowing on them permanent grassland and leguminous forages; better adapted, rapidly maturing crop cultivars should be sought; alternative cultivation systems which conserve soil moisture should be investigated; and it may be possible to trap and store the excessive and destructive runoff associated with heavy rains in ponds or dams constructed using draught oxen. Even a small store of irrigation water could be used on a limited area basis to establish crops just before the onset of the main rains or to enable them to mature without experiencing moisture stress; in either case, the growing period would be extended. When combined with more suitable crop cultivars and more widespread use of fertilizer, much better crop production could be expected; perhaps more importantly, the production would be more reliable than at present.

A partial and possibly only a temporary alternative to agricultural change is to alter the distribution of the population, by resettlement programmes in less drought-prone areas of Ethiopia. There are significant costs, both human and material, attached to both approaches. However, unless major change is attempted, more frequent and massive imports of food aid will be needed to alleviate the suffering associated with the inevitable famines of the future.

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