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LESOTHO AGRICULTURAL SECTOR ANALYSIS PROJECT

Ministry of Agriculture
Kingdom of Lesotho

Department of Economics
Colorado State University

RAINFALL OSCILLATIONS IN LESOTHO AND THE POSSIBLE IMPACT OF DROUGHT IN THE 1980s

Discussion Paper No. 10
Lesotho Agricultural Sector Analysis Project

by
Jerry Eckert
Agricultural Economist

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EXECUTIVE SUMMARY

Rainfall Oscillations in Lesotho and the Possible Impact of Drought in the 1980s

Scientific research from the last several years has confirmed that rainfall over much of southern Africa follows a pattern of regularly spaced wet and dry spells of 9-10 years each in length. This pattern has come to be called the "quasi 20-year oscillation" and it has been proved to have existed from 1841 to the present. If the pattern continues southern Africa will enter a 9-10 year period of below normal rainfall in 1981 or 1982.

Further research by the Lesotho Agricultural Sector Analysis Project confirms that the 20-year oscillation occurs in Lesotho and has been particularly evident since 1945. Lesotho is now coming to the end of an above-normal rainfall period and if the oscillation continues will average below normal from 1982-1990. [The present drought is simply a dry year that falls during an overall wet period].

During the dry period, summer season rainfall will be reduced by 20 percent and winter rains by 14 percent from their wet period totals. Butha-Buthe and Leribe districts will not be as seriously affected as other lowland districts. Wheat production may be seriously affected because the "shooting" stage of growth, which is particularly moisture sensitive, occurs during November which may be the most seriously reduced month. Maize yields will definitely be depressed but sorghum, which is insensitive to drought, will be only slightly affected. Maize yields can be expected to average between 160 to 310 kilograms per hectare (1-1.5 bags/acre) lower than has prevailed during the 1976-79 period. Annual production may average some 25,000 tons below those levels possible with present technology during a wet spell.

If summer season rainfall is reduced 20 percent, summer season stream and river flows will decline by more than 20 percent (perhaps as much as 30-40%) and will become more variable. This implies the need for water rights legislation to prevent conflict, especially by competing urban and agricultural demands for river flows. It also suggests the need for some new thinking on the feasibility of irrigation projects.

It is recommended that the Ministry of Agriculture undertake the following steps to minimize the possible impact of below normal rainfall in the 1980s.

1. Initiate with immediate effect a research program focused on improving farmer management of soil-plant-water interactions under Sesotho farming conditions. There are many such cropping practices which are possible for our small farmers.

They must be identified, the information assembled and extended to farmers as soon as possible. Many advanced techniques for moisture conserving farming are in use just across the border. It would be to Lesotho's advantage to borrow selectively from this knowledge, adapt it to fit our conditions and add it to the Extension message in Lesotho.

2. Give priority to programs which will capture as much precipitation as possible. Among these are:

   - repair and maintenance of conservation structures (preferably with labor intensive means).

   - conservation cropping techniques especially crop residue management.

3. Utilize government's seed importation capacity to obtain and spread the seed of drought resistent varieties.

4. Give immediate attention to a major new program to test and establish new cropping activities stressing crops which return high value per water unit. Normally these will be labor intensive horticultural crops which would also contribute to income and employment generation objectives. Tree and vine crops and others, once they are established can prove very resistent to moisture fluctuations. They would also lend themselves to being grown and possibly processed by some form of village or farmer's association.

5. Ministry of Agriculture together with Ministry of Water, Energy and Mines should seek a high level technical consultant team to suggest needs and optional forms for national water rights legislation.

Discussion Paper No. 10

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The Problem

In 1977 T.G.J. Dyer and P.D. Tyson published an interesting and provocative paper reporting their analysis of long-term weather patterns in the "summer rainfall region" of South Africa. Their principle finding was that this region is characterized by repeated periodic fluctuations of precipitation above and below the long-term average. The most dominant pattern was an oscillation with a period of 18.65 years on top of which were superimposed other patterns of shorter duration and less significance. The longer pattern has become known in the flurry of subsequent writings as the "quasi-20 year oscillation" (Dyer and Tyson, 1977). The pattern suggests that for periods of 9-10 years in length the annual rainfall averages alternately above, then below the long-term mean.

Their article analyzed data covering 1910 to 1972 and then ventured a prediction of rainfall patterns for the period, 1972-2000. It was only published after their predicted pattern for the mid-1970s had been confirmed by recorded precipitation measurements. If the defined pattern continues, it suggests significant implications for agricultural planners, research scientists and others concerned with food production. This would seem particularly true for a country such as Lesotho, which is situated completely within the summer rainfall region, which is seriously food deficit, and is entering a period of high and increasing dependence on agriculture for employment and income (Eckert and Wykstra, 1979).

Three questions are discussed in the analysis below:

1. What is the current status of Dyer and Tyson's findings and how well accepted are they?

2. Does a similar pattern of rainfall occur in Lesotho?

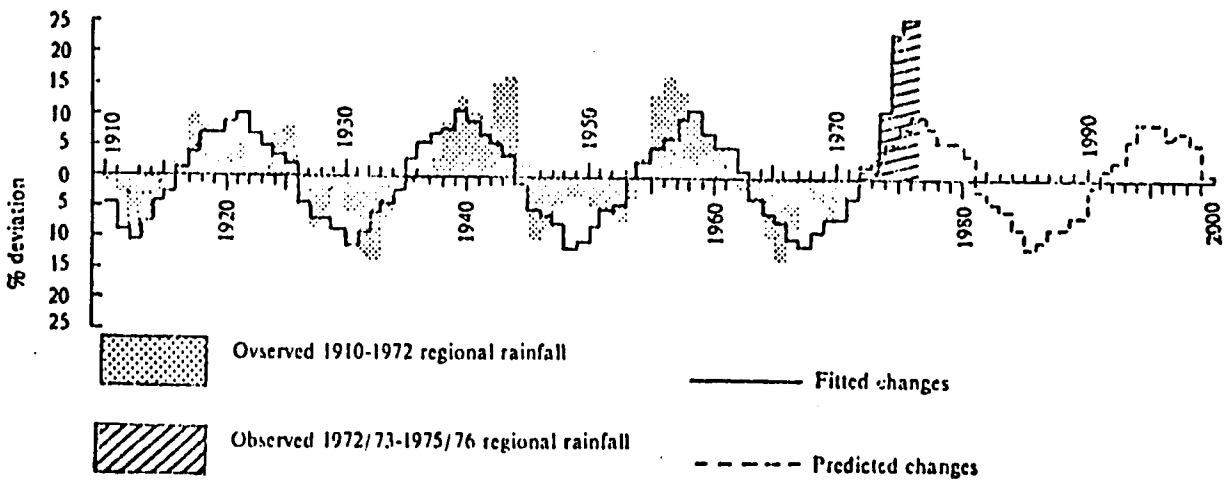
3. If so, what are the implications for agricultural productivity and for the development programs?

Evidence from South Africa

Review of Dyer and Tyson's Findings

Dyer and Tyson based their analysis on long-term precipitation records of 62 stations dispersed throughout the summer rainfall region.[1] The data were pooled, statistically smoothed and analyzed with a modified Fourier-type equation. The results gave the often reprinted pattern shown in Figure 1. Three oscillation periods, 18.65, 3.65 and 2.35, were measured and when combined resulted in the fitted and predicted path. The longer period provides the dominant oscillation with the two shorter movements contributing annual deviations.

Figure 1. Temporal periodic variations in seasonal rainfall for the Highveld of South Africa (after Dyer & Tyson, 1977).



Dyer and Tyson conclude that this temporally distinct pattern has persisted throughout this century. Early weather records and other accounts provide confirming records of prolonged dry or wet spells prevailed between 1880 and 1900. The authors suggest, very tentatively, a causitive

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[1] Roughly corresponds with the area of Transvaal, Orange Free State, Natal, Swaziland, Lesotho and Transkei.

linkage to the position of the Atlantic and Indian Ocean anticyclones for which a 19-year oscillation was also recorded as early as the 1841-1906 period. Finally, tree ring records from Pietermaritzburg suggest that the "quasi 20-year oscillation was present from 1910 back to 1750 (Hall, 1976)". In a subsequent paper the same authors amass an even more extensive array of confirming studies done by a number of scholars. They conclude "There is evidence to suggest it extended back in time to 1841" and leave the earlier tree ring record to be substantiated by further research (Tyson and Dyer, 1978).

The authors admit that their model predicts transitions from wet to dry or dry to wet spells more reliably than it does annual precipitation events. Annual variation does exist within either dry or wet spells including years which differ from long-term averages in the opposite direction from the pattern. For example, 1978/79 and 1979/80 were below normal years during an otherwise wet spell. It must also be pointed out that within the summer rainfall region there are localities for which additional or different patterns can be quantified although over time the incidence of deviant phenomena has been declining. Nevertheless, the combination of contemporary analysis, historical records and an apparently accurate predictive capacity provides strong evidence that a 19-20 year rainfall oscillation has been a sustained climatic phenomenon over a large portion of southern Africa, perhaps for centuries. Professor Tyson summarized their research, stating "---the oscillatory character of South African rainfall has been demonstrated beyond all reasonable doubt for the period 1910-1972---" (Tyson, 1978).

Future Expectations

Climatic researchers are notoriously hesitant to predict future events. Nevertheless, with appropriate qualifications Tyson and Dyer (1978) offer the following:

> "---the best assumption is that --- the quasi 20-year fluctuation will continue in the future as it has in the past ---"
>
> "---provided the oscillation continues in the future as it has since 1906, then the estimated future wet and dry spells are not only probable <u>but highly likely</u>." (emphasis added)

And then, using an updated set of calculations:

> "The 1910-77 model suggests that the present wet spell will continue with diminished rainfall receipts until 1982 or 1983. The succeeding dry spell will last until about 1992 and the following wet spell until the turn of the century. Past experience suggests that the type of model being used here is able to predict the duration of the wet and dry spells satisfactorily."

Thus the authors are evidently convinced of the oscillations authenticity and its probable continuance. These conclusions have significant implications for agricultural planners, farmers and others whose incomes or employment are related to rainfall.

Several additional observations are important for the analysis which follows. First, rather than diminishing there is evidence that the 20-year oscillation is becoming more widespread as the dominant pattern. This development is mapped for wet spells since 1935 in Tyson and Dyer's 1978 paper. The analysis has subsequently been extended backwards into the mid-Nineteenth Century and an increasing geographic coverage of both wet and dry spells is apparent in the longer series (P.D. Tyson, personal communication, April 1980). Thus the evidence does not suggest that this pattern is about to disintegrate, but rather that it has been expanding the geographic area over which it is the dominant pattern. At the same time there is evidence to suggest that there are fewer deviant years within wet or dry spells; they may be becoming more consistently wet or dry respectively. (See, for example, Figure 2 below).

Third, "over the period 1910-77 the dry spells have been somewhat more consistently dry than the wet spells have been wet. In addition, the dry spells have had a greater areal extent --- than the wet" (Tyson and Dyer, 1978). Thus, there seems little likelihood of affected areas escaping a long and uniformly dry 1980s.

Finally, there is some suggestion from Dyer and Tyson's figures (e.g., Figure 1) that the amplitude of the oscillation might be increasing. If true this would be consistent with an apparent increase in homogeniety within wet or dry periods. It would also agree with the spread of the area affected. In short it would seem that the 20-year oscillation is perhaps becoming more, rather than less, dominant, affecting a wider area, showing more consistency (fewer deviant years) within wet or dry spells and possibly be generating larger deviations from long-term average precipitation. While data and analysis are not yet available to confirm this, the latter is considered possible and worth further investigation (P.D. Tyson, personal communication, April 1980).

Acceptability and Extension of the Findings

Much subsequent work has followed the 1977 article, a good deal of it by one or the other of the authors themselves. Other researchers using different methodologies have contributed confirming evidence as well (e.g., Van Rooy, 1980: 27).

In 1978 the Standing Committee for Conservation and Land-Use Planning of the Southern African Regional Commission for the Conservation and Utilization of the Soil (SARCCUS) adopted a resolution as follows:

> "The Standing Committee --- commends the published works of Tyson, Dyer and co-authors to the Subcommittee for Agrometeorology and Climatology and requests the Subcommittee to investigate the applicability of this work and of cloud seeding in the SARCCUS Region, ---" (SARCCUS, 1978).

This action indicates a growing semi-official acceptance of Dyer and Tyson's work which is leading toward exploration of options for remedial programs and possibly policy alterations. The popular agricultural press in South Africa has expanded on the possible meaning of the "dry Eighties" for farmers, suggesting a shift toward drought resistent crops, alterations in livestock husbandry practices and more conservative financial management (Dickinson, 1979).

At the more scientific level the proceedings of a recent symposium of the South African Maize Breeders Association contains an article reviewing climatic variations and their implications for maize scientists and producers (de Jager and Ventor, 1979). The authors present data suggesting a positive correlation between sunspot activity and length of growing season. They further note a recent discovery of a possible causitive link between sunspot activity and the gravitational force of the planets when in certain alignments. They then point out:

> "that the significant alignment of solar planets pulling together in a line on the same side of the sun occurs once every 179 years, almost exactly right to account for the long-term variation in sunspots, in radiocarbon levels, tree rings, varves and in climate. The next alignment of this type is due in 1982 and hence one might predict this to be a particularly exceptional year for sunspot activity, long growing season and perhaps high temperature. As will later (in their paper) transpire this appears to be the year when rainfall on the highveld of South Africa is expected to change from a wet to a dry cycle and hence 1982 might prove to be South Africa's most cataclysmic climate year of all time."

Most pure meteorologists would disdain such apocalyptic predictions. The authors themselves use more moderate tones at a later point in the article: "---so this could prove to be an exceptionally long and dry growing season". Nevertheless, the projection that the summer rainfall area of southern Africa will enter a dry spell about 1982 seems to be gaining acceptance by members of government, the scientific profession and the popular media. What has not yet surfaced is a definitive, quantitative estimate of the possible effects of such a dry spell on agricultural production, water resources or other factors.

Confirmation in Lesotho

Only one previous analysis of rainfall periodicity is known for Lesotho specifically (Zinyowera, 1978). In it the author employs various statistical measures to search for patterns, with the following conclusions:

> "This sort of organized grouping in temporal variation of above and below 'normal' rainfall shows that the findings of Dyer and Tyson can be extended to Lesotho. ---However, the "quasi 20-year cycle" which was reported by Tyson and Dyer does not appear to be more important than the 9-10 year cycles which are superimposed on it."

A more detailed examination is presented below utilizing data from the seven lowland stations at district headquarters.[1] Each of these stations has rainfall records extending back at least to 1920. These stations have been averaged in this analysis to provide annual[2] figures characterizing Lesotho's Lowlands.

Figure 2 presents a graphical display of the results. Annual rainfall is shown as deviations above or below the 50-year mean of 735 mm. A nine-year moving average is used as a smoothing and generalizing device and the onset of wet and dry spells from Dyer and Tyson (1977) are shown for comparison.

Several conclusions may be derived from Figure 2. First, the "quasi 20-year oscillation" appears quite clearly in Lesotho's data since WWII. It is, however, only weakly suggested between 1935 and 1945 and does not appear before that time. One cannot rule out the possibility of more accurate recording procedures in the last three decades as the reason for the pattern's recent visibility. When rainfall recording was restarted after WWI, long-term averages were consistently lower than those recorded between 1885 and 1915 (see HSD, 1971). It is possible that new methods or equipment were introduced at that time. Similarly it is possible that more accurate procedures were introduced after WWII as attention returned to domestic affairs.

More plausible, however, is that the oscillation was, in fact, weaker or non-existent over Lesotho in early years. This conclusion is suggested by the observations above that the area covered by the oscillation is expanding, that periods above and below normal are becoming more uniform and that deviations from the long-term mean are possibly becoming larger. Any or all of these related factors could have resulted in the oscillation having only recently emerged decisively in Lesotho's data.

Detailed Observations

Precipitation differences between wet and dry spells in Lesotho are concentrated in four months, November to February, as shown in Table 1. Differences generally are statistically significant at the .90 confidence level or greater during November and December (see Appendix). Moisture

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[1] From North to South, Butha-Buthe, Hlotse (Leribe), Teyateyaneng, Maseru, Mafeteng, Mohale's Hoek and Quthing.

[2] Data are for the "water year", October through September taken from HSD, 1971 and HydroMet, various issues.

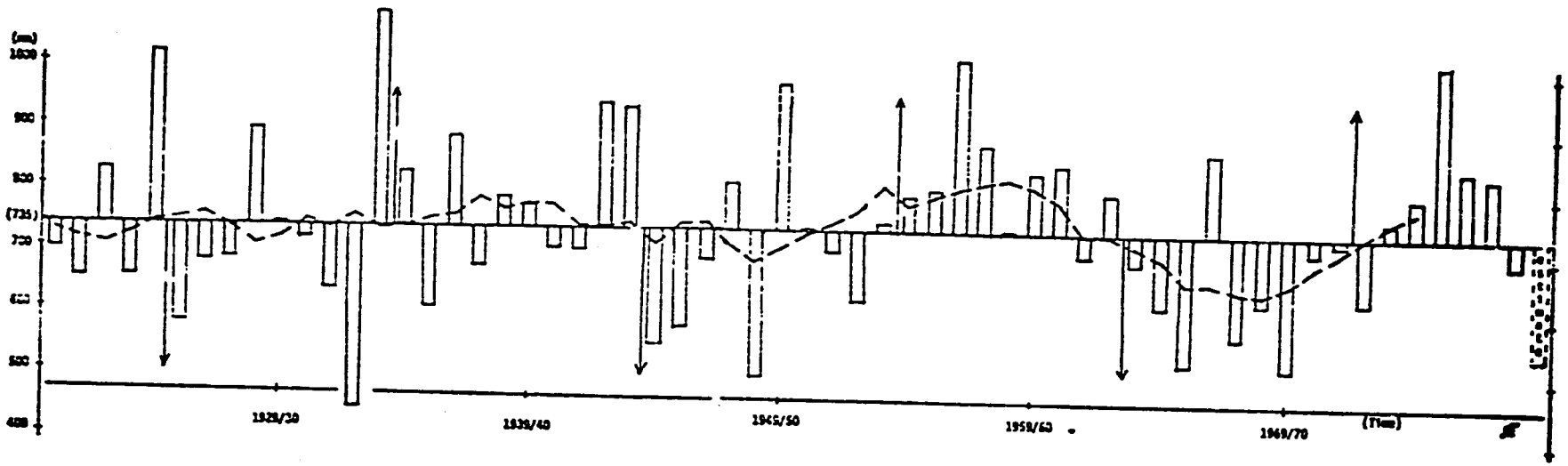

FIGURE 2. RAINFALL PATTERNS IN LESOTHO

VERTICAL BARS - ANNUAL RAINFALL
HORIZONTAL LINE - 50 YEAR MEAN

DASHED LINE - 9 YEAR MOVING AVERAGE
ARROWS - POINT OF ONSET OF WET OR DRY PERIOD (BYER & TYSON)

sensitive summer crops should show a production response to below normal rainfall during dry spells.

Table 1. Comparison of Monthly Rainfall Totals Between Wet and Dry Spells in Lesotho's Lowlands.*

Month	Average Rainfall (mm) Wet Spell	Dry Spell	Difference (mm)	Dry as % of Wet
October	62.4	68.6	-6.6	110%
November	101.0	64.6	36.4	64%
December	114.1	80.4	33.7	70%
January	130.9	105.6	25.3	81%
February	118.7	95.0	23.7	80%
March	111.9	96.9	15.0	87%
April	65.7	64.3	1.4	98%
May	30.9	33.3	-2.4	108%
June	13.9	11.4	2.5	82%
July	14.3	10.7	3.6	75%
August	18.7	15.9	2.8	85%
September	38.1	21.3	16.8	56%
ANNUAL	820.6	668.0	152.6	81%

*Data are averaged for 1945-1978 period.

Source: HSD 1971 and HydroMet, various issues.

Table 2 presents average differences in six-month rainfall totals for the lowland districts. As in Table 1 these data are drawn from the 1945-1978 period when the oscillation has become significant enough to affect Lesotho's statistics. Although the period used is short, the logic presented in earlier sections suggests that to include a longer time series would mask parts of the pattern now being experienced. This was the case in Zinyowera's work where the 1920-77 period suggested a 9-10 year oscillation of equal importance to the 19-20 year pattern. Certainly since 1945 the longer pattern has definitely emerged as dominant.

Table 2. Differences Between Districts in Growing Season Rainfall

District	October to March Wet Period	October to March Dry Period	Difference (mm)	Dry as % of Wet
Butha Buthe	653	550	103	84%
Leribe	655	568	87	87%
Teyateyaneng	683	520	163	76%
Maseru	602	467	135	78%
Mafeteng	609	500	109	82%
Mohale's Hoek	658	496	162	75%
Quthing	614	477	137	78%
Seven Station Average	639	511	128	80%

Source: Same as Table 1

Differentials appear between districts in the magnitude of the oscillation and in the resulting dry spell rainfall level. Butha-Buthe and Leribe, with relatively high wet period precipitation, experience the smallest average drop to dry period levels. Consequently the range from wettest to driest district is somewhat greater during dry periods. The range in the magnitude of the difference is also quite large, with Teyateyaneng and Mohale's Hoek averaging nearly twice the measured difference for Leribe.

Recent analysis has shown that small North to South gradients exist in several climatic parameters as measured in Lesotho's lowlands. It has been suggested that although differences are small these factors operate together to create progressively poorer growing conditions in the more southern districts (Eckert and Phoofolo, 1980). Growing season rainfall conforms more to this hypothesis during dry spells than at other times. During clusters of dry years there is a distinct decline in precipitation from North to South with the exception of Maseru station which shows the lowest precipitation total in both wet and dry periods.

Summary

The findings of Tyson and Dyer can be extended to Lesotho. The "quasi 20-year" oscillation can be identified in the pre-1945 period but has definitely emerged as the dominant pattern since 1945. Compared with a wet period such as the mid-1970s, the arrival of a dry spell will affect November, December, January and February (in descending order) most seriously. Summer season rainfall can be some 20.0 percent lower during a

dry spell whereas winter rainfall may be reduced by only 13.6 percent.[1] Finally, the impact of the oscillation differs in the various districts with the result that the ranking of districts from highest to lowest rainfall differs in the two periods.

Possible Implications for Crop Yields

The above conclusions suggest that winter crops may be less affected by a possible dry spell than summer crops. Whether this holds true or not depends on whether moisture sensitive stages of crop growth fall in either September or November. These two months have shown the most severe depression in percentage terms in the data from Lesotho's dry spells. Winter wheat, for example, may enter the boot stage in November and thus pass through its most critical growth stage in a period of moisture stress. The higher rains expected in December and January could produce a second round of tillering with the result being very uneven ripening within fields and an increase in pre-harvest shattering losses from those tillers that headed early. On the other hand, winter vegetable production should not be much affected.

Summer crops will be affected in direct relationship to their sensitivity (responsiveness) to rainfall. Recent research has estimated mathematical relationships between yields of selected crops and rainfall (Eckert, 1980). The following two equations can estimate yields for maize and sorghum during the near future:

$$\text{Maize Yield} = 595.6 + 1.27\ (\text{Oct-Mar Rain}) \qquad [1]$$

$$\text{Sorghum Yield} = 1143.0 + 0.36\ (\text{Oct-Mar Rain}) \qquad [2]$$

Both produce estimates in kilograms of grain per hectare. Neither equation is complete without additional variables which adjust the basic estimate to depict different yield levels occurring in each district. (Details are presented in the original source). Both equations explain approximately 85 percent of the variation in existing data and thus offer a reasonably reliable method for projection. The point for emphasis here is that maize is much more responsive to rainfall than is sorghum under Lesotho's conditions.[2]

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[1] $\frac{\text{Wet spell - Dry spell}}{\text{Wet Spell}} \times 100$

[2] The marginal product of one millimeter of rain is 1.27 kilograms of grain for maize and only 0.36 kilograms for sorghum.

One methodological consideration must be mentioned. Of the few years for which Lesotho has useful crop yield estimates only one (1969/70) falls within a dry spell as identified by Dyer and Tyson. The above equations are estimated primarily with wet period data. However, 1969/70 was an exceptionally dry year, with Lowland districts averaging only 340 mm. for October through March.[1] In addition, 1978/79 was also below normal even though it presumably falls within a wet spell. Consequently, the above equations do include below normal data and with appropriate care can be used to predict yields in below normal portions of the oscillation.

Table 3 develops such projections for each of the Lowland districts. In the absence of advanced knowledge about the area that will be planted, areas from 1978/79 are used to develop the weighted average for the seven districts. This figure is then adjusted to the national level using average relationships between the seven districts and national yields as measured over the 1976/77 to 1978/79 period.

Table 3. Estimated Crop Yields for Lowland Districts in Wet and Dry Spells*

District	Maize Yields			Sorghum Yields		
	Wet	Dry	Wet-Dry	Wet	Dry	Wet-Dry
Butha-Buthe	1677	1546	131	1444	1407	37
Leribe	1541	1430	111	1271	1239	32
Teyateyaneng	1382	1175	207	1351	1292	59
Maseru	1378	1206	172	1360	1311	49
Mafeteng	1252	1113	139	1224	1185	39
Mohale's Hoek	1285	1079	206	1576	1518	58
Quthing	1190	1016	174	1323	1274	49
7 Station Average	1398	1236	162	1272	1325	47
All Lesotho	1373	1214	159	1358	1312	46

*District figures estimated by applying [1] and [2] to rainfall data from Table 2.

The estimates of Table 3 do not represent expected yields for any particular year. Instead they represent what could be expected on average

[1]Unfortunately 1969/70 was the year of the last Agricultural Census. The present agricultural census (now underway) also falls in a year of very depressed rainfall. The low yields that will be measured will again (and, again, erroneously) be used by laymen to suggest a long-term decline in yields and to question the annual production survey data.

over wet and dry spells if these continue with the same visibility as has occurred since 1945. Furthermore, any use of these figures to project 1980's yields does so with the assumption of no change in technology. Should an effective extension program or fertilizer program be developed or should there be large changes in the availability of labor per cultivated hectare, the relationships in the underlying equations could gradually change.

With these qualifications one ventures the following conclusions. As noted earlier, sorghum yields will respond little to below normal rainfall. However, if the 20-year oscillation continues with a period of below normal rainfall in the 1980s and if that period matches the pattern noted since 1945 with respect to its extent below normal, then the equations given above would predict a maize yield for Lesotho of some 160 kg/ha lower than would prevail during the typical above normal wet spell.

One major qualification must be made to the above conclusion. The equations used for estimation pooled six years of data, three from before 1974/75 and three from after 1975/76. The before and after periods are characterized by quite different average yield levels as a direct result of the several changes in agriculture occuring between 1974 and 1976 caused by increased mine wages in South Africa (Eckert, 1980; Eckert and Wykstra, 1980). There is some evidence that yields may be more sensitive to rainfall variation at higher levels than at the lower levels of the earlier period.

To estimate this relationship the maize equation was estimated again using data from 1976/77 to 1978/79 only. The result is [3] which is compared with [1] below.

Maize Yield = -136.85 + 2.43 (Oct-Mar Rain) [3]

Maize Yield = 565.6 + 1.27 (Oct-Mar Rain) [1]

This equation suggests maize yields are nearly twice as responsive to rainfall at the higher yield levels of recent years. Working with averages for the seven lowland districts the two equations define high and low figures as shown below. Actual differences between wet and dry periods will probably fall within this range.

Period	Average 6-Mo. Rain	Estimate Yield (kg/ha) [1]	[3]
Wet	639 mm.	1398	1446
Dry	511 mm.	1236	1135
Difference	128 mm.	162	311

There is reason to suspect that [3] provides too large a coefficient for rainfall and thus overestimates yield differences between periods. 1978/79 rain for October to March totaled almost exactly what can be expected during dry spells. However the total hides the fact that most

months were well below dry period averages while December was the second wettest in recorded history. A significant portion of December's unusual rainfall disappeared as surface runoff and cannot be counted as effectively available for crop production. Assuming that 40-50 percent of December rain was lost to runoff and drainage, the very low yield figures are then associated with a much lower rainfall and the rainfall coefficient in [3] would approximate 2.0 rather than 2.4. Yield differences between dry and wet spells would then be approximately 250 kg/ha. This figure is considered to be a sufficiently accurate, mid-range estimate for long term planning. It is reasonable to expect, therefore, that recorded yields for 1978/79 were lower than are to be expected on average during a dry spell since most months experienced rainfall below what would normally be indicated by a 6-month total of 505 mm.

The difference in the two methods is important. In the first case a decline of 12 percent is suggested while in the second the decline equals 22 percent from estimated wet period levels. Once the data for 1979/80 are available these estimates can be further refined. Rainfall during the present crop season averaged 465 mm throughout the lowlands, relatively uniformly distributed in time and space. Yield data when received should give an assessment of crop response to rainfall totals that are below both the long-term average and the past dry spell average.

Program Recommendations

The analysis above suggests that climate will act to depress agricultural productivity during much of the coming decade. It is possible that Lesotho's basic food grain, maize, will be the most seriously affected with yields declining 12-22 percent from present levels. Wheat production could also become more difficult as the question of timing of growth stages becomes important. Planning and management of national food supplies will become even more important functions than they are already. In the context of these possible developments, several program actions seem advisable.

Crop Husbandry Research and Extension[1]

The observations and estimates made above assumed no change in the present level of Basotho farm management. There are, however, a great many technological innovations which could go a long way to eliminate the depressant effects of below normal rainfall. It should be noted emphatically that many practices which can reduce moisture loss are also those that one normally associates with modern dryland crop production anyway. Considering that very few of these practices are now in use by farmers, Lesotho has the definite possibility of increasing yields by widespread technological change, even under reduced precipitation. For example, maize yields over much of the Orange Free State exceed those in

[1] I am indebted to Dr. Al Law, Farming Systems Research Project, for several of the ideas in this section.

Lesotho by a sizeable margin and have been rising steadily even though O.F.S. rainfall levels are generally lower.

The challenge for Lesotho is to develop and extend a combination of approaches to permit agricultural growth despite reduced precipitation. Several suggestions follow. In many cases technologies are already available and can be adopted readily if the incentives are right. In other cases advanced technologies need to be examined for their basic principles and a method developed to apply these fundamentals under Basotho farming conditions. An effective adaptive research and extension program is a necessity. Among the components of an agricultural strategy for the 1980s are the following:

Managing Soil-Plant-Water Interactions: When moisture supplies are reduced the most important agronomic priority becomes managing soil-plant-water interactions so that a larger portion of the water supply is available to, and used by, the plant. There are a large number of such practices very many of which can be used on small farms with limited capital and skills. A partial list of techniques worthy of testing and adaptation to Basotho farming includes the following:

a. Increasing moisture holding capacity of soils can be accomplished by increasing the organic matter (OM) content. One of the best ways to do this is to incorporate plant residues in the soil. Under Lesotho's conditions a mixing rather than complete plowing under is preferable in order to leave some plant material on the surface to slow runoff and reduce wind erosion. Under present conditions of sparse plant populations and heavy winter grazing requirements, plowing down stubbles will also create problems in the livestock subsector. A partial solution would involve achieving optimum (higher) plant density in which case there would be a measurable increase in crop residues to meet both soil improvement and fodder objectives. Even without plowing under crop residues, higher plant densities can gradually contribute to higher O.M. levels because of the much greater volume of root material left to decompose in the soil. Application of organic manures is, of course, a standard prescription as well but may not be socially feasible on large scale in fuel scarce Lesotho.

b. Water harvesting refers to the several practices whose purpose is to increase the amount of precipitation captured in the root zone. Success in this dimension contributes both to crop production and conservation objectives since an increase in water harvested is a decrease in runoff. On Lesotho's sloping lands the principal technique to capture winter rain is to leave crop residue on the field in the manner recommended in the Conservation Cropping Guidelines. Again, a mixing of soil and residue is important because the plant material provides channels to help water infiltrate the soil more rapdily. The most effective

technique during the growing season is to achieve, as rapidly after planting as possible, a complete crop canopy thereby breaking the impact of rain and slowing runoff. Intercropping (maize with beans, etc.) can sometimes establish full canopy cover more quickly and maintain it longer than mono-cropping. Structural measures are also important. Repair and maintenance of existing conservation structures thus deserve high priority. Soil surface management can also be important. On some soils infiltration is increased by a loose (recently plowed) soil surface. On modest slopes a rough surface texture also slows runoff.

c. Plant density control is probably the single most missing element in Lesotho's cropping program. Large numbers of fields, perhaps even the majority, have sub-optimal plant populations. For lack of competition from the commercial or food crop, grass and weeds proliferate. Weeding is not done adequately, especially during the critical early growth stages. It is not uncommon in Lesotho to find fields in which more than half of the growing plant material is undesired species. The result is serious competition between crop and weeds for both water and nutrients. Even when the planted crop gets a good start, this competition can affect later moisture sensitive growth stages. Yields are reduced due to both the lower number of plants and depressed output per plant in addition to those factors already mentioned. Conversely too many plants can create their own competition. In a reduced moisture environment one of the highest priorities must be accurately calibrated plant populations. The extension message must include good advice on row and plant spacing, effective means of achieving germination and emergence and the like. While the basic concepts are readily available, specific recommendations need to be developed for Lesotho's soils and farm management conditions.

d. The crops research program of the Thaba Bosiu program has shown a dramatic potential for yield improvement through varietal substitution. Despite several problems with their research, improved varieties of maize, wheat and beans consistently and significantly outyielded the varieties in common use. The analysis in this paper suggests there is an additional case for varietal change to adopt those varieties which tolerate moisture stress well or those with growth habits that fit farming systems to be developed for low rainfall periods. Fortunately, Government can have an impact here in a short time if they were to establish a vigorous pure seed multiplication program.

Alternative Crops and Cropping Technologies: Lesotho's agriculture is largely composed of extensively grown rainfed field crops. Maize, sorghum, wheat, peas and beans account for over 95 percent of planted area. Irrigation remains experimental or at best a "pilot project" effort. If natural precipitation is to pass through a depressed period of perhaps a decade,

it would suggest new priorities among crops and a revised view of irrigation. This recommendation is particularly important in view of the need for generating growth in incomes and employment despite the possible decline in precipitation.

It would seem important to place priority in research and production programs on those crops which produce the highest value per unit of water. In most instances these crops will also require higher labor inputs per hectare thus generating viable jobs. And in most cases these crops will not be cereals.

It is a little known fact that potatoes produce more calories of food per unit of water used than any other widely grown crop. Maize exceeds wheat by this measure but all cereals are low producers except under very good management. In terms of economic value per water unit the horticultural crops have a distinct advantage. Vegetables are a logical alternative, particularly because of Lesotho's deficits in vegetable production. If grown on field scale, vegetables would likely be even more heavily dependent on irrigation during the 1980s than they are at present. Perhaps more important will be household scale vegetable gardens. A large-scale expansion of production from these small plots will likely require adoption of the concept of multi-purpose village water systems that will suffice to irrigate gardens as well as for household water.

Tree and vine crops offer enormous potential contributions to rural incomes and employment in Lesotho. They require careful moisture management and during the 1980s may require supplemental irrigation. However, with an appropriate irrigation technology tree and vine crops can produce very high yields with very little water. The technology suggested is trickle or drip irrigation in which only the individual trees are watered. Under Lesotho's topography trickle systems could be operated without the need for pressurized equipment and with only a solar powered pump to fill a reservoir. Such a system could be adapted to hillsides permitting orchard establishment on the warmer North-facing slopes including those too steep to be farmed conventionally.

A substantial word of caution is in order concerning conventional sprinkler irrigation. It is an expensive, capital intensive, high management technology which would seem to be inconsistent with Lesotho's resource endowments. Since reservoirs are questionable due to siltation these systems are largely dependent on stream flow. It was shown above that summer rainfall may decline as much as 20 percent during the forthcoming dry spell. Normally one would expect stream flows to decrease by more than this proportion.[1] It is quite possible to show through water

[1]Precipitation is the input into a water system with three sources of loss: surface runoff, subsurface drainage and evapotranspiration from stored soil moisture. Stream flows are fed only by the first two. Thus, if evapotranspiration needs remain constant a 20% reduction in precipitation will result in more than a 20% reduction in surface and subsurface drainage.

budgeting techniques that stream flows during the 1980s may be as much as 30-40 percent or more below levels of the mid-1970s. Furthermore, it can be shown that the groundwater contribution to stream flow will be more affected than will surface runoff. Consequently one would expect stream flows to be more variable as well as substantially lower.

Unfortunately, almost all studies of Lesotho's water resources were done during an above normal period in the oscillations. The observations above strongly suggest that the feasibility of irrigation projects may be substantially altered during the coming decade. On the one hand, water resources for irrigation may shrink and become more variable. On the other, the need for supplemental irrigation may be increased, especially with respect to high value crops. Investment and program decisions must be very carefully made and probably will require updated analysis. Choice of technology for irrigation will be one of the key factors in any successful program.

The Need for Water Rights Legislation: The observations above with respect to stream flow, raise another issue which has not yet been addressed in Lesotho. If available water resources are to decline, competition will increase between alternative users. This issue has already surfaced with respect to competing urban and agricultural demands for the flow of the Phutiatsana River. It would appear that the 1980s may increase the conflict level over this resource in the Phutiatsana valley and perhaps bring it to the surface in other areas as well. It is unfortunate that a legal system of water rights does not exist in Lesotho which would establish priorities between users, between upstream and downstream claimants, etc. Such a system may well become absolutely necessary during the forthcoming decade. This issue affects other Ministries as well. Furthermore it is a question on which much expertise exists elsewhere, especially in the arid western U.S. where urban-rural fights for scarce water have a long history. It is suggested that the Government of Lesotho tap this expertise in the form of a high level consultancy on areas and options for water rights legislation.

National Food Balance Planning: If the suggested dry spell occurs it will obviously depress domestic food production. Maize production could decline by 16,000 to 31,000 tons depending on which of the above equations proves most accurate. In a situation already characterized by national food deficits and a development objective of food self-sufficiency, planning and management of food supplies will necessitate an even higher priority during the 1980s.

Two tools are available to assist in the effort. First is a drought watch procedure developed by Dr. Wilken and now available at Hydro Meteorology for use. The procedure monitors precipitation during the growing season and identifies when cummulative totals beging to deviate significantly from normal.

The second is a procedure recently developed for early estimation of crop yields (Eckert, 1980). With it crop yields can be estimated usually to within ± 5 percent, as early as the first week in April when March rainfall totals are received. In the case of major shortfalls or surpluses, government can, using this procedure, have early warning before harvest begins and adjust the food importation program accordingly.

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Appendix: Average Monthly Rainfall Observations at District Headquarters Stations*

(Wet Period, Dry Period, Differences)

District	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Annual Totals
- - - - - - - - - - - - - - - - - - Wet Years - - - - - - - - - - - - - - - - - -

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