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QUANTITATIVE ANALYSES OF LESOTHO'S OFFICIAL YIELD DATA FOR MAIZE AND SORGHUM

Research Report No. 8
Lesotho Agricultural Sector Analysis Project

by
Jerry Eckert
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PREFACE

QUANTITATIVE ANALYSES OF LESOTHO'S OFFICIAL YIELD DATA FOR MAIZE AND SORGHUM

This analysis was undertaken to determine, at the level of macro-data, the relationships between crop yields in Lesotho and rainfall. A second objective which was considered equally important was to test the validity of Lesotho's official crop yield statistics.

Two equations are developed for each of maize and sorghum. The first relates yields to monthly rainfall observations while the second relates yields to total rainfall during the October to March growing season. Both equations yielded surprisingly good results. Use of individual monthly rainfall figures proved most accurate in modeling existing data but the relationship with six-month totals appears preferable for estimating other years.

One of the principal conclusions is that Lesotho's official crop statistics are highly reliable and the variation in them, which has been a source of concern, is simply an accurate reflection of existing variation that is present or has occurred in the farm environment. This conclusion is significant in that it now appears warranted to proceed with other analyses based on these data; analyses which could not be undertaken as long as the data remained in question.

The equations developed are tested against existing data to establish their validity and then applied to other analyses. Among them are:

1. Existing statistics are examined to identify those specific observations which probably contained errors. The techniques used can be applied each year as a means of verification prior to release of the final estimates from Bureau of Statistics.

2. A procedure is developed for early estimation of crop yields. By using this method government can know even before harvest what maize yields will be and can use this information to support better policy and program decisions on such issues as food imports, food aid negotiations and strategic food reserves. In the case of a particular localized shortfall government can also plan for the necessary inter-district food movements in advance. 1979/80 maize yields are estimated.

3. The analysis quantified significant differences in potential productivity between districts. Since the districts shown substantial productivity differences between the two crops there appears to be a clear case of different comparative advantages and hence a legitimate economic case for specialization in production and trade between the districts.

4. The 1949/50 Agricultural Survey data are re-examined and found to err dramatically only in the case of maize. A tentative reasoning for this observation is proposed and supported by an examination of factors (both climatic and administrative) affecting that survey. Perhaps this thirty-year old question has finally laid to rest.

5. The equations perform with sufficient accuracy in modeling existing data that it seems legitimate to use them to estimate other years for which no official statistics were collected. This is done for the early 1970s, completing the years between the 1969/70 agricultural census and the first annual agricultural production survey in 1973/74. With the exception of two atypical years (1974/75 and 1975/76) analysts can now work with a complete series of maize yields for the 1970s.

QUANTITATIVE ANALYSES OF LESOTHO'S OFFICIAL YIELD DATA FOR MAIZE AND SORGHUM

by

Jerry Eckert[1]

Introduction

Considerable controversy surrounds Lesotho's official estimates of crop yields. One of the issues in recent years has been the frequent assertion that the data show a long-term decline in yields. Another arises from the high degree of variability both within each year and between districts. A further problem arose in 1976/77 when reported yields jumped by 50 percent and more from earlier averages. Estimates have since remained at these higher levels. Because the annual sample was redrawn in that year, it is tempting to attribute the differences to sampling error and to conclude that either the earlier or later series is biased. As a result of these issues, the Bureau of Statistics has received considerable criticism in recent months.

Furthermore cropping in Lesotho is heavily influenced by climate. In part this susceptibility is the result of poor crop management by farmers. Several techniques for reducing weather-induced variability are discussed toward the end of this report. However, until these practices are in common use, cropping will reflect climatic variability very directly.

Rainfall in Lesotho is often characterized as low and variable[2] and precipitation events (drought, too much rain) and related factors (worms in association with drought) dominate farmers' perceptions of their most serious natural hazards (Wilken, 1980). Yet despite common agreement on the determinant role of rainfall no quantitative estimate of this relationship has been successfully developed for Lesotho.[3] Gillooly and Dyer (1977) demonstrated very significant relationships between maize yield, monthly rainfall and temperature for selected stations in the Orange Free State. Unfortunately their brief

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[1] The author is indebted to Messrs. Tuoane, Giri, Scherer, Law, Gay and Geuting for comments on an earlier draft. The author remains fully responsible for the conclusions herein.

[2] See numerous technical evaluations done by World Bank, IMF, FAO as well as annual reports of the Ministry of Agriculture.

[3] Tadic estimated a correlation between maize production and annual rainfall with a slope of .7554 and a coefficient of determination of .57. However, since production is the multiple of acreage x yield and acreage has been shown to vary substantially lately due to other than agronomic causes (Eckert and Wykstra, 1980) his analysis is of limited usefulness for projections. Furthermore, the use of annual rainfall totals masks important sources of variation affecting crop yields (see Tadic, 1972).

note does not publish the equations derived, possibly because the choice of quite different environments prevented generalization. For Lesotho, the record of temperature measurements is not adequate to permit analysis and the researcher is confined to rainfall-yield relationships.

This paper proceeds from the hypothesis that if crop yield estimates are reliable then a mathematical equation can be estimated depicting relationships between recorded yields and rainfall. Stated conversely if such a relationship emerges, it would tend to establish the reliability of the yield data by explaining most of their apparent variation.[1] Such an equation could also shed additional light on the points of controversy raised above.

The Available Data

Yield data are available from several years which are derived from crop cutting measurements in farmer's fields. Yield estimates are available for other years as well, but they were approximated by various means none of which included field measurements. In the interest of homogeniety, they were excluded from the study.[2] Yields estimated from crop cuttings include the following years:

Crop Year	Reference Source	Comment
1949/50	Douglas and Tennant, 1952	Lesotho's first Ag. Census
1960/61	Morojele, 1962, 1963	Second Ag. Census, methodology improved, text analytical.
1969/70	Bureau of Statistics, 1972	Third Ag. Census, methodology largely identical to 1960/61.
1973/74 1974/75 1975/76 1976/77 1977/78 1978/79	Bureau of Statistics Annual Statistical Bulletins	Annual Ag. Prod. Survey Methods identical to 1969/70 Census. Sample frame redrawn in 1976/77. Last Year's data forthcoming in 1980.

[1]With a minimum of 50 years continuous record at major stations, rainfall records are assumed accurate.

[2]Estimates excluded include the years 1967/68, 1968/69 (Tadic, 1972) and 1970/71-1972/73 (Giri, 1976) although the latter series are discussed later in the present paper.

The 1949/50 census provided a much needed national overview of Lesotho's agriculture. However, Morojele soundly criticized the sampling methodology used. He offers several reasons why Douglas and Tennant probably overestimated yields (Morojele, 1963; Part 4). Certainly the maize yield and production figures for the first census stood well above any other estimate unti 1976/77. Hence this first set of estimates is not used in the analysis below.

The 1960 and 1970 censuses employed nearly identical methodologies. Dr. Morojele, who was totally responsible for the 1960/61 effort, was active in guiding the 1970 effort and has made significant inputs into preparations for the 1980 census of agriculture as well thus ensuring continuity. Similar methods used for censusing were employed in the annual Agricultural Production and Livestock Inventory Survey which began in 1973/74. For the first three years the sample frame of the 1970 agricultural census was employed.

In 1976 the sample was redrawn from the sample frame of the 1976 Population Census. Simultaneously several other minor changes were made to improve the results. Yields reported for 1976 and later were 50 percent higher than previous averages, a fact which raised considerable doubt with respect to the comparability of early and later series. This discontinuity is discussed in depth below and in the Appendix. For the present it is sufficient to point out that the analysis below reaches two conclusions:

a. *The two periods 1960/61 to 1975/76 and 1976/77 to 1978/79 must be taken as methodologically consistent within each period.*

b. *Furthermore there is no known methodological distinction between the two groups that would suggest one is more accurate than the other. Unless additional proof is discovered they must then be taken as consistent with each other.*

Methodology

Yield observations for the present study were taken from recorded yield averages for each lowland district. Mountain districts were eliminated because of the many additional sources of variation present in that environment. Monthly rainfall observations from district headquarters were provided by the Hydrometeorology Office, Ministry of Works. Only maize and sorghum were considered widely enough grown to warrant analysis.[1]

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[1]Wheat could have been a third option but area is divided between winter and spring wheat plus the fact that yield levels in recent years have been affected by completely different technology of the Cooperative Crop Production Program.

Multiple linear regression related yield levels to monthly rainfall totals. Preliminary graphical analysis showed similar relationships between yield and rain within each district but that the districts seem to maintain different yield averages. In other words while yields in Butha-Buthe or Leribe rose and fell with rainfall, they fluctuated around higher means than did other districts. Accordingly dummy (zero-one) variables were introduced to capture district differences in average yield. Finally for similar reasons, another dummy variable was included to model the vertical shift in yields that occurred beginning in 1976/77. (Appendix B gives a layman's explanation of the use of dummy variables).

Data was refined as follows. Starting with a set of 59 observations, each representing one district in one year, certain observations were eliminated. 1974/75 and 1975/76 were seriously affected by disincentives arising from sudden, very large increases in household income from migrant remittances. Household incomes doubled in three years and remittances rose to 71 percent of total income. In this circumstance, planted acreage dropped precipitously, farmers may have been lax in their crop husbandry and yields fell. Yields of summer crops in 1975/76 declined even further because of excessive rains (Eckert and Wykstra, 1980). Because of this atypical incentive situation these two years were disregarded. Two observations were eliminated where there was some indication that data were incorrect. These two were: Quthing, 1978/79 for under-reporting of rainfall and Mohale's Hoek, 1973/74 because of an impossible yield figure. Finally, six observations were eliminated when early estimations identified them as outliers.[1]

Regressions were run on 39 data points. While the elimination of twenty observations may seem extreme, in Lesotho's case it is not only necessary but probably warranted. Twelve observations occurred during a highly atypical situation affecting farm management incentives. As to the remainder, it is an acknowledged fact that both the Ministry of Works weather reporting network and the Bureau of Statistics enumerators suffer from managerial and logistics problems from time to time with the result being an occasional piece of bad data. Thirty-nine observations were found sufficient to allow precise estimation and the thought that there can exist a somewhat higher degree of inaccuracy in the statistical systems of a developing country should not cause discomfort.

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[1]An outlier is a term in common statistical usage to identify a data point which lies sufficiently beyond the normal range so as to make it suspect. We defined outliers operationally as an observation which differed from the estimated value for that district and year by more than twice the standard error of the estimate. In other words, the probability that it was, in fact, part of the normal set of data was less than .025 (two tailed test).

PART I

RESULTS FOR MAIZE

Yield Relationships Quantified

Monthly rainfall totals were used as independent variables, initially including all months from September through April. However, September, October and April failed to produce significant coefficients in early estimations and were subsequently dropped. The final equation for maize was of the following form, where D_1-D_7 are zero-one variables representing lowland districts from North to South and "PERIOD" distinguishes the pre-1976 data from post-1976.

$$Y = f\ (RNOV,\ RDEC,\ RJAN,\ RFEB,\ RMAR,\ D_1,\ D_2,\ D_3,\ D_4,\ D_5,\ D_6,\ D_7,\ PERIOD)$$

Estimating the above results in the following rainfall coefficients:

$$\text{(Eq. \#1) Yield} = 471.4 + 1.35\ (RNOV) - 2.31\ (RDEC) + 1.01\ (RJAN) + 2.10\ (RFEB) + 1.39\ (RMAR)$$

Yields are in kilograms per hectare, rainfall in millimeters. All coefficients are significant at the 95 percent confidence level or higher.

The above estimates the relatinships between rainfall and yields for Maseru district as measured prior to 1976. To estimate other districts one adds the appropriate D_i coefficient:

Butha Buthe = D_1 = +323.2 kg/ha

Leribe = D_2 = +103.9 kg/ha

Teyateyaneng = D_3 = -59.7 kg/ha

Mafeteng = D_5 = -200.5 kg/ha

Mohale's Hoek = D_6 = -149.8 kg/ha

Quthing = D_7 = -196.1 kg/ha

To estimate yield levels as reported after 1976, one adds 668.7 kg/ha to the figure derived from the above equation.

Thus the full equation for, say, Leribe district in 1977/78 would read as follows:

$$\text{Yield (in kg/ha)} = 471.4 + 1.35\ (RNOV) - 2.31\ (RDEC) + 1.01\ (RJAN) + 2.10\ (RFEB) + 1.39\ (RMAR) + 103.9 + 668.7$$

Equation 1 explains 93.8 percent of the variation in the 39 yield figures used. An F ratio of 32.9 implies a very high degree of significance to the overall equation. And the standard error of the estimate of 117 kg/ha implies

that one can predict yields in a particular district with an accuracy of ± 234 kg/ha (2 x S.E.) and run the risk of being wrong only five percent of the time.

All coefficients are positive except for December rain where a negative coefficient suggests that December rains depress yields. In large part this is probably a statistical accident. In 1978/79 Lesotho suffered drought in October, November and March as well as in January in some districts. Yields were depressed accordingly. However, December 1978 was one of the wettest two or three Decembers on record. Rain fell in torrents even though large portions of it ran off fairly quickly. Statistically, the result was extremely high rainfall observations for December in a year of depressed yields overall.

There are at least two possible agronomic reasons which could lead to a negative relationship between December rain and yields. Heavy rains can interrupt field operations with the result that maize planted in October and November can miss its most critical weeding. The proliferation of weeds during a wet December can offer severe competition for moisture and nutrients later in the season. Second, heavy December rains can delay final plantings until beyond the third week of the month. Yields have been shown to drop rapidly for maize planted after December 21 in Lesotho (Powell, 1979).

Whatever the reasons a negative relationship exists in the available data for Lesotho. Perhaps it will disappear as a longer time series emerges. But for the time being, the relationship cannot be avoided without very questionable data transformation tricks.

It is sometimes desirable to relate yield to rainfall totals for the crop season. Equation 2 provides such a relationship utilizing total rain from October through March as the independent variable, and Maseru as the point of departure.

(Eq. #2) Yield = 111.6 + 1.27 (6 mo. total rain)

To estimate for other districts, add:

Butha-Buthe	+234.9 kg/ha
Leribe	+ 95.8 kg/ha
Teyateyaneng	- 98.8 kg/ha
Mafeteng	-134.6 kg/ha
Mohale's Hoek	-163.5 kg/ha
Quthing	-202.7 kg/ha

And to shift the estimate to the post-1976 period one must add 484.0 kg/ha.

Some precision is lost in the aggregation contained in Equation #2. However, the overall regression is highly significant, some 85.7 percent of the variation in yield is explained and the standard error of the estimate is relatively small at 165.8 kg/ha.

Analysis

Accuracy

Of the two equations, equation 1 has a slight edge in all measures of significance. This advantage arises from variability in the monthly rainfall pattern which is masked by the use of six month totals. Maize has definite periods of sensitivity to moisture stress, the two most important being just before and after pollination plus the period of root system establishment. Using monthly rainfall as independent variables picks up these intra-seasonal differences whereas crop season totals cannot.

Either equation can be used to estimate average yields for the lowland districts, which account for roughly 90 percent of total maize production in Lesotho. The methodology is simple. One estimates yield levels for each district, multiplies these by area harvested, sums the resulting production figures and divides by total area harvested in the seven districts. The result is a weighted average yield estimate for the districts included. Table 1 demonstrates the methodology for 1960/61 which is generally regarded as a normal climatic year. Table 2 presents similar figures for all years used in the study. In both cases Equation 1 proves the most accurate.[2] Despite the fact that the official data contain a few strange figures which were omitted in estimating coefficient, Equation 1 modeled weighted average figures for the seven lowland districts with a mean deviation of only 3.0 percent.

Table 1. Comparison Between Estimated Maize Yields and Official Statistics, 1960-61.

(Kg/Ha)

District	Estimated Yield From: Equation 1	Estimated Yield From: Equation 2	Official Data	Hectares Harvested
Butha Buthe	1,100	1,286	1,050	5,740
Leribe	791	900	929	38,981
Teyateyaneng	761	847	699	26,949
Maseru	771	824	657	26,823
Mafeteng	668	722	656	23,484
Mohale's Hoek	811	651	804	14,916
Quthing	813	789	779	8,848
Seven District Weighted Average[1]	778	831	775	

[1]District averages weighted by area harvested.

[2]"Accuracy" as used here is accuracy in modelling existing data and should not be confused with accuracy in forecasting as will be discussed later.

Table 2. Average Yields for Seven Lowland Districts: Estimated *vs* Official (Kg/Ha)

Crop Year	Estimated by: Equation 1	Estimated by: Equation 2	Official Data	Percentage Deviation[1] Equation 1	Percentage Deviation[1] Equation 2
1960/61	778	831	775	+0.4	7.2
1969/70	493	499	523	-5.7	-4.6
1973/74	955	886	964	-0.9	-8.1
1976/77	1,545	1,426	1,610	-4.0	-11.4
1977/78	1,419	1,347	1,435	-1.1	-6.1
1978/79	1,126	1,238	1,062	+6.0	16.5
Average[2]				|3.0|	|9.0|

[1] $\frac{\text{Estimate-Official}}{\text{Official}} \times 100$

[2] Average of absolute values.

Variability in the Official Statistics

One of the more frequent sources of controversy is the variability in official yield data. Variability has been noted between years and between districts within single years. However, no previous analysis has successfully rationalized visible differences with the result that many people view the Bureau of Statistics output with suspicion.

In part this problem results from the application of weak analytical tools in previous studies. A second contributing factor arises from the short period of record which is confused by two years of highly distorted farm management incentives. Lesotho has only now assembled a sufficient time series of non-distroted yield estimates to warrant detailed quantitative treatment.

This study suggests that Lesotho's yield figures, at least for maize and sorghum, are highly reliable and that their variation reflects actual agronomic and environmental determinants. Causes of variation have been disaggregated to isolate environmental differences between districts (primarily soils), the influence of variable rainfall plus the availability of labor and management as discussed below. The result in the case of maize is an equation explaining 95 percent of the variation in the data from all normal years since 1960/61. The fact that Equation 1 re-estimated official figures within ± 3.0 percent is further confirmation that the variation in yield data is systematic and accurately reflects the variable environment of Lesotho.

To reach this conclusion only a few assumptions were made, none of which violate the objectivity of the study. They are:

a. That only those estimates derived from crop cutting measurements are sufficiently homogenous methodologically to be pooled for analysis.

b. That 1974/75 and 1975/76 crops were sufficiently influenced by the increase in real mine wages (some 330 percent) that they constitute data from a different management environment and thus are not part of the homogenous population of estimates under study (see Eckert and Wykstra, 1980).

c. That there is a logical explanation for the increased yields measured since 1976/77 (see following section).

d. That occasionally the data do contain errors in one or another district but that these can be tentatively identified by objective statistical means and eliminated prior to deriving working equations.

The Yield Discontinuity of 1976

The analysis pooled two distinct sets of data referred to as early and late periods below.[1] It is shown that the relationship between maize yields and rainfall is nearly identical within each period but that the late period averaged 669 kg/ha higher than the early years. The equation itself does not explain this difference, it merely provides a satisfactory way of modeling it.

This apparent inconsistency has been the cause of many questions, and some condemnations. As a result, over the last two months the Bureau of Statistics, LASA and FAO have cooperated to critically scrutinize the present methodology in use as well as the changes made in 1976. While small influences (2-5%) could have occurred, there is no evidence that they would have operated in an additive fashion. Methodological changes in 1976 could not have added 50 percent to yields and present methods are believed to be relatively accurate, given the conditions of field work in Lesotho and the resource limits of the Bureau of Statistics. *Therefore one is left with the conclusion that the statistics reflect actual higher yields.*

Two explanatory hypotheses are offered, neither of which can be adequately proved. Both are drawn from the rapid reduction in planted area resulting from the mine wage increase of 1973 to 1976. During this period the real

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[1]Early = 1960/61, 1969/70 and 1973/74
Late = 1976/77, 1977/78 and 1978/79

value of remittances from abroad more than trebled, household income shot up to unprecendented levels and cropping declined to only 6 percent of rural household income. Under these circumstances the incentive for serious farming abated appreciably. From 1973/74 to 1976/77, planted area declined 38 percent[1] (Eckert and Wykstra, 1980).

An incentive structure that reduced planted area so abruptly would also operate selectively to cause lower yielding fields to be fallowed first. Farmers with fields of differing productivities would fallow the lowest yielding first. Land holders who, for reasons other than soil type, are poorer farmers would tend to fallow their land sooner than would those for whom farming provides a reasonable income. Finally, fields that are far from the homestead and thus more difficult to farm were probably fallowed first as well. Distant fields can be expected to fall within the low yield group because distance acts to prevent the full range of inputs being applied.

No yield figures are available which would compare fields fallowed with those still cropped. However, for the sake of illustration, assume that fields fallowed averaged only 75 percent of the overall yield level. In that case a reduction of 38 percent would have created a 15 percent increase in average measured yields even with no actual change in productivity on any field.

A second, and probably more important, factor is the change in man:land ratio occurring at the same time. Migration had essentially peaked by 1973 and since that time new entrants to the labor force have been forced to look to the domestic economy for work. Since 1977 there has been a progressive reduction in migrant numbers which adds to the available labor supply (CPDO, unpublished data). Table 3 combines these trends with changes in planted area to show that *available male labor supply has increased approximately 82 percent on a planted hectare basis since 1973.*

Most analysts concur that the absence of males in the household has been a serious constraint to farm productivity. Their absence affects decision making, labor inputs and the timeliness of field work operations. Table 3 makes a strong case that there has been a significant relaxation of this constraint in recent years. Certainly not all of the above labor is applied to agriculture, however, if the proportion devoted to farming remained constant, then the percentage increase noted above would have applied to farming as well as to the total. Utilizing averages of .34 manyears per hectare for 1970-1974 and .61 for 1977-1979 and relating these to the 669 kg/ha difference in yield suggests a marginal productivity for labor over this range in maize production of 2240 kilograms per hectare per male manyear of available farm labor. The implications of this figure for the possible impact on agriculture of a decline in migration are clear.

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[1]From 340,900 hectares to 210,300.

Table 3. Estimated Recent Changes in Approximate Male Labor Supply per Planted Hectare

(data in thousands)

Year	Male Labor Force	Migrant Workers	Domestic Male Labor Supply	Planted Hectares	Male Labor per Planted Hectare
1970	245	134	111	346.9	.32
1971	251	129	122	345.4**	.35
1972	257	147	110	343.9**	.32
1973	263	155	108	342.4**	.32
1974	269	142	127	340.9	.37
1975	275	154	121	303.3	.40
1976	281	160	121	278.8	.43
1977	287	160	127	210.3	.60
1978	294	155	129	239.1	.58
1979	301*	150*	151	232.9	.65

*Provisional
**Approximated by linear trend from 1970 to 1974.

Source: Eckert and Wykstra, 1980.

The two changes have acted together, with a much higher labor supply being concentrated on the more productive fields. Marginal productivity of labor inputs would be expected to rise in the process. *Hence there are three co-incident factors, which taken together offer ample justification for a sudden 50 percent increase in yields. In summary they are:*

a. *An arithmetic increase derived from averaging yields only on the more productive fields.*

b. *An increase of 82 percent in the available male labor per hectare.*

c. *Higher production per labor unit because manhours are being concentrated on the more productive fields.*

Testing the 1949/50 Census Figures

As mentioned Douglas and Tennant conducted Lesotho's first agricultural census in 1949/50. Their work was in conjunction with the first FAO world census of agriculture. Neither Douglas and Tennant nor FAO had an established methodology at their disposal. Consequently, there was considerable experimentation and refinement in the field as the survey progressed.

Data produced in 1949/50 contain exceptionally high national yield levels for maize. Their production estimate exceeded those immediately before and after the census year by 200-300 percent (LASA, 1978:II-4). Douglas and Tennant themselves anticipated a controversy and offered ten points for possible consideration. The thrust of their argument was that other yield estimates to which theirs were being compared in 1950 had less justification for being considered accurate than did the census figures (Douglas and Tennant, 1952:81-82). Morojele points out that the final choice of area to be sampled was left to the enumerators with little supervision. He then alleges that enumerators might have subjectively deviated toward "areas that are more extensively cultivated, to avoid travelling. These areas would turn out to be the most fertile and the yields obtained would be inflated." He also found "unsatisfactory" procedures in the methods of field and plot selection as well as the small size of the plot cut. All of these factors could have inflated yield estimates (Morojele, 1963: Part 4).

More recently there has been a tendency to look at yield estimates from the three census years and conclude Lesotho suffers from a long-term chronic decline in yields. Opponents of this view point out that while 1960/61 was a relatively normal rainfall year, 1949/50 was one of the wettest in history and 1969/70 was "the worst drought in living memory" (MOA, 1971). Thus, it is easy to suggest that the three yield figures represent rainfall induced variation and that the "long-term downward trend" is an accident of statistical timing.

To test this hypothesis Equation 2 was used to re-estimate yield levels for 1949/50 using the methodology of Table 1. Weighted average yields were 921 kg/ha compared with 1192 kg/ha estimated by Douglas and Tennant.[1] The probability that the original estimates could have been derived by the response relationships of Equation 2 is only .02. Furthermore the regular pattern of differences between districts does not appear in the 1949/50 data. While there are inter-district yield differentials they are small and bear little relationship to known differences in soils or to the rainfall pattern of that year.

Consequently one must conclude that, while Douglas and Tennant's work provided an invaluable source of field data where none existed before, the accuracy of their estimated maize yields is not good enough to warrant their use with more recent data in long-term, time series analysis. Paradoxically, their yield estimates for other crops do not show a corresponding overestimation. A possible explanation lies in the timing of rainfall. Most districts measured 2-3 times normal rain in April and May 1950. Douglas and Tennant make mention of crop cutting activities in these months being hampered by excessive rains. The hypothesis arises that wet grain was weighed. Dry weight factors were obtained by a few days of air drying which, in a period of frequent heavy rains may have given inadequate downward adjustment factors. Finally, the instructions to enumerators do not specify husking. Perhaps it is this factor that causes only maize to be spectularly out of line. Whatever the reason, this early study has served its purpose and contemporary analyses must begin with the 1960/61 census.

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[1] The rationale for use of Equation 2 is given in the following section.

Connecting yield estimates from the 1960/61 census to those of the 1969/70 census still suggests declining yields. However, as Table 2 indicates the difference between the two is almost entirely accounted for by differential rainfall. *Therefore, Lesotho's data do not support the assertion that long-term yield declines are (or have been) underway. In fact there is no evidence of any trend at all in the data.*

Applications

Predicting Yields in Advance

Once the relationships between crop yield and determinant factors are known they may be used to predict yields without actual field sampling. This can be particularly useful in countries such as Lesotho where manual tabulation of survey results delays considerably the availability of official crop estimates. Even though subject to a margin of error, yield and production estimates can be derived before harvest which would serve usefully as advance planning tools.

Dyer and Gillooly (1977:252-253) have developed maize yield estimation equations for four locations in the Orange Free State. While their equations are reasonably accurate at modelling existing data, they depart from reality by ignoring those variables that have insignificant regression coefficients. Their equations therefore are more accurately characterized as representations of a particular data set rather than of agronomic truth.

To avoid this criticism it was desired to include all months of rainfall during the growing season. Two options are available. First, one can include each month's rainfall as a separate independent variable when it becomes available. The sequence of equations is given in Table 4 which leads to Equation 1 when all data are available. Alternatively, rainfall may be added throughout the season as in Table 5 with the result being Equation 2 as of the end of March.

The choice of estimation methodology is important when policy or program analysis is to be based on estimated figures. In this regard one hesitates to use Equation 1 when the regression coefficient for December rainfall deviates from expected agronomic relationships. While Equation 1 models the existing data with more precision than Equation 2, it may well prove less accurate when applied to other years.

Table 4. Sequential Equations for Early Prediction of Maize Yields in Lesotho with Monthly Data

Date of Estimation	Constant (b_0)	RNOV (b_1)	RDEC (b_2)	RJAN (b_3)	RFEB (b_4)	RMAR (b_5)	D_1 (b_6)	D_2 (b_7)	D_3 (b_8)	D_5 (b_9)	D_6 (b_{10})	D_7 (b_{11})	Period (b_{12})	R^2	Standard Error of Estimate
Pre-Season	747.0	-	-	-	-	-	287.3	40.9	9.8	-76.6	-217.6	-165.1	618.5	.73	224.1
After Nov.	619.4	1.9	-	-	-	-	272.3	45.6	-23.0	-49.3	-191.4	-127.9	662.7	.76	217.2
After Dec.	1007.6	2.8	-3.1	-	-	-	386.8	102.9	20.6	-62.5	-168.5	- 70.3	797.2	.82	191.0
After Jan.	833.1	2.4	-2.4	1.7	-	-	383.7	137.6	-46.2	- 0.1	-104.1	- 28.2	749.7	.87	163.8
After Feb.	881.1	2.4	-3.3	1.2	2.1	-	395.3	166.1	-22.7	-93.5	-108.0	- 92.1	745.3	.91	140.2
After Mar.	471.4	1.4	-2.3	1.0	2.1	1.4	323.2	103.9	-59.7	-200.5	-149.8	-196.1	668.7	.94	117.2

Notes: 1) The above are the estimated values of b_i (regression coefficients) in the following equation:

$$\text{Maize Yield} = b_0 + B_1\,(\text{RNOV}) + b_2\,(\text{RDEC}) + b_3\,(\text{RJAN}) + b_4\,(\text{RFEB}) + b_5\,(\text{RMAR}) + b_6\,(D_1) + b_7\,(D_2) + b_8\,(D_3) + b_9\,(D_5) + b_{10}\,(D_6) + b_{11}\,(D_7) + b_{12}\,(\text{Period})$$

2) Equations estimate yield (Kg/ha) for Maseru District (D_4) when all $D_i = 0$. To estimate value for another district set the relevant $D_i = 1$ holding all other $D_i = 0$. Since no adjustment is needed for Maseru, D_4 is omitted.

3) Value of PERIOD is set at 0 for years befdore 1976 and set at 1 for 1976/77 and later years.

Table 5. Sequential Equations for Early Estimation of Maize Yields in Lesotho Using Cummulated Rainfall Observations

Date of Estimation	Rainfall Summed for:	Constant (b_0)	Rain (b_1)	D_1 (b_2)	D_2 (b_3)	D_3 (b_4)	D_5 (b_5)	D_6 (b_6)	D_7 (b_7)	PERIOD (b_8)	R^2	**Standard Error of Estimate**
After Jan.	Oct-Jan	368.9	1.06	281.7	101.8	-43.9	-18.7	-167.4	-117.2	538.6	.76	**213.2**
After Feb.	Oct-Feb	297.5	1.07	274.0	116.1	-49.3	-52.6	-159.8	-146.6	517.9	.79	**202.7**
After Mar.	Oct-Mar	129.0	1.27	234.9	95.8	-98.8	-134.6	-163.5	-202.7	484.0	.86	**165.8**

Notes: 1) The above are the estimated values of b_i (regression coefficients) in the following equation.

$$\text{Maize Yield} = b_0 + b_1\,(\text{Rain}) + b_2(D_1) + b_3(D_2) + b_4(D_3) + b_5(D_5) + b_6(D_6) + b_7(D_7) + b_8(\text{PERIOD}).$$

2) Equations estimate yield (Kg/ha) for Maseru District (D_4) when all other $D_i = 0$. To estimate average yield for another district set the relevant $D_i = 1$ holding all other $D_i = 0$.

3) Value of PERIOD is set at 0 for years before 1976 and at 1 for 1976/77 and subsequent years.

The crop year 1979/80 is a case in point. Rainfall was depressed in most months including December. In using Equation 1, where $b_2 < 0$, low December rains add to estimated yields thereby partially offsetting the reduction that would be suggested by other below normal months. In a year like 1979/80, where most months were uniformly low, Equation 2 should predict a lower average yield than will Equation 1.

For these reasons and until more official data can be included in the estimation procedure, the analyst is probably safer in using Equation 2 for years other than those used in this study. Consequently the methodology of Table 5 is applied below. Table 6 shows how sequential estimates would have gradually moved to predict final official figures in two selected years. 1969/70, which turned out to be a drought year, and 1977/78, ultimately above normal, are used to illustrate both extremes.

Table 6. Sequential Yield Estimator Applied to 1969/70 and 1977/78

Year / District	Yields Estimated After January	February	March	Official Figures
1969/70 (Very Dry)				
Butha Buthe	1007	1002	938	828
Leribe	729	700	583	616
Teyateyaneng	593	567	440	615
Maseru	653	607	525	603
Mafeteng	616	582	407	272
Mohale's Hoek	505	489	425	459
Quthing	535	479	342	283
Weighted Average	646	614	499	523
Deviation in %	23.5	17.4	-4.6	
1977/78 (Above Normal)				
Butha Buthe	1566	1540	1628	1827
Leribe	1479	1457	1480	1482
Teyateyaneng	1362	1329	1368	1354
Maseru	1247	1242	1308	1248
Mafeteng	1248	1194	1247	1289
Mohale's Hoek	1130	1121	1167	1802*
Quthing	1238	1188	1209	868
Weighted Average	1326	1301	1347	1435
Deviation in %	-7.6	-9.3	-6.1	

*Logic is presented in the next section suggesting that this figure is in error. If one substitutes the estimated 1167 for the figure actually recorded, the weighted average for the official column becomes 1341 kg/ha. This estimating procedure would have missed that figure by only 0.4 percent.

Source: Equations in Table 5.

Early season estimates will most accurately predict final results in "normal" rainfall years as in 1977/78. However, even in years where a large surplus or deficit in precipitation accumulates, relatively accurate estimates are available at least by the end of January with February and March adding further refinement. In fact, it is specifically years that deviate from normal in which this estimation technique will be most useful in giving government early warning of deficits or surpluses in cereal production. *By February or March 1970 agricultural planners could have known that maize yields would approximate only 500 kg/ha (± 30% below normal) in the lowlands districts. Without these equations, this fact was first identified statistically in 1972 with the publication of the 1970 Agricultural Census Report.*

The estimates in Table 6 utilized actual acreage harvested to obtain weighted average yields for the lowlands. In practice actual area harvested will not be known until some months after harvest. Therefore, predictions for a crop season presently underway must rely on acreage harvested one year before as an approximation. Table 7 predicts yield levels by district for the lowlands for the 1979/80 season. This estimate is prepared on May 26, 1980. Although 1978/79 crop figures are available informally they have not yet been published by the Bureau of Statistics. Nevertheless we have used their unpublished acreage figures for weights in Table 7. This procedure contains one major assumption; that there has not been a significant increase in acreage planted which would have put some of the less productive fields back into the overall averages. If acreage has expanded significantly average yields will be lower.

As expected two quite different estimates arise from the two equations. Comparing them with similar estimates derived for 1978/79 (from Table 2), one projects an increase of 28 percent and the other a decrease of five percent. The difference could prove an acid test for the two equations once the official data are received. At present, however, field reports are available from Ministry of Agriculture personnel suggesting that the 1979/80 maize crop was seriously depressed due to below normal rainfall. These observations lend support to the prediction from Equation 2 of a further slight decline from yield levels of the previous year. Applying the decline in estimated yield levels to last years official figure would suggest an official average yield for the seven lowland districts of 1012 kg/ha.[1]

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[1] (1979/80 estimate ÷ 1978/79 estimate) x 1978/79 actual.

Table 7. Estimated Maize Yields for 1979/80

District	Rainfall (mm) Oct	Nov	Dec	Jan	Feb	Mar	Estimated Yield Eq. #1	Eq. #2	1978/79 Acreage
Butha Buthe	94	108	89	61	91	41	1,713	1,463	7,242
Leribe	69	132	103	86	107	60	1,579	1,416	21,937
Teyateyaneng	100	99	90	55	80	81	1,342	1,156	19,879
Maseru	85	63	57	37	62	62	1,347	1,078	21,504
Mafeteng	80	57	27	112	148	32	1,423	1,057	13,470
Moahle's Hoek	128	42	16	58	148	67	1,473	1,032	11,487
Quthing	92	51	62	68	99	54	1,221	951	5,329
Weighted Average Yield							1,441	1,180	

Prepared 26/5/80
Source for rainfall: HydroMet 1979, 1980.

Improving the Data Base

Checking for Errors: The equation developed in this paper depicts normal relationships affecting maize yields as observed in Lesotho's data. Reasonably accurate predictions are available for each district. One of their potential uses, therefore, is to identify figures which might be in error as the annual Agricultural Production Survey proceeds to develop estimates. An estimate derived from Equation 2, ± twice the standard error of the estimate includes 95 percent of all estimates that would result from the relationships included in the equation. The probability of an estimate falling above or below this range is .025 for each side of the range.

As a practical measure, statisticians could compare their preliminary estimates from the annual survey with those derived from Equation 2 and flag for careful scrutiny those which fell outside the 95 percent confidence interval. Applying this criterion retrospectively to Lesotho's maize data identifies the observations in Table 8 as possibly containing errors.

Table 8. Maize Yield Observations Which May Have Incorporated Errors in Their Estimates*

Observation District	Year	Official Figure	Estimated Figure	Probability that official figure could result from Equation 2**
Mafeteng	78/79	599	1,113	<.005
Quthing	78/79	1,408	819	<.0005
Mohale's Hoek	73/74	1,160	687	<.005
Mohale's Hoek	77/78	1,802	1,167	<.0005
Butha Buthe	76/77	2,272	1,747	<.005

*Identified as those observations where $|y-\hat{y}| \geq 2\ SE_{\hat{y}}$

**Calculated from $t = \frac{y-\hat{y}}{SE_{\hat{y}}}$

Note: None of the other differences were significant at the 95 percent level.

Supplying Missing Data: Each of the three agricultural censuses contain a strong plea to develop a statistical system that would provide annual crop estimates. Yet the first annual data in non-census years appears for 1973/74. Eliminating 1974/75 and 1975/76 as unusable for most analyses limits the amount of data during the 1970s to five years, only three of which are in sequence. Some types of analysis require a more complete series than is available from official data. For example, the study of total food consumption usually requires an association between production figures in one year and trade data for the following year. With a broken series these important relationships become difficult if not impossible to quantify. Similarly, the analysis of risk in cropping requires an extended series of annual variations in order to construct estimates of probability of loss or gain.

If field estimates had been obtained for the three years immediately following the 1970 Agricultural Census analysts could work with two periods of successive production estimates, one of five years and the other of three years length during the past decade. One effort to provide the missing data was produced (Giri, 1976), however, the estimates contained therein are largely based on subjective factors. At the time the author stated "Formulation of any mathematical model --- for these years from available data appears unthinkable". He further concludes "--- the estimates for the non-survey years of 1970/72 to 1972/73 are just intelligent guesses and are subject to further examination and review."

Now that sufficient data have accumulated to develop a quantitative model it seems appropriate to re-estimate the missing years in order to provide as complete a series as possible for analysis of trends during the 1970s. Table 9 provides maize yield estimates based on rainfall. Acreage harvested is estimated from an assumed linear trend connecting district figures as measured in 1969/70 and 1973/74. Production is obtained by multiplication. Finally, figures for Lesotho as a whole are estimated by adjusting the lowland district figures for yield and area to national levels using the average relationships found in 1969/70 and 1973/74.

The estimates in Table 9 differ substantially from those prepared by Giri as the following comparison of national figures show:

	1970/71	1971/72	1972/73
YIELD (Kg/ha)			
Giri*	550	540	610
Revised	691	881	622
PRODUCTION (000T)			
Giri	74	59	70
Revised	92	119	85

*Giri presented figures rounded to nearest ten.

Table 9. Revised Estimates of Maize Production and Yield for Non-Survey Years*

	1969/70	1970/71	1971/72	1972/73	1973/74
	- - - - - - - - -Areas in Hectares - - - - - - - - - - -				
Butha Buthe	5,176	5,657	6,138	6,619	7,100
Leribe	26,980	27,310	27,640	27,970	28,300
Teyateyaneng	19,712	19,134	18,556	17,978	17,400
Maseru	21,964	22,398	22,832	23,266	23,700
Mafeteng	20,463	21,747	23,032	24,316	25,600
Mohale's Hoek	12,690	12,168	11,645	11,122	10,600
Quthing	7,307	7,230	7,153	7,077	7,000
7 Districts	114,292	115,644	116,996	118,348	119,700
Lesotho	129,303	133,476	135,037	136,597	140,900
	- - - - - - - - - - Yield in Kg/ha - - - - - - - - - - -				
Butha Buthe	828	1,046	1,070	1,039	1,235
Leribe	619	782	902	819	1,008
Teyateyaneng	615	614	992	668	840
Maseru	603	729	918	533	946
Mafeteng	272	714	848	497	881
Mohale's Hoek	459	498	808	467	1,294
Quthing	283	576	662	454	809
7 Districts	523	701	894	631	964
Lesotho	514	691	881	622	949
	- - - - - Production in Metric Tons - - - - - - - -				
Butha Buthe	4,286	5,917	6,566	6,877	8,769
Leribe	16,701	21,356	24,931	22,907	28,526
Teyateyaneng	12,123	11,748	18,408	12,009	14,516
Maseru	13,244	20,561	20,960	12,401	22,420
Mafeteng	5,666	15,527	19,531	12,085	22,553
Mohale's Hoek	5,825	6,060	9,409	5,194	12,656
Quthing	2,067	4,164	4,735	3,213	5,663
7 Districts	59,812	81,064	104,594	74,678	115,391
Lesotho	66,462	92,232	118,968	84,963	133,714

*Estimated using Equation 2; Lesotho totals obtained by adjusting the seven district totals for their average relationships with national totals. Production figures obtained by multiplying area by yield. Data for 1969/70 and 1973/74 are official figures.

The revised figures are believed to be much more accurate representations of actual events. They were derived by a procedure which was proved highly accurate in modeling maize yields in survey years. Furthermore Table 9 shows relationships between districts that are consistent with those of the existing official data base. High yield and production figures in 1971/72 are the estimated responses to one of the most optimum rainfall years on record.

Application to Planning

One of the more important uses of this analysis is in advance prediction of food supplies as already noted. Domestic production can be predicted within a narrow range as early as April when harvest begins and plans for importing grain can be formulated at that time. Several other important conclusions affect development planning.

The Absence of Technological Change: Ninety-four percent of all variation in observed yield was explained by an equation which contained no trend term. Furthermore early years were as accurately depicted as later years. These two factors suggest there is no evidence of long-term trend in yield levels. The often asserted long-run yield depression due to erosion is not supported even though the data extends over nearly 20 years. Nor is there any evidence of a rising trend in yields which would indicate the gradual spread of improved technology. The only evidence of a yield change was the one-time jump in 1976/77 and this seems adequately explained by factor productivity and factor intensity considerations resulting from abandoning 38 percent of the cultivated area.

Thus one concludes that development programs have yet to reach the average maize grower; the challenge of technical change still lies ahead. While fertilizer use has been expanding it has yet to reach application levels that would affect national yield measurements.

Reducing Cropping Variability: This analysis confirms that rainfall differentials contribute significantly to variability in yield. Annual differences are particularly visible in Table 9. Uncertainty for the household with respect to food supplies and incomes is the logical result. Uncertainty of this magnitude will provide disincentives to investment in farming as well. An important priority for research and extension programs should therefore be to develop and test cropping practices which will reduce this variability. Proper plant spacing, controlled depth of planting, choice of drought resistent varieties, weed control, soil ammendments, control of surface texture , residue management and other practices can contribute measurably toward soil moisture conservation. Yet few of these techniques are being researched and even fewer are in Extension's message at present. To be appropriate to Basotho farmers, the recommendations of the more advanced countries for similar climates need to be refined to fit the resource mix on Basotho farms. It is suggested that the Research Division of the Ministry of Agriculture accept as a high priority the objective of testing risk minimization practices such as listed above.

Regional Planning: Finally, the analysis uncovered significant differences between districts in crop productivity. Some 73 percent of variation inherent in the data was explained by the variables for district and period. Average maize yield differences showed the following relationship in nearly all regressions.

Butha-Buthe > Leribe > TY = Maseru > Mohale's Hoek > Mafeteng = Quthing

The normal range from the highest to lowest exceeds 630 kg/ha.

Differences of this magnitude definitely suggest the need for specialization in production within different regions followed by trade in food commodities. The northern lowlands quite obviously have a comparative advantage in maize production. The higher yielding environment combined with a more favorable rainfall pattern imply that investment by either government or farmers in maize production programs will yield much greater returns if concentrated in the North.

PART II

RESULTS FOR SORGHUM

Yield-Rainfall-Area Relationships

Identical analyses were performed on Lesotho's official yield data for sorghum, a crop grown equally widely in the Lowlands. Rainfall was significantly related to yields only in the months of January through April. Apparently as grown in Lesotho sorghum is relatively insensitive to rainfall variation in the early stages of growth. Equation 3 presents the relationships between monthly rainfall and yield for Maseru district, prior to 1976.

$$\text{(Eq. \#3)} \quad \text{Sorghum Yield} = 545.8 + 1.54\,(RJAN) + .61\,(RFEB) - .84\,(RMAR) + 1.95\,(RAPR)$$

To adjust for yields in other districts the following coefficients are used:

Butha-Buthe	$= D_1 =$	+138.58 kg/ha
Leribe	$= D_2 =$	- 38.97 kg/ha
Teyateyaneng	$= D_3 =$	- 39.87 kg/ha
Mafeteng	$= D_5 =$	- 50.44 kg/ha
Mohale's Hoek	$= D_6 =$	+279.14 kg/ha
Quthing	$= D_7 =$	+ 63.30 kg/ha

To adjust for yields in the post-1976 period, one adds 521.70 kg/ha to the figures derived by the above.

Equation 3 models the existing sorghum yield data relatively well as shown by the following statistical measures:

$$R^2 = .89$$
$$F = 19.2$$
$$S.E._{\hat{y}} = 118.60$$

Unfortunately one negative coefficient appears and cannot be legitimately removed. Consequently for estimating other than the present data set, Equation 4 below is preferable.

(Eq. #4) Sorghum Yield = 658.68 + .36 (6 mo. total rain)

To estimate other districts add:

Butha Buthe	+ 66.02 kg/ha
Leribe	- 108.04 kg/ha
Teyateyaneng	- 37.71 kg/ha
Mafeteng	- 138.05 kg/ha
Mohale's Hoek	+ 196.06 kg/ha
Quthing	- 40.79 kg/ha

To estimate post-1976 yields add 484.31 kg/ha.

Equation 4 also provides reasonably precise estimations of sorghum yields.

$$R^2 = .83$$
$$F = 17.2$$
$$S.E._{\hat{y}} = 141.64$$

Analysis

The interested reader is invited to duplicate, using the sorghum equations, whichever tables in Part I might be of interest. Similar conclusions will be obtained concerning the accuracy of the data.

A Last Look at 1949/50

One significant difference appears when examining Douglas and Tennant's sorghum data. Equation 4 estimates the results of the 1949/50 survey very closely, giving a weighted average lowland district yield of 873 kg/ha compared to the published 870 kg/ha. The near identity of these two figures has two significant implications. First it suggests that Douglas and Tennant's overestimations are confined to maize. *This observation lends strong support to the hypothesis offerred earlier that the 1949/50 maize data are in error due to weighing wet and possibly unhusked ears during a period of high humidity and excessive rain.* Simultaneously one must question Morojele's criticisms which focussed on possible sources of bias in the area and field selection process. If enumerators had, in fact, selected the

more productive areas, their bias would presumably have affected all crops sampled, rather than simply maize.

Our ability to accurately re-estimate 1949/50 sorghum figures also strengthens the earlier conclusion that there has been no technological change in cereals cropping. With the sorghum figures this conclusion can be said to embrace a thirty-year time span.

Equations 2 and 4 permit a comparison of the sensitivity of maize and sorghum to rainfall variations under Basotho farming conditions. The two crops have regression coefficients of 1.27 and 0.36 respectively with respect to six-month rainfall totals. Both coefficients are significant at the 95 percent confidence limit. Numerically they represent the change in yield (in kg/ha) associated with each change of one millimeter in six-month rainfall totals. Maize is obviously more responsive than sorghum however this fact is a two-edged sword. In periods of good rain the farmer should experience a larger increase in production with maize. The reverse is also true. Below normal rainfall will depress maize yields more than sorghum. Consequently this analysis substantiates, from Lesotho's official yield data, the widely held belief that sorghum is a more drought resistent crop.[1]

Finally, the differing responses to environment measured above for the two crops suggest a difference in comparative advantage between the lowland districts. Inherent yield differences based on soils and other factors (except rain) are shown by the coefficients for each of the D_i variables representing districts. These may be interpreted to show relative rankings in productive potential per hectare for the lowland districts as follows:

	Relative Ranking (Production/hectare)	
	Maize	Sorghum
Butha Buthe	1	2
Leribe	2	5
Teyateyaneng	4	6
Maseru	3	4
Mafeteng	7	7
Mohale's Hoek	5	1
Quthing	6	3

(from comparison of Equations 1 and 3)

Simple application of the principle of comparative advantage would suggest that the northern lowlands, especially Butha Buthe and Leribe districts should specialize in maize production. Conversely Mohale's Hoek and Quthing districts should concentrate on sorghum. If such a strategy of specialization were to be followed, it would necessitate trade between the two regions if the nation as a whole is to benefit from the higher output possible throughout comparative advantage.

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[1] It should be emphasized that conclusions from this analysis apply only to the type of farming environment and the range of precipitation in which the raw data were measured.

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APPENDIX A

Methodological Questions Concerning Survey Changes Made in 1976

Due to an apparently large change in reported crop yields that occurred in 1976/77 and subsequent years, many individuals have questioned the methodological changes made in that year. Their hypothesis has usually been that the changes introduced in 1976 resulted in bias in the statistics since that time. Due to the many questions raised, the Bureau of Statistics has repeatedly examined their methodology. The Lesotho Agricultural Sector Analysis Project assisted with additional analyses and FAO/Rome dispatched an agricultural statistician, Mr. Stefinovic, for an indepth evaluation. Listed below are most of the questions which have been recently raised and the conclusions of the examination which followed.

1. The annual agricultural survey shifted from British to metric measurement units in 1976. The probability was raised that adjustment and expansion factors were not completely modified to reflect this change. Detailed examination has shown that this was not the case and that, in fact, all necessary adjustments in tabulation methods to accommodate metric units had been made satisfactorily. In addition, a physical check of field equipment showed that this too had been uniformly converted to the metric system.

2. The plot size for crop cutting measurements was reduced and the hypothesis has been advanced that this resulted in a statistical phenomenon known as border bias which would have increased measured yields. Mr. Stefinovic, who is familiar with a great deal of the literature concerning crop cutting techniques and has performed experiments himself on this subject, was able to demonstrate adequately that plot sizes presently in use do not experience a sufficient border bias to affect estimated yields significantly. This factor arises only when plot sizes much smaller than those used in Lesotho are employed.

3. Beginning with 1976, areas planted to crops around the house, known locally as "farmstead plots", were added to the total area sampled. Two hypothesis have been advanced by critics of the Lesotho data. The first asserts that the inclusion of farmstead plots would have significantly inflated total acreage. The second suggests that since these plots are closer to the household they would receive better care and attention, produce higher yields and consequently inflate average yields if included in the total. The LASA Project has carefully examined the 1976/77 data and separated out all farmstead plots in order to determine their true effect on national totals. In most cases

(except peas) farmstead plots contributed 2 percent or less of the measured acreages in the survey. Consequently it is not possible for these plots to have had a significant effect on average yield figures. The single exception is the case of peas in which some 12 percent of the measured acreage was composed of farmstead plots.

4. The sampling method was modified in 1976 to include a proportional stratification of households among ecological zones as well as administrative districts. Simultaneously a departure from previous methods occurred in that a new sample of farmers was drawn for 1976/77 and for each subsequent year. Previous surveys had used a sub-sample of the population surveyed during the 1970 Census of Agriculture. It has been suggested that one or both of these changes also contributed a significant departure from previous estimates. Mr. Stefinovic's report clearly shows that none of the methodological changes made in 1976 could have contributed more than a 5 percent change in yield estimates. He further shows that some of these changes, by operating in different directions, would have offset each other. He demonstrates that the revisions in sampling procedures in all probability would have contributed to greater precision in the estimates, reducing standard errors of the estimates but not contributing bias. In his presentation of his report to the Government, Mr. Stefinovic also asserted that while Lesotho's statistical methods could be gradually improved they were, at present, sufficiently accurate for a country at Lesotho's stage of development.

The ultimate conclusion of this coordinated examination of the agricultural statistics methodologies was that data before and after 1976 can be considered consistent with each other, that there was probably an improvement in precision in 1976, and that the cumulative total effect of all changes made in 1976 could not result in more than a 5 percent difference. The analyst is thus left with the conclusion that the yield levels measured before and after 1976, which differ from each other by a factor of 50 percent, are real differences and that the statistics reflect actual changes occurring in Lesotho's agricultural sector.

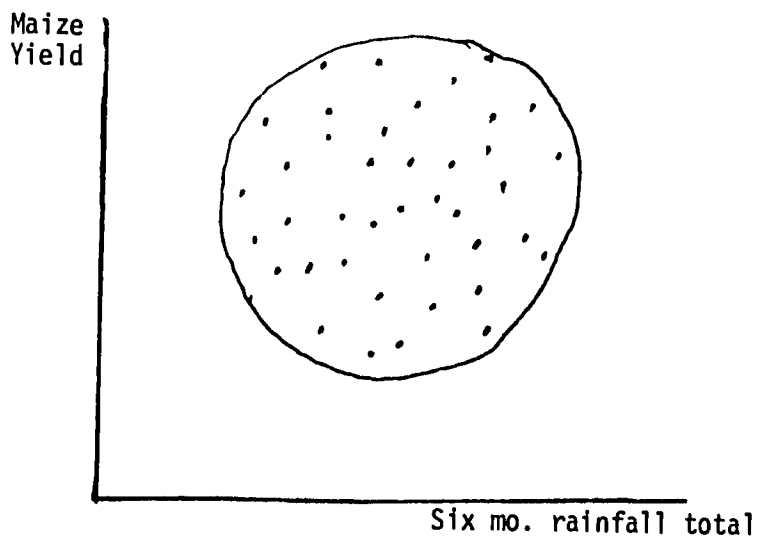
APPENDIX B

A Layman's Explanation of The Use of "Dummy Variables"

Dummy variables are a statistical technique for use when two or more sets of data are combined in an estimation procedure and when there is reason to believe that the two sets of data share a common relationship even though they may each be influenced by additional exogenous factors. The explanation is perhaps easiest when illustrated as below with Lesotho's crop yield and rainfall data.

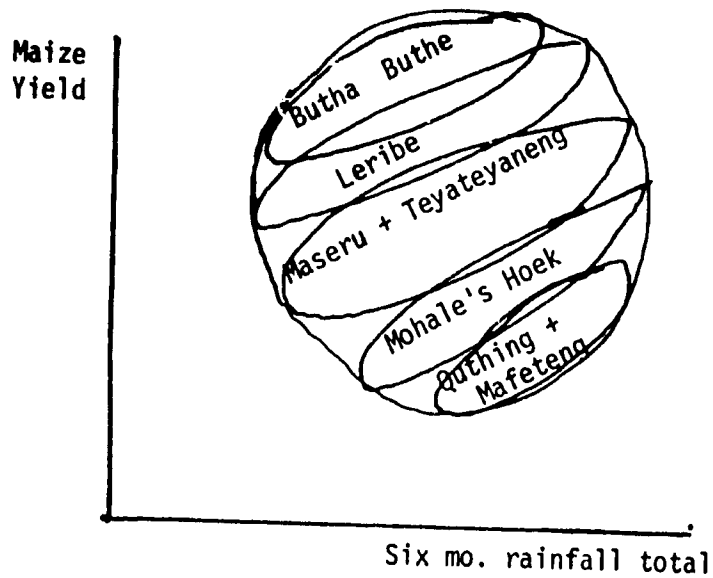
If one takes a set of data composed of paired observations of maize yield and six month total rain for each district and year one would obtain a scatter diagram similar to Figure B-1. With only this to look at one must conclude there is no relationship between rainfall and maize yield.

Figure B-1



However, if one identifies each observation by district, it appears as shown in Figure B-2. The overall scatter is composed of several sub-units which, while there is some overlap, appear relatively distinct.

Figure B-2



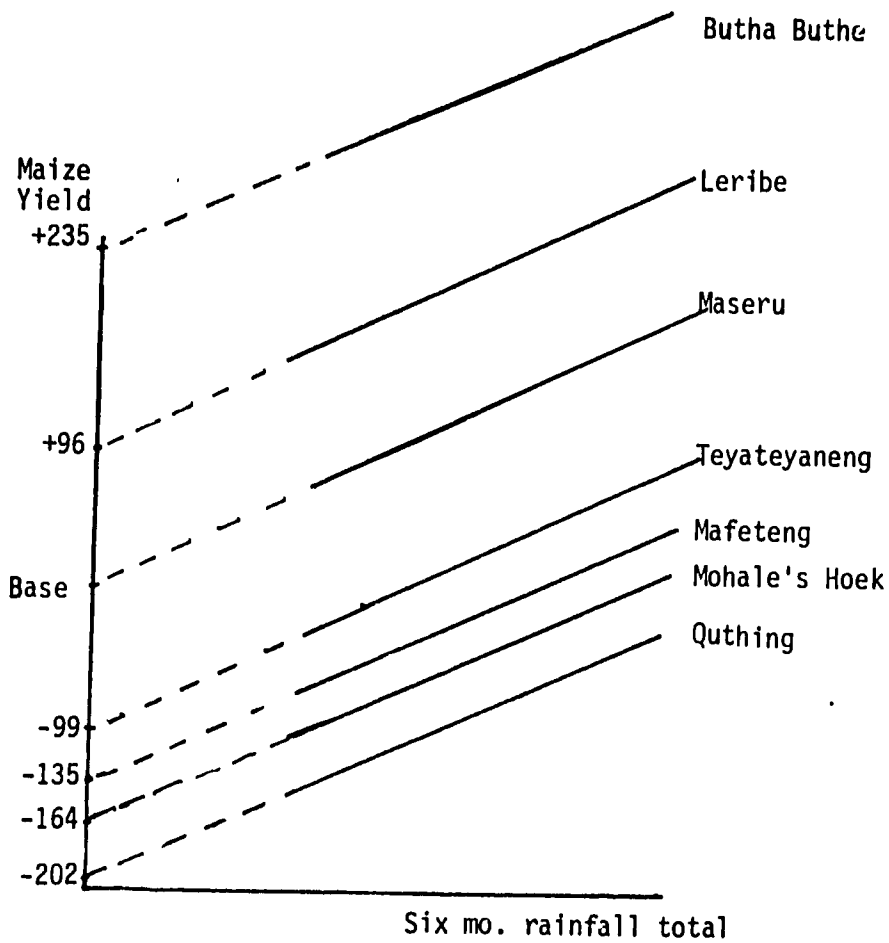
Furthermore, the relationship between rainfall and yield (the slope of the plot) appears to be relatively constant between districts with the principal difference being that the relationships occur at different yield levels. This is precisely the case for use of dummy variables. The dummy variable captures the vertical difference between groups yet permits all data in the combined sample to be used in estimating the basic relationship, which in this case is the relationship between rainfall and yields. One must be able to defend the assumption that basic relationship is the same among all groups, because the estimation procedure forces it to be constant.

In utilizing dummy variables (D_i) it is necessary to choose a base period or district because the D_i will then give deviations above or below the base. In the foregoing analysis Maseru was used as a base because of its central location among North to South climatic gradients known to exist in Lesotho. The result was a single rainfall coefficient, e.g. in the equation:

$$\text{Maize Yield} = 129.0 + 1.27\ (\text{6 Mo. Rain})$$

This slope (1.27 kg/mm) applies to all districts since it was estimated from the entire set of data. The D_i then give the amounts of vertical displacement from the Maseru base. Graphically the result is shown in Figure B-3.

Figure B-3



While the technique may seem complicated, the data suggested it automatically once they were graphed. And given the importance of these inter-district differences it is doubtful if the underlying relationship could have been determined without this type of statistical separation. Certainly several previous attempts by this author and many others have been unsuccessful.