HUMAN ADJUSTMENT TO AGRICULTURAL DROUGHT IN TANZANIA: PILOT INVESTIGATIONS

by

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PREFACE

This paper is one in a series on research in progress in the field of human adjustments to natural hazards. It is intended that these papers will be used as working documents by the group of scholars directly involved in hazard research as well as inform a larger circle of interested persons. The series is now being supported mainly from funds granted by the U.S. National Science Foundation to the University of Colorado, Clark University and the University of Toronto.

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TABLE OF CONTENTS

Introduction

For those who live with the land in East Africa, time is punctuated by the crop cycle and the rains that accompany the shifting zenith of the sun. In some years and in some places, in ways we do not fully understand, the rains lag behind this seasonal shift or seemingly fail altogether. In such years the crop cycle is broken and drought ensues. Men and nations suffer setbacks to their modest hopes for improved life and livelihood and even, more rarely, the death and desolation of famine.

This publication presents reports on a number of pilot investigations into the problem of drought in Tanzania. Burton, Kates and White have developed a research approach which, for any natural hazard, seeks to 1) assess the extent of human occupance of hazard zones, 2) identify the full range of possible human adjustment to the hazard, 3) study how men perceive and estimate the occurrence of the hazard, 4) describe the process of adoption of damage-reducing adjustments to the hazard, and 5) to estimate the optimal set of adjustments in relation to the economic and social setting.[1]

To assess the extent of human occupance by hazard zones, we present a report on the contrasting magnitude, intensity and frequency of drought and famine in the Eastern and Central regions of Tanzania over the last 45 years. To attempt to identify the full range of human adjustment to the drought hazard we undertook extensive interviews with Tanzanian farmers, a search of the available technical literature, and consultation with agricultural experts in East Africa. As a contribution to the study of how men perceive the occurrence of hazard and adopt damage-reducing adjustments we present the results of interviews with 219 farmers in 11 areas of Sukumaland, covering the entire range of crop hazards with 460 farmers at 21 sites in Eastern and Central Tanzania dealing specifically with

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[1] Ian Burton, Robert W. Kates and Gilbert F. White, "The Human Ecology of Extreme Geophysical Events," Natural Hazard Research Working Paper No. 1. Toronto: Department of Geography, University of Toronto, 1968.

drought.

Finally, as a basis for choosing some optimal set of adjustments we suggest a theoretical model that might be used to evaluate the impact of specific adjustments in the context of East African smallholder agriculture. Such models require improved climatological data and we conclude with a sample computer program for the analysis of moisture stress.

The work reported on herein reflects the efforts of many. The analysis of drought and famine frequency was prepared by Len Berry and Robert Kates assisted by Messrs. Chiwanga, Choka, Daraja, Gandawega, Juma, Kajula, Kifua, Kilyingo, Lukuta, Magwene, Mapunda, Mfwangavo, Mlagulwa, Mlay, Msungu, Mussa, Omari, Sabaya and Tem. Adolpho Mascarenhas provided useful advice and in earlier work the methodological basis for the historical study of famine. Berry and Kates were also responsible for the sections on drought adjustment and the drought perception field studies. Tom Hankins carried out the Sukumaland investigation with the help of James R. Finucane, Robert H. Hulls, Arne Larsen and Messrs. Augustine Mashishi, Mipawa, Masesa, Madaha, Masija, Luhaga, Manyanda, Limihigatia, Busongo, Idama and Nkwabi. The model of drought is by Berry and Kates, drawing heavily on notes prepared by Philip Porter and Leslie W. Maki, who also prepared the computer program for moisture stress.

Thus these pilot studies are truly a cooperative effort involving the collective efforts of the staff of the Bureau of Resource Assessment and Land Use Planning, Department of Geography and the Interdisciplinary Rural Research Project, of the University of Dar es Salaam, the Graduate School of Geography of Clark University (with support from the National Science Foundation) and the Department of Geography of the University of Minnesota. Dissemination of these studies is a joint undertaking appearing simultaneously as Natural Hazard Research Working Paper No. 19 (issued at the University of Toronto) and Bureau of Resource Assessment and Land Use Planning, University of Dar es Salaam, Research Paper No. 13.

This cooperative effort is continuing and these studies serve as a pilot for a comprehensive study of agricultural drought now being undertaken in Tanzania. Related to this study are others, in Australia, Northeastern Brazil and Yucatan, Mexico, reflecting our conviction that drought in East Africa, and indeed the world, is a problem worthy of a major research commitment within an organized framework of relationships as tentatively set forth in our model. It is a difficult problem and dramatic advances in coping with drought are not to be expected. What can be anticipated from the current research is a better measure of the magnitude of the problem in its national setting, a selection of more promising adjustments either for immediate adoption or further development and a strategy for encouraging adoption based on detailed knowledge of farmers' perception and attitudes towards drought. The rains will surely fail again as they have in the past but perhaps the agricultural system and the life and livelihood it provides for may be made less vulnerable to the disruptive impacts of such failure.

The Magnitude and Frequency of Drought and Famine in Eastern and Central Tanzania

Drought in Tanzania, as everywhere, is a joint product of man and nature, related both to the variability of climate and man's degree of adjustment to such variation. Thus a certain level of soil moisture might wither a hybrid maize crop but have little effect on drought-resistant millet or cassava. The burden of drought is two-fold: first, the actual losses of plant and animal production: second, the efforts expended to anticipate drought and to prevent, reduce or replace such losses.

For a general assessment of drought in Tanzania, we have to rely on more general descriptions of drought occurrence. The most widespread effect of drought is in food shortages which are well reported in various records though not all such shortages may be caused by shortages of moisture. Shortfalls in moisture for plant growth can be expressed as negative deviations form the mean of rainfall, stream flow, or soil moisture content or by other appropriate climatological and edaphic indices; these taken together with crop production data and food shortage information provide indications of the causal factors involved.

In this study which spans the years 1923-1969 data on food shortages for early years were obtained from a study of the district books for the area concerned, while in the last decade of the period newspaper reports were used. The nature of these data meant that information was collected on the results of abnormal conditions, though some views on the causes were usually given. Our data and also that of Brooke[2] and Mascarenhas[3] show there was a range of causes involved, though drought was a major factor.

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[2]C. Brooke, "The Heritage of Famine in Central Tanzania," Tanzania Notes and Records, No. 67 (1967), pp. 15-22: "Types of Food Shortage in Tanzania," Geographical Review, Vol. 57 (1967), pp. 333-357.

[3]A. Mascarenhas, "Aspects of Food Shortages in Tanganyika (1925-45)," Geography Department, University College, Dar es Salaam, Research Paper 6643, 1966 (mimeo).

The area studied covered the Central, Eastern and Tanga Provinces of the Early British Administration (Figure 1), covering a wide range of climatic conditions. Each of the regions itself contains a range of climate, though the Central Province is generally the driest with annual means 20" - 30"; the Eastern Province has a wider range with parts of the Ulugurus receiving over 100" per annum and other areas less than 30". Tanga likewise has a range from the moist Usambaras (40" - 50") to the semi-arid Pangani and Handeni districts (25" - 30").

The data were collected by districts and the literature was combed for references to crops and conditions generally. Rather than attempt to pick out only those years which showed abnormal conditions, each year in each district of the three provinces was classed when information was available, on a seven point scale (Table 1) and these were combined into a general assessment for the province. In many cases the same sources indicated the perceived cause of the food shortage or famine and these were coded as in Table 2.

TABLE 1

RATING SCALE FOR FOOD AVAILABILITY BY DISTRICT, CENTRAL, TANGA, EASTERN PROVINCES

1. Severe Famine, Loss of Animals and Loss of Life
2. Famine with Distress and Loss of Life
3. Appreciable Shortage Requiring Food Imports
4. Local Shortage or for Limited Periods
5. No Shortages Reported, an Average Year
6. Satisfactory Food Availability
7. Ample Food Availability

TABLE 2

CAUSE OF FOOD SHORTAGE OR FAMINE

1.	Game Animals	6.	Lateness of Rains
2.	Locusts	7.	Overall Drought
3.	Other Insects	8.	Floods
4.	Birds	9.	Unseasonal Rains
5.	Failure of Rains, not Specific	10.	Heavy Rains
		11.	Disease

The extent of food shortage or deficiency is summarized by province in Table 3 and shown graphically in Figure 2.

TABLE 3

FOOD AVAILABILITY BY PROVINCE AND RATING SCALE FOR VARIOUS YEARS

Rating Scale	Central 1923-69		Eastern 1926-69		Tanga 1930-69	
	No. of Years	% of Years	No. of Years	% of Years	No. of Years	% of Years
1. Severe Famine	3	6.4	-	-	-	-
2. Famine	3	6.4	-	-	-	-
3. Shortage	8	17.0	2	4.5	-	-
4. Local Shortage	8	17.0	15	34.0	12	30.0
5. No Shortage	12	25.6	11	25.0	16	40.0
6. Satisfactory	10	21.2	9	20.4	8	20.0
7. Ample	3	6.4	7	15.9	4	10.0
Total	47	100.0	44	99.8	40	100.0

In Central Province nearly 50% of all years had conditions substantially below "normal;" i.e., they rated 4 or less on our scale and 13% of years fell into the famine category. Food shortages are obviously no stranger to this area. Droughts and famine in the central areas of Tanzania are an important part of the oral history of the Gogo. Rigby in his recent book[4] lists the names of most famines during this period. Brooke has produced a similar (though not identical) record.[5] Our survey agrees generally with these more direct studies though our study tends to undervalue the severity of some famines.

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[4]Peter Rigby, Cattle and Kinship Among the Gogo. Ithaca: Cornell University Press, 1969, p. 21.

[5]Brooke, *op. cit*.

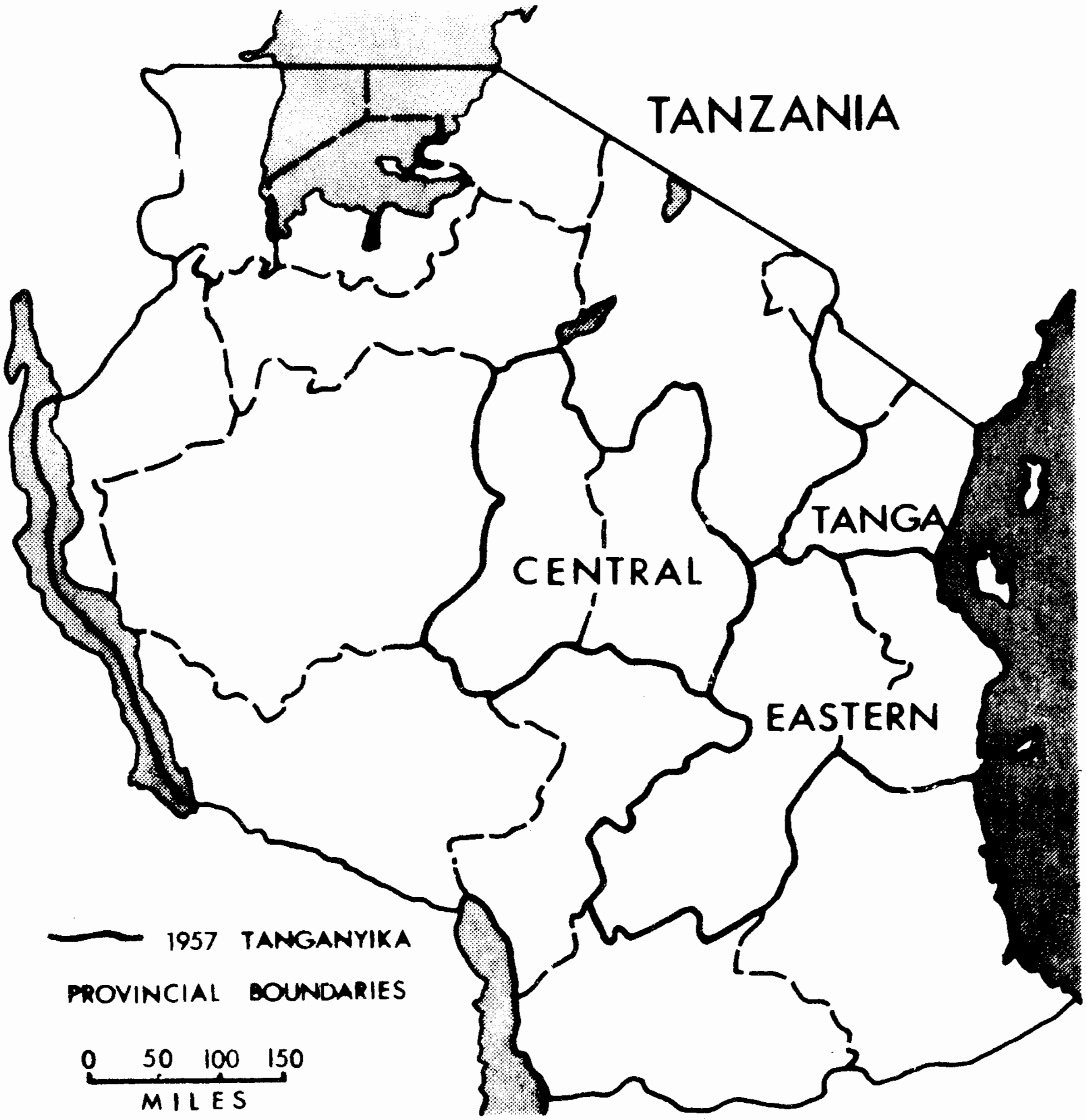
TANZANIA
TANGA
CENTRAL
EASTERN
1957 TANGANYIKA
PROVINCIAL BOUNDARIES
0 50 100 150
MILES

FIGURE 1

Most severe years tend to be separated in time by a series of moderate or even good years. The run of relatively good rains in the 60's had, for example, led farmers to move away from the traditional millet to the less drought-resistant maize, and in 1968 Dodoma region was the major maize producer in Tanzania - to be followed by the 1969 drought in which almost no maize was produced in the region. Government crop priorities which had maize as a high priority were revised then to upgrade millet but in the current rains (1970) massive maize planting is again in progress.

In Tanga Region, there is a greater variety of conditions but hazards are seldom serious enough to provide a province-wide emergency. Seventy-five percent of all years rate as good or satisfactory to the local agricultural administrators of to the press. However, Hadeni district, where data are available, suggests a pattern more like that of Eastern Province or even Central Province and crop and livestock problems are the most pressing in Tanga Region. No very serious region-wide famines seem to have occurred though Handeni has suffered periodic food shortages.

Eastern Province covers a range of conditions and shows composite characteristics somewhat between those of Tanga and Central. Significant food shortages do occur and nearly 40% of years are classed as having problems of a region-wide significance. According to the record very major famines do not occur. However, the Provincial area rates a higher percentage of good or very good agricultural years than the other areas, 36% being so classed.

Eleven causes of poor agricultural conditions and food shortages were mentioned more than once in the literature searched (Table 4). Frost (in Lushoto) and unwise early sales of maize in Handeni were also mentioned. Mascarenhas, in some notes on food shortages,[6] points out the importance of unwise post-harvest

[6] Mascarenhas, op. cit.

sales on later food shortages; this being an important factor particularly in the German period. Food was often sold to soldiers and migrant labor with the result that later in the season local supplies were found to be insufficient. The practice of migrant labor buying up local grains and other foodstuffs must have continued into the period under discussion.

TABLE 4

MAJOR CAUSES OF FOOD SHORTAGE BY PROVINCE OR DISTRICT FOR VARIOUS YEARS

Major Cause	PROVINCE					
	Central		Eastern		Tanga	
	No. of Years	% of Years	No. of Years	% of Years	No. of Years	% of Years
Wild Life	12	17.4	11	19.3	4	7.3
1. Animals	1		1		1	
2. Locusts	5		10		3	
3. Other Insects	2		0		0	
4. Birds	4		0		0	
Insufficient Moisture	48	69.6	30	53.6	40	70.3
5. Rain Failure	21		18		22	
6. Late Rains	2		2		0	
7. Overall Drought	25		10		18	
Excess Moisture	7	10.1	15	26.3	5	9.1
8. Floods	3		9		3	
9. Unseasonal Rain	2		4		2	
10. Heavy Rains	2		2		0	
Disease	2	2.9	1	1.8	4	7.3
11. Disease	2		1		4	
Others	0	0.0	0	0.0	2	3.6
12. Others						
Total	69	100.0	57	101.0	55	100.3

In our coding of stated causes three headings dealt with insufficient moisture and in each province this group made up a high percentage of the total. In Central and Tanga Provinces over 70% of causes mentioned were related to those categories, though in Eastern Province it was significantly different with Locusts (18%) and Floods (16%) being other important causes. Most of the floods were in Rufiji district where this hazard is a recurring phenomenon.

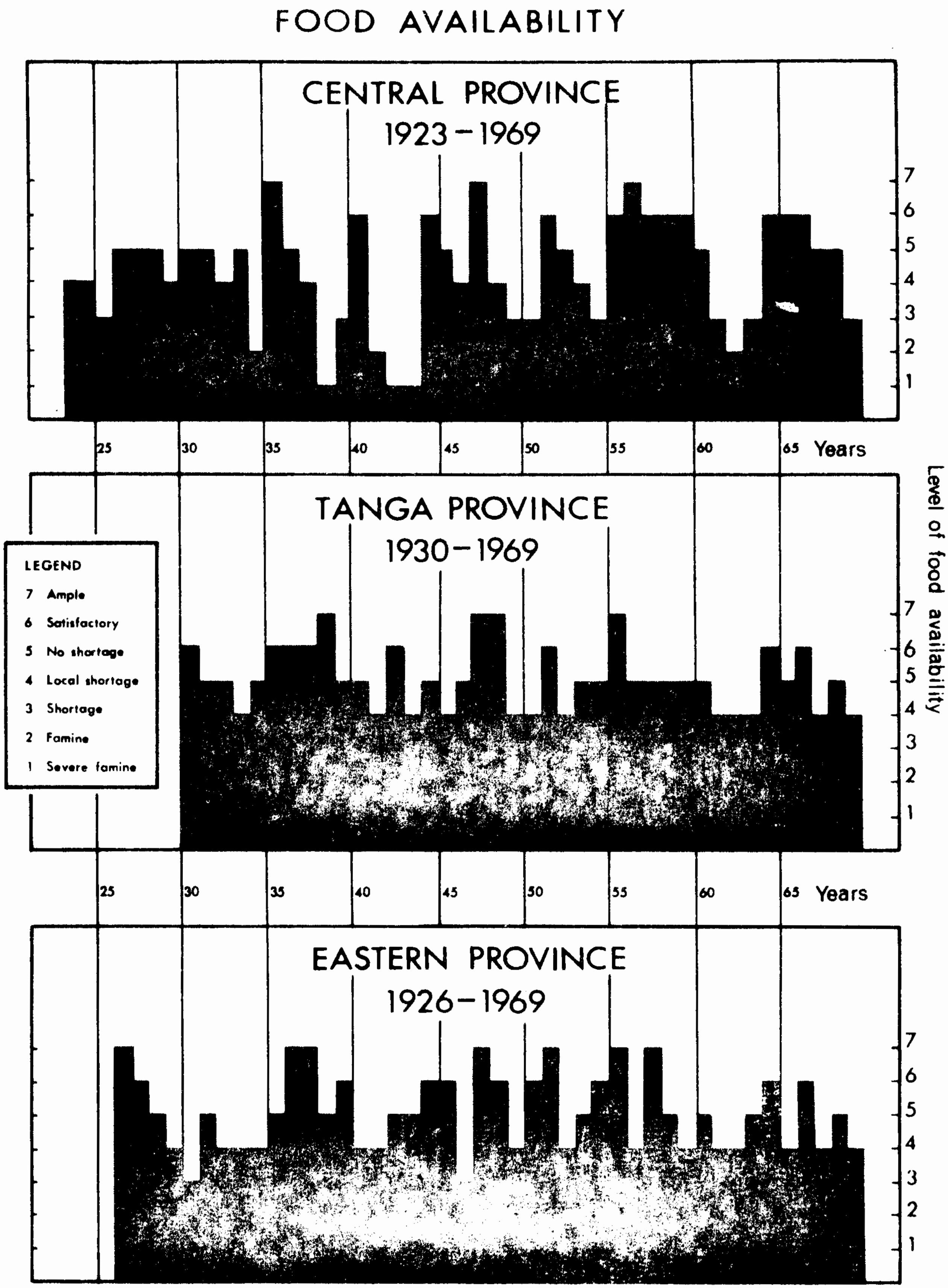
FOOD AVAILABILITY
CENTRAL PROVINCE
1923 – 1969
TANGA PROVINCE
1930 – 1969
EASTERN PROVINCE
1926 – 1969
25 30 35 40 45 50 55 60 65 Years
1 2 3 4 5 6 7
Level of food availability
LEGEND
7 Ample
6 Satisfactory
5 No shortage
4 Local shortage
3 Shortage
2 Famine
1 Severe famine

FIGURE 2

Locusts were also an important contributary cause in Central and Tanga region, and birds rate as a hazard in Central Province where the Sudan Dioch is a particular menace. Disease has been a factor of some note in Tanga Province.

With insufficient moisture the major stated cause of food shortage, it seemed worthwhile to attempt an analysis of the available rainfall statistics on a monthly basis for two long term stations in each of the provinces. A scale of rainfall was drawn up on a seven point scale similar to that used for food availability based on percentage of a particular year's rainfall total of the 30 year mean (see Table 5). These annual scaled rainfall totals were rank-correlated with the scaled food availability statistics and are shown in Table 6.

TABLE 5

RATING SCALE OF MOISTURE AVAILABILITY
AS PERCENT OF AVERAGE ANNUAL MONTHLY RAINFALL

1. 12.5 - 37.5
2. 37.5 - 62.5
3. 62.5 - 87.5
4. 87.5 - 112.5
5. 112.5 - 137.5
6. 137.5 - 162.5
7. Over 162.5

TABLE 6

CORRELATIONS BETWEEN RAINFALL AND
FOOD AVAILABILITY

Province	Station	Correlation Coefficient
Central	Manyoni (1923-69)	.39
	Dodoma Met. (1923-69)	.30
	Dodoma Reservoir (1931-69)	-.28
Eastern	Morogoro (1923-69)	.25
	Dar es Salaam (1923-69)	.03
Tanga	Lushoto (1923-69)	.50

Only the Manyoni and Lushoto stations show a statistically significant correlation ($P \leq .05$) between food availability and rainfall, suggesting the complexity of relating food shortage directly to drought and the need for more precise data.

With this latter task in mind Len Berry and Ian Jackson have in Dar es Salaam attempted to produce a linked environmental and economic evaluation of the 1969 drought in Tanzania. Monthly rainfall data through 1968-69 show a clear build up of drought conditions and will provide a specific analysis of the real spread and intensity both of the meteorological conditions and of some of their consequences.

In summary, a preliminary analysis of food shortages and famines in Tanzania has yielded some information on the relative proportions, frequency and magnitude of climatic and other hazards in the area, but more detailed studies of both environmental and economic aspects are needed.

The Range of Adjustment to Agricultural Drought Hazard

In areas of persistent and recurrent drought hazard, subtle and varied modes of accomodation have been evolved to enable man to survive. To these artful and efficacious adjustments, ceremonial appeals to the supernatural are commonly added. The efficaciousness of rainmaking might be questioned, but not its importance. It is widely practiced in East Africa and may play an important role in helping men to cope with the great uncertainties of semi-arid tropical agriculture.[7]

In addition to these adjustments that have evolved over time through the agricultural system, there are more recent opportunities for adjustment made possible by technology, improved transportation, and the more elaborate social organization of the nation-state. The complete range of drought adjustments might be classified as variants of four general approaches of human adjustment to any natural hazard: adjustments that affect the basic cause of the hazard; adjustments that modify the hazard; adjustments that modify the loss potential of man and his works; and adjustments that deal with recurrent losses by simply suffering them, planning and providing for them, or sharing them with others.

In terms of drought, we may seek to affect its cause by altering the pattern of precipitation. Presently this is done in East Africa in two ways. There has been a limited amount of experimentation with weather modification, mostly centered on reducing hail damage[8] rather than increasing precipitation per se. And recourse to rainmaking and prayer as a means of influencing the occurrence of rain is widespread.

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[7]Rainmaking also played an extremely significant role in tribal leadership and coalescence; see A. Roberts, ed., Tanzania Before 1900. Nairobi: East African Publishing House, 1968, especially the chapters on the Shambaa by Feierman and the Pare by Kimambo.

[8]See reports by H.W. Sanson: "Research on Hail Suppression in East Africa," Proceedings of the Third Specialist Meeting on Applied Meteorology, Muguga, Nov. 25th & 26th, 1965 (mimeo), "A Report on Hail Suppression Problems in Kenya," Proceedings of the Fourth Specialist Meeting on Applied Meteorology, Nairobi, Nov. 26th, 1968 (mimeo).

A variety of adjustments is available to better utilize the existing rainfall and in so doing modify the hazard by increasing the effective rainfall. A farmer can either seek land with a high mositure storage capacity or match his available land to crops with compatible moisture needs and tolerances. Varying cultivation practices can also increase effective rainfall. Tie-ridging may prove very effective in increasing yields under marginal rainfall conditions and certain soil types.[9] Weeding and spacing may be used to diminish competition by plants for scarce water. Irrigation will directly increase the available moisture.

Farmers can plant dry before the rains or early enough to minimize the likelihood of moisture stress during critical stages of the growth cycle. Forecasts of the onset of the rains would help in the choice of planting times. Gichuiya's work at University College Nairobi suggests the possibility of developing a forecast of a week's warning for the onset of rains within 100 miles of a radiosonde station.[10] And there are indications that some culture groups and particularly the "diviners" within these groups may have considerable short-term forecasting ability. Without specific forecasts, optimum planting dates based on long-term average experience may prove helpful. Optimum planting dates, whether suggested by agricultural officers or traditional lore, are often rigidly specific in theory and widely disregarded in practice. Indeed in the face of the uncertainty of forecasting the patterns of rains and the inconvenience of a rapid planting schedule, the most frequently adopted adjustment is that of staggered planting. A first planting may fail because of poor short rains and replanting is done to take advantage of the expected long rains.

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[9]M. Dagg and J.C. MaCartney, "The Agronomic Efficiency of the N.I.A.E. Mechanized Tied Ridge System of Cultivation," Experimental Agriculture, Vol. 4 (1968), pp. 279-294.

[10]S. Gichuiya, "An Investigation into the Onset of the Rains," Proceedings of the Fourth Specialist Meeting on Applied Meteorology, Nairobi, Nov. 26th, 1968 (mimeo).

As we can modify the hazard by increasing the effectiveness of water use, so a farmer can modify his loss potential by reducing the vulnerability of his crops to moisture stress. Changing crops and varieties of crops can reduce their moisture requirements. Or he can shift the locus of his family activity or cattle grazing and concentrate his efforts in an area not affected by the drought. Such an adjustment is often practicable, especially in areas with steep environmental gradients (adjacent plains and mountains) where many farmers have access to both types of land.[11] It is also common in drier areas where rainfall may be irregularly distributed in any one year. Rigby reports that Gogo kin groups move several times over considerable distances (30-40 miles) during one lifetime in response to micro-spatial climatic variation.[12] There is evidence that migration was often undertaken in the historical past.[13] Finally, a major form of modifying one's loss potential is the systematic adjustment of dietary needs to the available food supply, Current research suggests long-term adaptation in East Africa and elsewhere to reduced caloric intake.[14]

A farmer can suffer his losses, either in figurative silence, through doing nothing, or by seeking alternative employment for his labor. He can also plan ahead for future losses by storing food, saving money, or investing in cattle. Finally, he may share his losses with his extended family or by partaking of charitable or government relief.

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[11] See P.W. Porter, "Environmental Potentials and Economic Opportunities - A background for Cultural Adaptation," American Anthropologist, Vol. 67 (1965), pp. 409-420 (description of Pokot holdings in West-Central Kenya).

[12] Rigby, op. cit.

[13] Roberts, op. cit.

[14] M.C. Latham, "A Clinical Nutrition Survey of Part of the Rufiji District," East African Medical Journal, No. 40 (1963): J. Kreysler and C. Schlage, "The Nutrition Situation in the Pangani-Basin in Northeast Tanzania," in H. Kraut and H.D. Cremer, eds., Investigations into Health and Nutrition in East Africa. Munich: Welt Forum Verlag, 1969.

As individual farmers adjust to drought, so do various collectivities: families, clans, villages. government at every level. The extended family system, the exchange and dispersal of cattle and food, all serve to buffer drought effects. Organized relief and storage are governmental equivalents of the traditional buffers. The drilling of wells to provide auxiliary cattle and drinking water is widely practiced, in part to make accessible more varied grazing (although occasionally with negative effect). Emphasis on pastoral activity and drought-resistant grains are other common governmental responses.

All of the foregoing adjustments are theoretically possible. Some are practical but in little use, while others are widely adopted. (They are summarized with the degree of adoption in Table 7.) But as one might anticipate it is in the truly marginal areas for agriculture that the adoption of the widest range of adjustments comes into play. Porter describes such agriculture in the Kitui district of Kenya:

> Fields are deployed great distances from one another, over 10 miles sometimes. A multitude of crops, many of them quick-maturing, hardy and drought resistant, are sown in what appears to have been a fit of temporary insanity. Seeds are all thrown together and worked into large dryland clearings that are virtually unmappable. Here is a list of crops from one field: maize, beans, cow peas, groundnuts, red millet, sorghum, castor, bulrush millet, cassava, pumpkins, calabashes, and pigeon peas. Six kinds of millet are grown here.
>
> Care is taken to plant before or with the rains; indeed the second planting is done in amongst standing unharvested crops from the grass rains. This second crop is usually a forlorn hope. Early weeding is done; timing is most important.
>
> The great number of crops, mixed sowing, placement of fields far apart -- all are attempts to reduce the risk the individual takes.[15]

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[15] Porter, op. cit., pp. 418-419.

TABLE 7

RANGE OF AGRICULTURAL DROUGHT ADJUSTMENTS IN EAST AFRICA

Type of Adjustment	DEGREE OF ADJUSTMENT		
	Theoretical	Practical In Limited Use	Practical In Wide Use
Affect the Cause:			
Weather Modification.....	*		
Rainmaking, Prayer.......			*
Modify the Hazard:			
Change Plot/Field.......			*
Location..........			*
Change Time of Planting..		*	
Change Cultivation			
Practices...		*	
Irrigation..............		*	
Forecast and Warning.....	*		
Modify the Loss Potential:			
Change Crop, Variety.....			*
Move From Drought Area...			*
Forecast and Warning.....	*		
Adapt to Lower Caloric			
Intake......			*
Adjust to Losses:			
Bear Them:			
Move for Work...........			*
Do Nothing.............			*
Plan for Them:			
Store Food, Save Money..		*	
Buy Cattle.............			*
Spread Them:			
Take Relief, Share......			*

Crop Hazards and Adjustments in Sukumaland

From April to November, 1969, the Interdisciplinary Rural Research Project of University College, Dar es Salaam, carried out four rounds of interviewing at eleven sites in Sukumaland designed to provide basic data on the agricultural activities of smallholder farmers. The sites covered the range of climatological and ecological conditions characteristic of the area in Mwanza Region and Shinyanga district, south of Lake Victoria. Rainfall varies from 23" to 36" annually, and land forms range from flat alluvial deposits to rolling slopes with granite outcrops.

One aspect of the inquiry dealt with crop hazards and adjustments as perceived and reported by the respondent farmers. During the trial round of interviews the 219 farmers were asked questions of the form:

1. Are your crops ever damaged by_________?
2. What crops are most damaged by this?
3. Approximately how frequently are your crops damaged by this?
4. How much damage does this usually cause?
5. Is there anything farmers can do to protect against this damage? If so, what?
6. Do you do this?

Answers to questions 1 to 4 are summarized in Table 8 and described below.

Crop hazards

Birds, insects, wild animals, hail, insufficient rain, excess rain, plant diseases, and wind storms all cause considerable crop damage in Sukumaland according to the estimates of the farmers. Over 40% reported damage from each of these hazards. Damage from theft and by grazing livestock are not considered by the farmers to be as serious. Only some 20% reported damage from those sources.

Very few reported damage from magic, displeased ancestors (masamva), and weeds and parasites. These results may be a function of the interview procedure however. It is possible that the farmers were hesitant to discuss magic and the power of their ancestors with an interviewer whom they did not know well. The

TABLE 8

FREQUENCY AND EXTENT OF CROP HAZARDS REPORTED BY 219 FARMERS, MWANZA AND SHIHYANGA REGIONS

Type of Hazard	Farmers Reporting		Major Crops Damaged	% Reporting Frequency of Annual Damage				% Reporting Usual Extent of Damage		
	No.	%		1.0	.5	.3	<.3	10%	10-50%	50%
Birds	184	84	Sorghum, Rice, Millet	81	10	3	5	35	46	19
Insects	174	80	Cotton, Maize, Sorghum	66	15	6	12	23	63	15
Wild Animals	166	76	Maize, Cotton, Cassava, Sweet potato	82	12	2	2	35	53	10
Hail	146	67	Cotton, Maize	9	20	34	27	19	63	18
Drought	134	61	Maize, Cotton, Rice Sweet potato	3	12	43	42	14	46	40
Excess Rain	129	59	Cotton, Maize, Sorghum	5	14	47	34	17	64	18
Plant Diseases	102	47	Cotton, Maize	79	1	8	11	35	60	4
Wind & Storms	89	41	Maize, Sorghum, Cotton Cassava, Millet	22	26	32	21	62	34	4
Livestock	51	23	Cotton, All food crops, Maize, Sorghum	55	7	2	36	70	23	7
Theft	43	20	Maize, Cotton, Cassava, Rice	57	11	7	21	46	32	21
Weeds & Parasites	6	3	Sorghum, Maize, All crops, Millet	50	16	16	16	33	67	0
Magic	16	7	All crops	10	30	10	20	0	78	22
Displeasure of Ancestors	2	1		Not Calculated				Not Calculated		

problem of weeds and parasites was not asked directly; rather the replies listed here were responses to the inquiry of whether or not there were other problems that damaged the farmer's crops. Had this been asked directly undoubtedly more farmers would have reported this as a problem.

As expected, specific crops damaged varied according to the nature of the hazard. Birds caused the most serious damage to the exposed grain crops. Wind and storms damage maize most heavily because of the ease with which it is flattened, while they do not affect low crops such as sweet potatoes or groundnuts. Insects appear to farmers to cause the greatest damage to sorghum, maize, and cotton. Some crops are damaged both by too much rain and by too little rain. This is true of maize because if the field is water logged for any time the crop will die, while the low water holding capacity of many Sukumaland soils leads to rapid wilting of maize during periods without rain. Similarly, cotton has high water requirements during the period of rapid vegetative growth from mid-February to mid-March, but the quality of the crop can be severely damaged by heavy rains after boll burst.

Birds, insects, and wild animals, the three hazards most often mentioned by the farmers as damaging to their crops, are a problem in most years. Over 80% of the farmers reported damage from these three hazards in at least half of the years. At the same time they did not regard damage from these hazards as extremely severe; only 19% estimated that bird damage usually exceeded 50% of the crop affected, and even fewer did so for insects and wild animals.

Hail, excess rain, and drought are hazards regarded by farmers as occurring infrequently but causing serious damage when they do. Fewer than 30% said hail occurred as often as every other year. Fewer than 20% thought that rain or drought damage happened that frequently; the modal expectation for drought being evenly divided between one in three years and greater than three years. For farmers reporting a specific type of damage, drought was most seriously regarded with 86% of the farmers estimating damage in excess of 50% of the crops affected. Hail and excess rain affected crops less severely by farmers' estimates.

About one half of the farmers recognize plant disease to be a factor reducing yields of cotton and maize. Eighty percent of them estimate that it damages their crops every year, and 64% believe this damage causes a loss of over 10% of their crop.

Farmers were not consistent in their estimates of the frequency of wind and storm damage, but well over half of them agreed that such damage usually amounted to less than 10% of their crops. The pattern from theft and livestock damage appears to be frequent, although such damage occurs to but a few farmers.

Hazard adjustments other than drought

The responses to the questionnaire indicate that farmers fail to report a number of simple adjustments to crop hazards. This is, to a large extent, a fault of the method of information gathering. From observations and reports it is clear that additional adjustments to some hazards are practiced. These additional adjustments are included in the following discussion.

Birds. Birds are a problem to which the Sukuma have made two major adjustments. One, the practice of chasing birds from their fields, is an old one. This method is effective provided there is sufficient labor available. Traditionally, this job has been done by children, but as more and more parents have sent their children to school there has been less and less labor available for bird scaring. As an alternative to protecting their crops in this way many farmers have taken to growing maize instead of sorghum or millet because it is less susceptible to damage by birds. Maize, less drought-resistant than sorghum or millet, is now the most commonly grown grain.

Another means of dealing with the bird hazard is frequently used in some rice growing areas. There a sort of scare-crow is erected consisting of strips of cloth flown from poles or from ropes strung between two poles. To date, modern technology appears to have nothing practical to offer the Sukuma farmer to help him deal with the bird problem that he is not doing already.

Insects. Although insects were recognized as a serious problem by 80% of the farmers interviewed only 24% recognized any way to lessen this damage. Effective traditional methods have evidently never been found to deal with this problem, and modern methods including insecticides are not well known. This lack of knowledge of insecticides persists in spite of emphasis by agricultural offices on the use of these materials in recent years.

Similarly, the practices of uprooting and burning and good weeding, which the farmers often do, do not appear to be recognized as important in this context despite the fact that farmers do know that the purpose of uprooting and burning is for insect control. When 186 of the cotton growers in our sample were asked whether or not they thought uprooting and burning to be important and why, 112 (65%) replied that it was because of usefulness in insect control.

The possibility of insect-resistant crop varieties was not recognized by the farmers at all. In the case of cotton, at least, this perception is not important directly to the use of the adjustments since the seeds are regulated and provided by the local cooperative societies. The value of planting cotton early and before maize for insect control is likewise not perceived by the farmers in the interviews.

Wild animals. As with birds, the adjustments made to wild animal damage are primarily traditional ones. The hunting and killing of the animals is practiced by over twice as many farmers as is the scaring away of animals. In spite of these adjustments farmers estimate that their losses remain high. Modern technology again has little to offer to the farmers to help them cope with this problem although in some cases poisons might be effective.

Hail. Hail is a problem to which the farmers suggested no adjustments at all, and probably there is nothing profitable for them to do. Some crop substitution favoring groundnuts and sweet potatoes would be possible, but with the infrequent occurrence of hail and the limited damage which it causes there would likely be little net benefit to the farmers.

Excess rain and plant disease. Adjsutments to excess rain and plant disease problems are discussed in connection with drought and insects.

Wind and storms. Wind and storms offer little opportunity for adjustment. In Sukuma tradition the practice was to stay out of the fields on the day following such an occurrence in order to prevent its happening again. Only one of our farmers suggested that this be done today. Farmers do frequently lift such crops as maize or sorghum back up when blown over, and they may prop them up by hoeing soil around the stalk or by tying the fallen plants to upright ones.

Weeds. The weeding that is done by farmers is probably done because the farmers want to keep the weeds from overcoming the crops. Few farmers recognize the importance of weeds as hosts for insects and diseases or as a competitor for water in the soil. Ridged cultivation provides effective weed control in the early weeks and makes later weeding easier. In areas plowed by oxen or tractor and planted on the flat, weeds are much more of a problem. Fields are not planted in rows which slows down the weeding operation and weeding by oxen or tractor is not practiced.

Drought Hazard adjustment

Drought is a very serious problem in Sukumaland in that it is the major cause of famine, both large and small, in the region. In response to the hazard survey only 4 farmers suggested any means of adjustment to drought, yet farmers regularly practice several adjustments and have traditionally done so.

Only three farmers suggested the use of rainmakers to end drought even though the rainmaker was once a very important factor in Sukuma society. Responsibility for rain in an area rested with the chief, and when in need each chief would employ the best rainmaker available. According to Cory the use of rainmakers was ordinarily supplemented by another form of adjustment that relied on forecasting the rains for the coming season.[16] In that way the chief could tell his people what crops to plant and what soil types to use.

We cannot say with confidence how important the role of the rainmaker is today. It is probable that he has declined in importance along with the chief. The response to the hazard survey and other inquiries that have been made indicate that few farmers rely on them. The survey asked if there were any practitioners around who could predict the rains. Thirty-eight farmers answered in the affirmative. Fifteen of these said that farmers sometimes consulted these practitioners about what crops to plant while the balance suggested that they were not consulted because of either the farmers' lack of faith in them or because their role was to predict or make rains, not to advise on crops.

The practices of adjusting to the drought hazard by soil and crop selection are closely related to one another. The importance of weather prediction in this process has already been mentioned. With increasing rains the higher, lighter soils become more successful, but in drier periods the lower, heavier soils may provide the only harvests of some crops.

In many cases it appears that the Sukuma farmer decides what to plant and where to do it as the season goes on. If the year is dry he will turn to the mbuga (heavy) soils, if he has any, as a place to plant maize or he may substitute sorghum or millet for maize. In years with continuing heavy rains he will plant more and more paddies of rice as the water becomes available (again assuming that he has suitable land). Occasional farmers approach this problem by sowing both rice and maize in their mbuga rice fields. They reckon that if the rainfall is good they will have rice and if not they will have maize.

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[16] H. Cory, The Ntemi. London: McMillan and Co., 1951.

Sukuma farmers appear to make only limited adjustments in their cultivation practices as a result of drought. In response to the question of whether or not a farmer should do his work any differently when the rains are poor than when they are good, 136 out of 204 said that no changes should be made. Fewer still (31) of the remainder suggested actual changes in the form of adjustments. The adjustments suggested included use of drought-resistant or short-term crops, concentration on food crops, weeding, and early and extensive cultivation.

Adjusting to the drought hazard by planting early is much more widely practiced in Sukumaland than the foregoing suggests. Judging by their actions most farmers understand that by planting early they have the best chance of harvesting a crop. If the rains begin early and last long, early planting enables them to plant and harvest more crops than they otherwise could. If the rains should end early, the early-planted crops have the best chance of reaching maturity. Of course, the early-planted crops might fail because of drought, but in this case the farmer is not much worse off than if he had not planted any early crops.

The importance of planting cotton at the proper time has been one of the main pieces of information offered by agricultural officers with early December as the recommended time. The fact that the recommended planting date is the same for all of Sukumaland does not mean that circumstances are considered to be so similar throughout the region that only one recommendation is necessary. In fact, the suggested date is the same in the wet areas as in the drier ones only because of a coincidence of circumstances.

In the South where rainfall is usually lower over the growing season, early December is recommended in order to have peak water demand of the cotton plant coincide with the probable time of peak rainfall. In the wetter areas the rainfall distribution allows more flexibility in planting with respect to the rainfall needs of the plant. Planting could frequently be successful 2 to 4 weeks earlier in these areas. It is not recommended that this be done because the great likelihood of heavy rains at the end of the growing season poses a threat to the quality of the crop.

The government has had only limited success in getting farmers to plant cotton in early December. Of the farmers in our survey only about half of them planted their cotton in December. (Yet in response to the question "Do you usually manage to plant your cotton at the best time?" 74% said that they did.) The farmers do recognize that a delay usually results in poorer quality cotton. Only 16% of the farmers said that a delay of 3-5 weeks in planting cotton after the 'best time' would not have a detrimental effect on yields. Of these a further 12% said that it might or might not depending on the weather.

The primary reason for the failure of most cotton growers to plant in early December is the need to also sow food crops. Few families harvest so much food that they are not running low by the time the rains begin. The food crops thus receive first priority. Twenty-nine percent of our farmers told us that it was more important to plant food crops at the best time because they needed to ease their food shortage by getting food as soon as possible. Over half of the farmers answered this question even more simply. They said that food crops were more improtant because "food is life." Only 14% of the respondents gave cotton priority over food crops at planting time.

Interesting, but not at all conclusive at this point, are the comparisons we have made of farmers' yields of cotton and the dates on which their cotton was planted. So many factors are at work here that it would be surprising if there were a high correlation between the two. We were not surprised, but we did find that a weak positive correlation exists in the overall data, although not at specific sites.

TABLE 9

TIME OF PLANTING IN RELATIONSHIP TO MEAN YIELD FOR COTTON

		Plant in December		
		Yes	No	Total
Yield	Below Mean	36	58	94
	Above Mean	47	41	88
	Total	83	99	182

From this table the tetrechoric correlation coefficient was determined to be approximately +.24, indicating that there is some evidence that those planting at the recommended time did receive higher yields.

The government's efforts at assuring proper planting time are primarily in the interest of achieving larger cotton crops and do not necessarily improve the lot of the farmer. They could even leave him worse off than if he ignored their advice, considering the real problem of food needs in a small holder, agricultural economy.

One new development that may possibly be of assistance to Sukuma farmers in their attempts to adjust to the drought hazard is the unibar set of implements to be used with oxen. This promises to be relatively cheap and to facilitate cultivation, weed control, and to increase the use of tie-ridging (a water conserving practice) since the unibar can do this automatically.

Adjustment to losses

Only brief mention need be made of how the costs of these crop losses are covered because this appears to be handled in the same way for each hazard. There is sharing among families and friends. Nearly half of our respondents said they got help from friends or relatives in other areas when their crops failed. Also, the farmers plan for losses to an extent by storing some food and by investing in cattle, Unfortunately, these measures are not always sufficient to cope with heavy crop losses. When this happens, starvation becomes a serious problem. The government may provide assistance in these cases, but this is frequently poorly administered and may be of little benefit to those in greatest need who cannot afford to buy the grains brought into the area for relief.

Conclusion

The hazards discussed in this paper result in considerable crop losses. In most cases the adjustments practiced by farmers are not particularly effective in reducing damage but as in all agricultural systems the "normal" system itself is in part an adjustment to hazard.

Drought Perception and Adjustment Among Tanzanian Farmers

To seek to understand the human ecology of agricultural drought is to seek first to understand the perceptions, attitudes and actions of the farmers themselves. In all, 460 Tanzanian farmers have been interviewed concerning their perception of drought and drought-reducing adjustments. The interviewing was carried out in two stages. The first stage, in April-May of 1968, involved interviews with 265 farmers at 16 different sites as an adjunct to other research that required detailed farmer interviews, a comparative study of settlements and a study of population-resource relationships in dense mountain areas. The dispersion of studied settlements provided a wide range of agricultural and climatic types.

The short questionnaire (Appendix A) was administered by Tanzanian university students who translated it from English into Swahili or a local vernacular (half the students spoke the local vernacular) and the answers were usually recorded in English. The emphasis, as usual in natural hazard research, was on open-ended questions with the interviewer having considerable responsibility for obtaining the desired understanding of the farmers' attitudes and perceptions. The students were generally familiar with the agricultural system. However, the number of interviewers was considerably larger than usual and the training time used for the drought study relatively limited. A further possible complication was that interviewing took place during and after a series of exceptionally heavy rains and floods.

The second stage of interviewing was carried out in September in a single area, the Uluguru mountains. A more extensive questionnaire (Appendix B) was used to probe more carefully into the adjustments among farmers (195) who have a common cultural background but live along an extremely sharp environmental gradient (major climatic differences over a horizontal distance of fifty miles and a vertical distance of 6,000 feet).[17] Unfortunately, a new set of student interviewers had to be used and their data, although potentially more useful, are somewhat less dependable than the first set.

As an initial study, the survey work suffers from problems of design, execution, and analysis. The questionnaire could not be pre-tested in the full range of situations in which it was used, nuances were lost in recording and retranslation, some interviewer bias was observable, and the danger of imposing response categories derived from other livelihood systems on Tanzanian experience was not wholly avoided.

In part, the study was undertaken just to identify such problems. Nevertheless, the actual data should be treated with some caution. Thus, we have sought to limit this report to four key questions related to the overall assessment of land quality and the perception of drought frequency, cause and adjustment. And to minimize interviewer variation we have grouped the data into six regional groups based on climatic-geomorphic criteria, each one containing at least 45 respondents (see Table 10).

Quality of area. Is This a Good (Or Bad) Place to Be a Farmer?

Whenever you ask people about a locational choice (residence, farm, industrial site, commercial business), a sizable majority demonstrate a positive attitude towards their present location. In North American studies on a variety of locational preferences, favorable attitudes have been found in at least two-thirds of the respondents. Thus, the use of a quality-of-area question in hazard research is more helpful in focusing the respondent's attention to the attributes of the site and situation than in eliciting actual differences in locational attitudes. Nevertheless, the high preference universally exhibited for the very contrasting ecological environments shown in Table 11 reinforces the general expectation of the farmer's high attachment to his land. This

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[17]The concept of environmental gradient is developed by Porter in "Environmental Potentials and Economic Opportunities - A Background for Cultural Adaptation."

TABLE 10

REGIONAL GROUPINGS OF STUDY LOCALITIES
N-461

Region and Locality	Climatic-Geomorphic Type	Annual Rainfall	Sample Size
1. Dodoma Region	E. Central Plateau Low Rainfall	18" - 30"	N-51
Nduruguni			8
Mseta			12
Ikowa			17
Matongoro			14
2. Singida-Tabora Region	W. Central Plateau Low Rainfall	20" - 30"	N-80
Mbutu			19
Mgori			18
Puma			18
Mangonyi			25
3. Tanga-Morogoro Region	Low Plateau Low Rainfall	20" - 30"	N-45
Pare Plains			7
Changalikwa			20
Uluguru Plain			18
4. Tanga-Morogoro Region	Mountain Blocks High Rainfall	40" - 60"	N-108
Pare Mountains			50
Kiwanda			11
Uluguru W. Foothills			47
5. Tanga Region	Eastern Lowlands High Rainfall	40" - 60"	N-47
Mbambara			21
Kwamangugu			18
Segera			8
6. Morogoro Region	Mountain Blocks Very High Rainfall	60" - 90"	N-130
Uluguru East Foothills			56
Uluguru Middle Slope			26
Uluguru High Interior E.			29
Uluguru High Interior W.			19

TABLE 11

RESPONDENTS ASSESSMENT OF QUALITY OF AREA FOR FARMING BY RAINFALL REGIONS

Assessment	Dodoma E. Central Plateau 18"-30"		Singida-Tabora W. Central Plateau 20"-30"		Tanga-Morogoro Low Plateau 20"-30"		Tanga-Morogoro Mountain Block 40"-60"		Tanga Eastern Lowlands 40"-60"		Morogoro Mountain Block 60"-90"		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Good	48	94	58	72	40	89	85	79	41	87	104	80	376	82
Mixed	2	4	7	9	4	9	11	10	2	4	11	8	37	8
Poor	-	-	15	9	1	2	12	11	2	4	15	11	45	10
Not Ascertained	1	2	-	-	-	-	-	-	2	4	-	-	3	1
Total	51	100	80	100	45	100	108	100	47	99	130	99	461	101

favorable response persists despite perceived differences in drought frequency, and in the case of the Uluguru study, perceived differences in quality between upland and lowland. (Favoring of upland areas is found only for the high rainfall mountain sites.)

Drought frequency. "Do the Rains Fail Often? How Often?"

The perceived frequency of rain failure is related to the average annual and seasonal rainfall an area receives, but not in a simple linear relationship (see Table 12). A fourth of the respondents perceive rain failure as a fairly frequent occurrence even in the high rainfall areas while significant differences in the perception of drought are found between the East (Dodoma) and West (Singida-Tabora) Central Plateau areas with the greatest perception of rain failure found in the slightly better watered West Central region (Singida-Tabora). Also, the Low Plateau, low rainfall study sites (Tanga-Morogoro) are much more similar to the high rainfall sites in the East than to the low rainfall sites on the Central Plateau. This may be a function of the relationship in at least two of the three sites between lowland and upland farming, with many farmers having land in both areas. Nevertheless, significant perceived differences in the rain failure frequency occur and they await further work to compare them with frequencies derived from climatological research.

Causes of drought. "When There is a Drought, What is the Reason for It?"

In general, North American hazard respondents find it very difficult to explain the cause of extreme events, as do their scientific compatriots. Tanzanian farmers also evidenced some difficulty, possibly for different reasons. A fourth of their answers were either not ascertained or not appropriate (Table 13); nevertheless, a large number replied with alacrity. Coding of the answers provided difficulties as causation was often attributed to multiple sources, and the co-existence of Christian, Moslem and Traditional religious persuasions influenced many replies and made their simple categorization difficult.

TABLE 12

RESPONDENTS' PRECEPTION OF KREQUENCY OF RAIN FAILURE BY RAINFALL REGIONS

Frequency	Dodoma E. Central Plateau 18"-30"		Singida-Taboro W. Central Plateau 20"-30"		Tanga-Morogoro Low Plateau 20"-30"		Tanga-Morogoro Mountain Block 40"-60"		Tanga Eastern Lowlands 40"-60"		Morogoro Mountain Block 60"-90"		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
None or Only in Dry Season	11	21	8	10	6	13	19	18	17	36	51	33	112	24
Rare: Recurrence Unspecified or 1-3 times	17	33	4	5	32	71	53	49	17	36	61	47	184	40
Occasional: Recurrence Unspecified of Every 5-10 Years	2	4	-	-	-	-	5	5	6	13	6	5	19	4
Frequent: Recurrence Unspecified or Every 2-5 Years	7	14	20	25	-	-	18	17	2	4	2	2	49	11
Very Frequent: Recurrence Unspecified or Every 1-2 Years	11	21	44	55	6	13	10	9	4	9	2	2	77	17
Not Ascertained	3	6	4	5	1	2	3	3	1	2	8	6	20	4
Total	51	99	80	100	45	99	108	101	47	100	103	101	461	100

TABLE 13

RESPONDENTS' PERCEPTION OF CAUSE OF DROUGHT BY RAINFALL REGIONS

Cause	Dodoma E. Central Plateau 18"-30"		Singida-Tabora W. Central Plateau 20"-30"		Tanga-Morogoro Low Plateau 20"-30"		Tanga-Morogoro Mountain Block 40"-60"		Tanga Eastern Lowlands 40"-60"		Morogoro Mountain Block 60"-90"		Total	
	No.	%*	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Natural Cause or Phenomenon	5	10	7	9	10	22	20	19	5	11	8	6	55	12
God's Will	37	73	47	59	26	58	41	38	37	79	73	56	261	56
Traditional Spirits	-	-	-	-	-	-	2	2	2	4	7	5	11	2
Human Agent Manevolence or Failure	5	10	23	35	10	22	3	3	1	2	11	8	58	13
Not Ascertained	11	21	9	11	4	9	43	40	5	11	43	32	115	25
Total	58	114	90	114	50	111	109	102	50	107	142	108	500	108

*Percentages are of total respondents (461), not total replies as multiple answers are recorded.

However, one might look on the replies as representing a continuum of explanation ranges between natural and human influence. In such a continuum, God stands somewhere in between nature and man, all-powerful, but capable of responding towards human supplication. On the natural end of the continuum, about an eighth of the respondents saw drought as a regular or random natural process. Another eighth saw drought due to the failure or manevolence of the human agents who intercede with the spirits (rainmaking, witchcraft, etc.) and one half of the respondents saw drought directly or indirectly as the will of God or in some cases traditional religious spirits.

Drought adjustment. "If the Rains Fail, What Can a Man Do?"

The individual farmer seldom suggested more than a single alternative adjustment and some adjustments integral to the farming system, such as staggered planting, were not identified as adjustments. Nevertheless, the collective list is extensive and of considerable interest (see Table 14). (Failure to elecit multiple actions might have been a function of the way the interviewer posed the question or an expression of the limitations on choice actually perceived by farmers.)

Doing nothing or just waiting in the face of drought is the most common adjustment (23%), followed by rainmaking or prayer (22%), shifting location in search of better land, work or food (18%), and the use of stored food, money of the sale of cattle (8%), a shift in choice of crops (11%), irrigation (5%), a shift in planting locations to river valley bottoms, wet places (5%); shifts in timing or planting (1%), and changes in cultivation methods (1%). Thus of the adjustments suggested less than a third involve adjustments in the agricultural system directly on the farm.

Some areal variations in preferred adjustments are of interest. Movement is highest among the cattle-keeping people of the plateau (39%), above average among the Eastern Lowlands respondents (20%, 23%) and lowest in the mountain

TABLE 14

RESPONDENTS' PERCEPTION OF FEASIBLE ADJUSTMENTS BY RAINFALL REGIONS

Adjustments	Dodoma E. Central Plateau 18"-30"		Singida-Taboro W. Central Plateau 20"-30"		Tanga-Morogoro Low Plateau 20"-30"		Tanga-Morogoro Mountain Block 40"-60"		Tanga Eastern Lowlands 40"-60"		Morogoro Mountain Block 60"-90"		Total	
	No.	%*	No.	%	No.	%	No.	%	No.	%	No.	%	No.	
Do Nothing, Wait	7	14	10	13	17	38	40	37	3	6	29	22	106	23
Rainmaking, Prayer	2	4	13	16	9	20	14	13	5	11	59	45	102	22
Move to Seek Land, Work or Food	20	39	31	39	9	20	9	8	11	23	4	3	84	18
Use Stored Food, Saved Money, Sell Cattle	8	16	8	10	2	4	16	15	3	6	-	-	37	8
Change Crops	1	2	8	10	6	13	4	4	13	28	18	14	50	11
Irrigation	11	21	4	5	1	2	15	14	4	9	1	1	36	8
Change Plot Location	1	2	3	4	-	-	8	7	10	21	-	-	22	5
Change Timing of Planting	-	-	-	-	-	-	-	-	1	2	2	2	3	1
Change Cultivation Methods	-	-	1	1	-	-	-	-	-	-	-	-	1	0
Others	1	2	11	14	4	9	1	1	8	17	1	1	26	6
Not Ascertained	6	12	4	5	-	-	14	13	3	6	35	27	62	13
Total	57	112	93	117	48	106	121	112	61	129	149	115	529	115

*Percentages are of total respondents, not total replies as multiple answers are recorded.

block areas (8%, 3%). These seem in accord with general impressions about regional mobility.

Rainmaking, conversely, is extremely high in the Uluguru (very high rainfall) area apparently refelcting a long established cultural tradition and possibly a better chance of apparent success. Irrigation is favored in the settlements where water is available and where it is traditional, as in the Pare Mountain area. Finally, an interesting order emerges in adjustments that represent key agricultural decisions, what to plant (11%), where to plant (5%), when to plant (1%), and how to plant (1%), but given the small numbers the differences may be insignificant.

How the range of adjustment perceived by our respondents relates to the practical and theoretical range of adjustment is not yet clear as there is still much to learn about what constitutes the practical range of adjustment as well as some of the more theoretical possibilities. However, timing and method of cultivation (planting dry, minimal cultivation, tie-ridges, etc.) might be major drought adjustments that are little used at present.

Models of Drought in East African Smallholder Agriculture

The impact of drought on the agricultural system of the Tanzanian farmer is extremely complex, being compounded of both natural variation in climate and human adjustment to nature. Models which preserve the essential features and relationships of complex systems while at the same time simplifying them can be helpful in several ways.

The model can serve as a test of our understanding. If it is incomplete it may indicate the direction further research should take. If it is reasonably complete, routing real world data through it should provide results similar to real world behavior. Such simulations provide a test of our social and natural science understanding and offer a way to examine the impacts of events which have not occurred in the recorded past but could reasonably occur in the future.

Finally, a working model of a complex social-natural system is a tool for decision-making as it enables us to simulate the impact, not only of natural events, but of human policy as well. In the drought context, we could use a model to systematically examine the impact of the range of drought adjustments with a view to choosing the optimal set that would minimize the social costs of drought.

A human ecological model

A special type of drought model employs a human ecological perspective within a general systems framework. The ecological perspective is described in a recent working paper[18] and a brief example of a drought model is reproduced therein.

In this model, reproduced as Figure 3, characteristics of the agricultural systems (human use system) and climatic and edaphic factors (natural events system) combine to present a hazardous potential in the form of reduced moisture

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[18] R.W. Kates, "Natural Hazard in Human Ecological Perspective: Hypotheses and Models," Natural Hazard Research Working Paper No. 14. Toronto: Department of Geography, University of Toronto, 1970.

resulting in lower yields. Varied hazard effects are suggested, for little is actually known about these, but they include health, wealth, and migration effects. The hazard potential and experience prompts varied adjustments, primarily by individual farmers, intended to modify the hazard effects, the agricultural system or the availability of soil moisture.

The model itself is frankly speculative, but it does provide a framework for summarizing what we know about agricultural drought adjustment in East Africa. In brief, we know least about hazard effects and the water-yield relationship, more about adjustments, and most about factors of moisture need and availability and it is upon these factors that the balance of the paper focuses.

Moisture need and availability

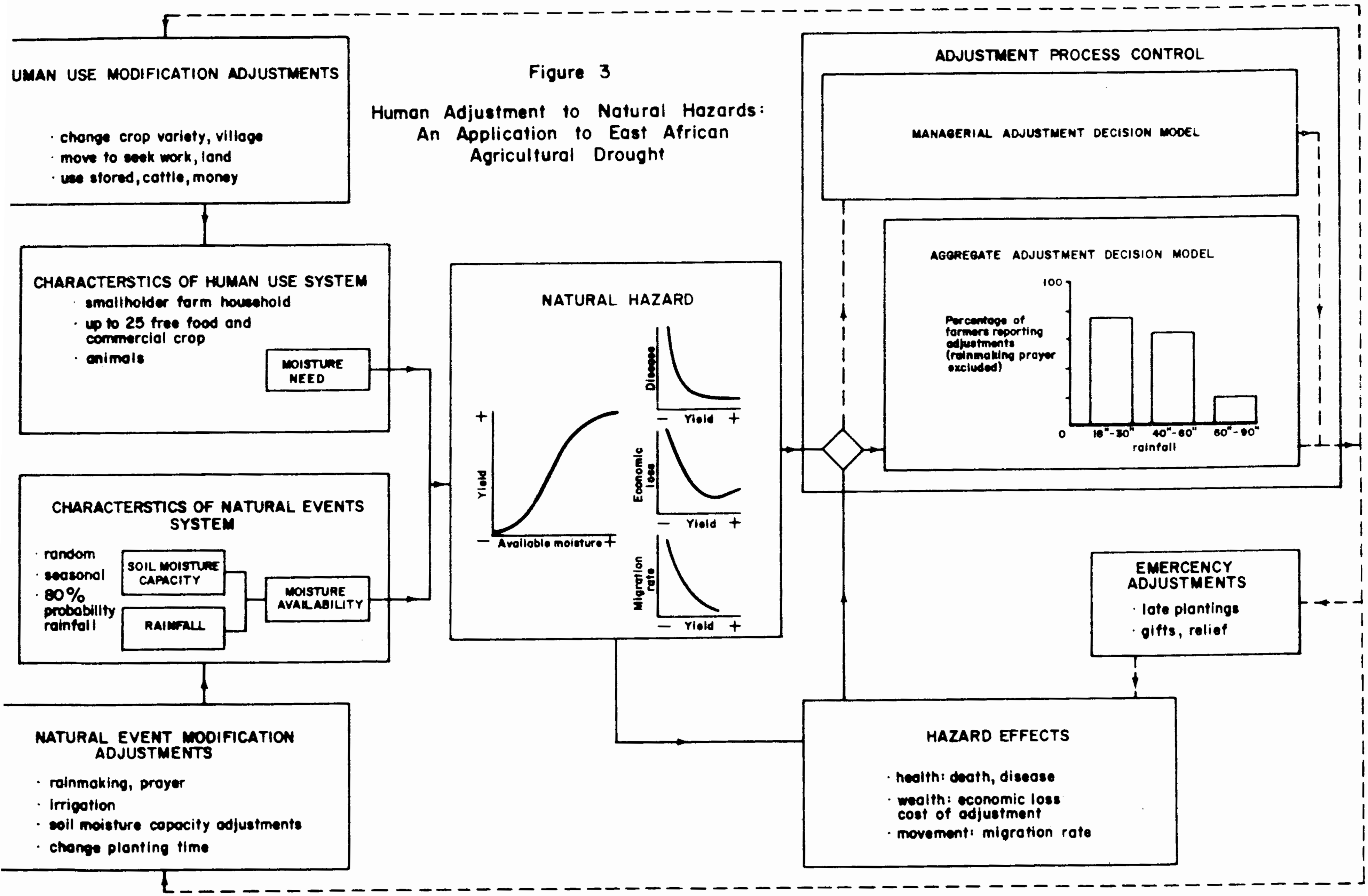
Water availability is primarily related to the pattern of precipitation but other climatic factors -- radiation, wind and humidity -- provide a stress on plants and at the same time affect the amount of water available in the soil. Plants have variable genotypic and phenotypic water needs. The gradient, texture and chemical composition of the soil determines its storage capacity. Competitive vegetation can affect the plant's access to the available moisture.

Control over the many factors of water availability in agriculture is shared between nature and man. Climatic events are little affected by man, but other events are commonly manipulated. Drought, as we have defined it, is a joint product of nature and man, being a series of situations in which the conjunction of climatic events and farmers' production decisions cause some injurious or disturbing impact on man.

Season length and phenological considerations. Farmers' production decisions affect both the basic water-yield relationship and the actual evapotranspiration. The farmer's decision as to what to plant (crop and variety) sets a pattern of water requirements for stages of the growth cycle that in

Figure 3

Human Adjustment to Natural Hazards:
An Application to East African
Agricultural Drought



effect change the water-yield relationship for each stage.

A critical factor in growing a crop is the length of time during which moisture is required by the plant. If one asks a farmer when he harvests his crop one may be misled as to season length, for it is common practice to allow the crop to stand in the field to dry for several weeks before harvesting it. There is a dearth of phenological information on plants in East Africa.[19] It is necessary to know by plant variety the lengths of time taken by distinctive phases in the life of the plant. These phases may be somewhat arbitrary (e.g., 7-leaf stage) and they differ from crop to crop. It is useful to break plant growth into periods because water stress has more serious consequences in some periods than it does in others. As Salter and Goode note: "The possibility exists that each individual organ of the plant may have its own sequence of water requirements during its development."[20]

For example, the crop season of maize can be divided into five stages: a) germination to 7-leaf stage; b) 7-leaf stage to brush (tassel) stage; c) brush formation to end of flowering; d) start of grain formation to milk ripe stage; and e) milk ripe to complete ripeness of the grain. Other terms such as silking, tasselling, dough stage, etc., have been used to divide the season according to significant events or stages in the life of the plant. Moisture stress in maize in the vegetative period (stages a and b above) is not especially serious. It will reduce the dry matter production substantially, but not have any marked effect on grain yields. So long as the top two leaves of the plant are turgid and able to carry on the vital process of photosynthesis, the plant

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[19] Such information as is available will be found in P. Porter's Environment and Economy in East Africa, Chapter 7, (forthcoming).

[20] P.J. Salter and J.E. Goode, Crop Responses to Water at Different Stages of Growth, Farnham Royal, Bucks., England: Commonwealth Agricultural Bureau, 1967, p. 193.

will survive.

There are two periods when moisture stress has serious consequences. If moisture stress occurs during silking and tasseling, fertilization of the seed may be incomplete, and even with adequate moisture later on, the harvested cobs will have a few normally developed kernels and many undeveloped kernels. The second period when moisture stress has serious consequences is during the grain ripening phase. In the latter part of the crop season dry matter production is concentrated in grain. If moisture is limited during this period, the kernels will be small. Thus, although all the seed may have been fertilized, the final weight of the grain may be reduced. Weight loss caused by moisture stress in this period is proportional to the amount of the moisture deficit; it is a matter of degree. Moisture stress in the silking period results, as it were, in quantum differences in yield.

To give some figures to the above discussion, we may cite the results of the study by Robins and Domingo.[21] They allowed maize to deplete the soil moisture to wilting point at tasseling and silking stage and maintained this situation for one to two days. Subsequent yileds were reduced by 22%. When the wilting point was maintained for six to eight days at silking and tasseling the yield reduction was 50%.

A maize variety like Katumani that tassels at the end of 52 days from planting and whose grain has reached full weight by the 90th day is much better adapted to a short season than a variety that requires 70 days or more to tasselling.

Other staple food crops grown in East Africa have different phenological characteristics. Sorghum, for example, can recover fully from two weeks of continuous moisture stress (with available soil moisture at wilting point level)

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[21] Cited in Salter and Goode, op. cit., p. 30.

during the vegetative phase. The only time moisture stress affects sorghum is at the heading stage.

For a specific variety, crop season may vary as a function of location, elevation, and the like. Such variation based on one variety is shown in Table 15.

TABLE 15

AVERAGE CROP SEASONS AS A FUNCTION OF ELEVATION

Elevation (in feet)	Days to Flowering Stage (based on Hill Maize)	Length of Ripening Period (days) 95% Physiological Maturity	Length of Crop Season (days)	(approx. mos)
Sea Level	60	36	96	3
1000	60	36	96	3
2000	60	36	96	3
3000	60	36	96	3
4000	65	42	107	4
5000	75	51	126	4
6000	90	65	155	5
7000	105	79	184	6

Source: East African Regional Maize Variety Trials: Kenya, Tanzania, Uganda, 1967 and 1968, courtesy of Mr. Michael Harrison, Maize Unit, National Agricultural Research Station, Kitale, Kenya.

Potential Transpiration (E_t/E_o). It has been known for a long time that plants transpire at different rates during different parts of their growth cycle. When plants are very young and small and a field consists mostly of dry bare soil, moisture is transpired (or evaporated) to the atmosphere at a very low rate. As plants gain in size and the surface area of leaf increases, the rate of transpiration increases. When a plant reaches maximum size and vigor it may transpire at a rate well above E_o -- the rate at which a large open water surface will evaporate moisture into the atmosphere. This is due partly to the geometry of the transpiring surface, its roughness, and partly to the greater area of transpiring surface as compared to the area of ground beneath. The leaf-area index is a measure of this relationship. It is common for fields covered with young plants to have an E_t/E_o coefficient of 0.50. During the second month the E_t/E_o rate may average 0.80. If in the third month full vegetative growth is achieved, the rate may be 1.00 to 1.20, and in exceptional cases, even up to 1.60, as with, for example, closely spaced irrigated grains such as sorghum.

The following table (Table 16) represents either observed or estimated E_t/E_o coefficients for various crops. Experimentally derived data on the following crops are cited: Maize, sorghum, rice, groundnuts, bananas, and beans. (There are also empirical data for cotton, sugar cane, tea, and coffee.) We have estimated the coefficients for bulrush millet and finger millet (the latter of which, we believe, would have an E_t/E_o profile resembling oats). We have also assigned what we believe to be reasonable figures to cassava and sweet potatoes, although empirical data are lacking.

TABLE 16

E_t/E_o VALUES FOR CROPS IN DIFFERENT MONTHS OF THEIR SEASON*

Crop	Month 1	2	3	4	5	6	7	etc
Bananas	0.40	0.50	0.60	0.70	0.80	0.95	0.95	
Beans	0.75	0.90	1.25	1.35	0.85	0.60		
Bulrush millet	0.50	0.90	1.00	0.60				
Cassava	0.50	0.70	0.70	0.70				
Finger millet	0.50	0.80	1.00	1.00	0.70	0.50		
Groundnuts	0.50	0.80	0.90	0.90				
Maize	0.50	0.90	1.00	1.20	0.80	0.50		
Rice	0.65	1.30	1.30	1.30	1.30			
Sorghum	0.50	0.80	1.00	1.20	0.50			
Sweet potatoes	0.50	0.70	0.70	0.70				

Note: E_t/E_o values for one crop will vary according to variety and season length.

*Data: Mainly after D.A. Rijks, with modifications from Wangate and Dupriez.

D.A. Rijks, Namulonge, Uganda, personal communication, July 1969.

F.J. Wangati, "The Water Use of Maize and Beans - Results Obtained with Hydraulic Weighing Lysimeters, Mwea Irrigation Scheme," Fourth Specialist Meeting on Applied Meteorology, 25-26 November, 1968, 9 pp.

G.L. Dupriez, L'Evaporation et les Besoins en Eau des Differents Cult Cultures dans la Région de Mvuasi (Bas-Congo), Série Scientifique, No. 106, INEAC, 1964, p. 35.

Rooting Depths. The decision as to what to plant also determines the general root depth of the plants even though root depths themselves are somewhat a function of water availability. Each plant has what might be termed a maximum genetic rooting depth beyond which it will not go, but the actual depth depends on the depth of the soil, the character of the soil and the water table, the time of planting, and the spacing between plants. There are, no doubt, other influencing factors as well. A crop planted in a moist soil may not develop as full and deep a network of roots as the same crop planted earlier in a dry soil. Later on in the season, if the top layers dry out, the plant whose roots developed in a moist soil will be poorly equipped to obtain the necessary moisture.

Plants tend to use the moisture at upper levels in the soil, and as the upper levels become exhausted, to commence extraction of moisture at successively deeper levels. If a plant has a rooting depth of six feet, and it rains, thereby resupplying the upper layer of soil, the plant will cease moisture extraction at the five foot level and will put out new roots to tap the moisture in the upper layer. Although 95% of a plant's rooting system may be within the top three feet of soil, the deeper roots, the prop roots in maize for example, are absolutely crucial, for they can sustain the plant in a dry period from moisture available at depth.

The following table (Table 17) gives the approximate rooting depths of some of the East African staple crops for different soil types.

TABLE 17

SOME APPROXIMATIONS OF ROOTING DEPTHS FOR EAST AFRICAN STAPLE FOODS, BY SOIL TEXTURE

Crop	Soil Texture				
	Coarse loamy sand	Coarse sandy loam	Sandy clay loam	Clay loam	Clay
Bulrush millet	5'	5'	4'	3'	2'
Finger millet	3'	2'	2'	2'	2'
Maize	7'	6'	5'	4'	4'
Rice	(Dry planting, up to 8'; under irrigation, to 3')				
Sorghum	8'	7'	6'	5'	4'
Groundnuts	7'	7'	5½'	4'	3'
Bananas	7'	6'	5'	4'	3'
Cassava	(Rooting depth not known, probably deep, est. 7')				
Sweet potatoes	8'	8'	6½'	5'	4'

Source: Dr. M.D. Gwynne, Plant Physiologist, EAAFRO, Muguga, Kenya.

Soil Moisture Capacity. The decision as to where to plant (plot/field location) fixes the choice of soil depth, the soil type, and with the choice of crop, the approximate rooting depth of the plant. With these, we can then estimate the amount of moisture the soil column will hold at field capacity. This moisture must be used in conjunction with precipitation to determine the amount of moisture available to plants for transpiration. Table 18 shows the amount of moisture in inches for different soil types.

TABLE 18

AVAILABLE MOSITURE PER FOOR OF SOIL DEPTH FOR DIFFERENT SOIL TYPES

Textural class	Range in available moisture in inches per foot
Coarse sand	0.5 to 0.8
Fine sand/coarse loamy sand	0.7 to 1.2
Fine loamy sand/ coarse sandy loam	1.2 to 1.6
Sandy clay loam/ clay loam	1.4 to 1.8
Silty clay loam/ clay loam	1.8 to 2.6
Sandy clay/clay	1.6 to 2.1
Heavy black clay	2.0 to 2.8

Source: J.M. Watermeyer, "A Simple Practical Method of Pre-Determining and Scheduling Irrigation from Climatic Data," Dept. of Meteorological Services, Salisbury, Rhodesia, 29 June, 1965, 5 pp., (mimeo).

Field location, particularly field slope, may influence infiltration, with greater runoff taking place on steeper slopes, leaving less rainfall available to recharge the soil.

Time of Planting. The decision as to when to plant can increase or diminish the expectation of moisture during the growing season. If we relate the growing season to the rainfall seasonality of East Africa for any specific crop/soil/location combination, a specific planting date exists that would assure over the long run a maximum E_t/E_o ratio at the critical periods of the growth cycle. An approximation of optimal planting time suggests a rule to plant when rainfall is equal to half the potential E_t rate. In tests this has been shown to approximate very closely the assumption of 2 inches of rainfall in the month commencing the season.[22]

Cultivation Practices. Finally, the decision as to how to plant and cultivate affects in several ways the effective moisture available. The choice of cultivation practices "flat ridge" of "tie-ridge" can, for a given soil and slope, change the infiltration/runoff ratio and thus effectively increase the moisture availability.[23] Such hypothesized relationships are shown in Figure 4A. Competition for available moisture can be minimized either by weeding and/or plant spacing and one possible set of relationships is shown in Figure 4B.[24] Water can also be applied directly to the fields by irrigation

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[22] H.L. Manning, "The Statistical Assessment of Rainfall Probability and Its Application in Uganda Agriculture'" Research Memoirs, No. 23. London: Empire Cotton Growing Corporation, 1956, p. 468.

[23] Dagg and McCartney, op. cit.

[24] F. Ogada, "The Role of Maize Research in Stimulating Agricultural Progress in Kenya," a paper presented to the East African Agricultural Economics Society Conference, June 1969, 10pp plus appendix; A.Y. Allen, "A Review of Maize Agronomy Research in Western Kenya," a paper presented to the Third East African Cereals Research Conference, Zambia and Malawi, 10-15 March, 1969, 13pp.; and M.N. Harrison et al, "How Hybrid Seed is Revolutionizing Maize Growing in Kenya," International Development Review, September, 1968, pp. 9-13.

thereby increasing the available moisture, as in Figure 4C.

Porter - Maki computer program

A computer model designed by Porter and programmed by Maki is currently operational. It permits analysis of moisture availability, moisture need, and a crude estimate of expected yield.

Computer Input. To utilize the program, one needs to supply the following information:

1. Monthly rainfall figures for the period to be studied, in inches or millimeters. For calculating probabilities, 11 years in minimum length of record. Some 600 stations in Tanzania meet this criterion.

2. Evaporation data (E_o) for each month. Monthly means rather than actuals may be used in tropical Africa although in higher latitudes actual values would be desirable. E_o is "open water surface evaporation" and based on the Penman equation as modified for East Africa by McCullough[26] and uses all E_o estimates for station examined by Rijks and Owen[27] (Uganda) and T. Woodhead[28] (Kenya and Tanzania). From these, regression equations predicting E_o for all stations based on elevation, longtitude and latitude were derived.

3. Length of crop season derived from maize trials shown in Table 15, page 41.

4. E_t/E_o coefficients for the crop/season. (See Table 16, page 42.)

5. Soil type. (See Table 18, page 44.)

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[25] Salter and Goode, op. cit.; P.J. Kramer, Plant and Soil Water Relationships: A Modern Synthesis. New York: McGraw Hill, 1969.

[26] J.S.G. McCullough, "Tables for the Rapid Computation of the Penman Estimates pf Evaporation," East African Agriculture and Forestry Journal, Vol. 30 (1965).

[27] D.A. Rijks and W.G. Owen, Hydrometeorological Records from Areas of Potential Agricultural Development in Uganda. Kampala: Government of Uganda, 1965.

[28] T. Woodhead, Studies of Potential Evaporation in Kenya. Nairobi: Government of Kenya, 1968; Studies of Potential Evaporation in Tanzania. Nairobi: EAAFRO, 1968.

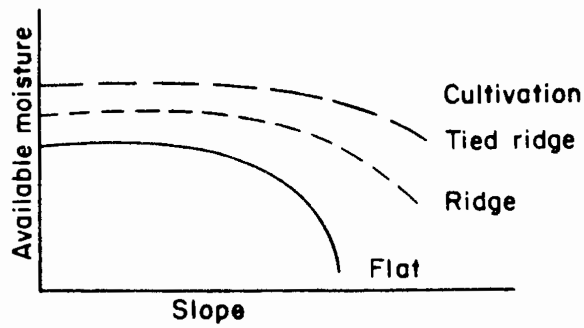

FIGURE 4A HYPOTHESIZED EFFECT OF DIFFERENT CULTIVATION PRACTICES ON SOIL MOISTURE AVAILABILITY

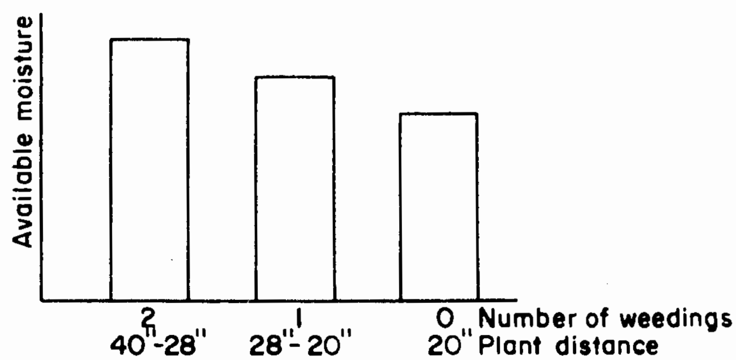

FIGURE 4B HYPOTHESIZED EFFECT OF WEEDING AND SPACING ON SOIL MOISTURE AVAILABILITY

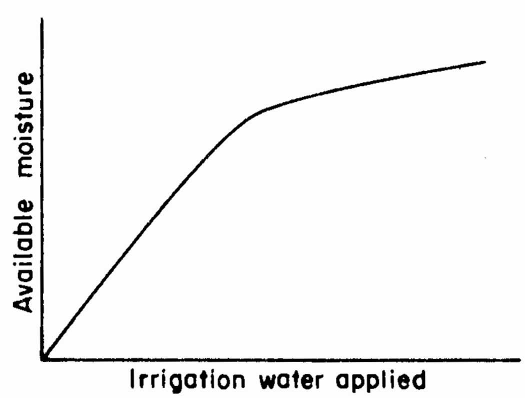

FIGURE 4C HYPOTHESIZED RELATIONSHIP OF THE AMOUNT OF IRRIGATION WATER APPLIED TO SOIL MOISTURE AVAILABILITY

6. Rooting depth of plant (See Table 17, page 44.) which, taken together with soil type, can be converted into an estimate of available soil moisture. The program then selects the soil moisture supply equation (a schedule of moisture availability given increasing matric suction) appropriate to the soil and the specified amount of moisture held in the soil column at field capacity.

Table 19 shows the sort of data one would provide to the computer.

Preliminary analysis. The program has to determine how to start a season. It does this in two phases. Phase I is to define the month when the search for the month to begin the season commences. If, say, November is that month, one wants to retain the flexibility the farmer has of planting in October if the rains are early or in January if in a particular year the rains fail until then. In defining what month to begin a season, the program uses a confidence limit of 1:1, which is to say that in the long run the farmer has a 75% chance of success in obtaining $0.5E_o$, a measure of the moisture needed for planting. (It is argued that if one is likely to be successful in getting a crop to germinate 3 out of 4 years on average, it is worth risking the seed.) This set of assumptions only suggests the sort of month we should look at first. There are three search options for Phase I, and we will return to them presently. Phase II in the search procedure gives flexibility to season commencement. If the month of "initial search" (say, November) meets the criterion for season commencement, the previous month (October) is examined. If October also qualifies, the season commences in October. If it does not qualify, the season commences in November. However, if November initially does not meet the criterion for season commencement the next month (December) is examined. If this month too does not achieve the $0.50E_o$ level in the particular year examined, the next two months in turn are examined. If January were to fail to qualify, the season has to begin in February regardless of the ratio of precipitation to E_o.

In the first option of Phase I the computer searches back each month from the month which has the mean maximum rainfall (April - 8.76") until a month

TABLE 19

SAMPLE COMPUTER INPUT

STATION:

RAINFALL	J	F	M	A	M	J	J	A	S	O	N	D
E_o (in ")	5.7	5.4	5.6	5.2	5.3	5.4	5.8	5.8	5.8	6.1	5.3	5.3

Assumptions =		
Maize = (First Planting)	Soil moisture = 7"	
	Season length = 6 months	
	E_t/E_o coefficients = month 1	0.50
	2	0.90
	3	1.00
	4	1.20
	5	0.80
	6	0.50
	all other mos.	0.50
Maize = (Second Planting)	Soil moisture = 7"	
	Season length = 4 months	
	E_t/E_o coefficients = month 1	0.50
	2	0.90
	3	1.20
	4	0.70
	all other mos.	0.50

Sources: M. Dagg, "A Rational Approach to the Selection of Crops for Areas of Marginal Rainfall in East Africa," East African Agricultural and Forestry Journal, Vol. 30 (1965) pp. 296-300; and F.J. Wangati, "The Water Use of Maize and Beans - Results Obtained with Hydraulic Weighing Lysimeters, Mwea Irrigation Scheme," see Table 16.

of less than 0.750 probability of success is discovered. That is defined on average as a "drought month" and the search commences with the month which follows it. The examples here (Tables 20 and 21) illustrate the problems one can encounter with this search option. January and December have probabilities that rainfall = 0.5Eo of less than 0.75, thus requiring the search for season start to begin in February. This option works well in areas with single peaked rainfall regimes.

The bimodal rainfall curve can be a problem to the search procedure outlined above, and two additional options on the manner in which the beginning season is commenced have been provided. One is to instruct the search to begin, not backward from the month with the highest average rainfall, but forward from the month with the lowest average rainfall until a month satisfying the PE (E_t/E_o) factor and the probability assumptions has been found. That month becomes the first wet month, and thereby the month from which the usual search procedure of Phase II for beginning of a season commences. In the case of the example provided here, a search beginning initially with the month with lowest average rainfall (July - 0.36") would designate November as the first wet month. A search initiated from the month with the highest average rainfall would, as we have seen, work back from April (8.76") to February, but would fail to go beyond since January has a probability of rainfall equaling $0.5E_o$ of only 0.676 (and December has a value at 0.730). In fact, there are two agricultural seasons in Rubya Mission. The first begins in October and November, and a short second season of approximately four months (February through May) is agriculturally feasible.

A third option is to designate a specific month in which the search is to begin. This procedure was used in the example shown here, December being the month in which the search commenced. Since November at Rubya Mission has a very high probability of rainfall = $0.5E_o$ the season for the most part begins in that month. The command for the third option simply preempts this part of

```
91.31001 01 .55S   31 37E  .700  RURYA MISSION
PE FACTOR  .500   THE PROBABILITY VALUE FOR DETERMINING THE END OF DRY SEASON IS   .750

SOIL MOISTURE DEPTH  7.00 INCHES

THESE ARE THE PE VALUES FOR THE RESPECTIVE MONTHS
  5.7   5.4   5.6   5.2   5.3   5.4   5.8   5.9   5.8   6.1   5.3   5.3

THE NUMBER OF YEARS FOR WHICH THERE WERE DATA FOR RESPECTIVE MONTHS
   37    37    37    37    37    37    37    37    37    37    37    37

PROPORTION OF YEARS THAT INDIVIDUAL MONTHS WERE SUCCESSFUL

JAN  .676

FEB  .784

MAR  .946

APR 1.000

MAY  .811

JUN  .054

JUL 0.000

AUG  .162

SEP  .405

OCT  .676

NOV  .919

DEC  .730
```

TABLE 20

MEAN MONTHLY RAINFALL VALUES FOLLOW

JAN	4.05
FEB	4.90
MAR	6.36
APR	8.76
MAY	5.75
JUN	.88
JUL	.36
AUG	1.54
SEP	2.96
OCT	4.28
NOV	6.00
DEC	5.24

APR WAS THE MAXIMUM PRECIP AND THE VALUE IS 8.76

USER CHOOSE TO BEGIN SEARCH PROCESS IN MONTH 12. THIS OVERRIDES THE MONTH WHICH THE PROGRAM PICKED OUT TO BEGIN THE SEASON

KEY----
A=STATION CODE (COUNTRY,LAT-LONG,STATION NUMBER)
B=YEAR IN WHICH THE SEASON BEGAN
C=MONTH IN WHICH THE SEASON BEGAN
D=LOWEST RATIO FOR THE SEASON
E=MONTH OF SEASON IN WHICH THE LOWEST RATIO OCCURRED
F=LENGTH OF SEASON
G=SOIL MOISTURE DEPTH VALUE
H=MONTH OF YEAR IN WHICH LOW RATIO OCCURRED. IF BLANK, THEN NO MONTH IN SEASON HAD RATIO OF LESS THAN ONE.
I=DAYS OF STRESS FOR THE SEASON

MTH	YEAR	PET	PRECIP	P - PET	APWL	ST CHANGE	AE	RATIO	STORAGE	DAYS/STRESS
1	32	2.85	3.35	.49	-6.51	.49	2.85	1.00	.49	0.00
2	32	4.85	4.33	-.52	-7.03	0.00	4.33	.80	.49	3.02
3	32	5.63	5.47	-.16	-7.19	0.00	5.47	.96	.49	.87
4	32	6.28	4.25	-2.03	-9.22	0.00	4.25	.20	.49	9.70
5	32	4.25	12.80	8.54	-.68	6.51	4.25	1.00	7.00	0.00
6	32	2.70	0.00	-2.70	-3.37	-3.40	2.70	1.00	3.60	0.00
7	32	2.89	0.00	-2.89	-6.27	-1.50	1.50	0.00	2.10	14.93
8	32	2.89	2.32	-.57	-6.84	-.25	2.57	.80	1.85	3.44
9	32	2.91	4.84	1.93	-4.91	1.93	2.91	1.00	3.78	0.00
10	32	3.07	.63	-2.44	-7.35	-2.13	2.76	.80	1.65	3.15

	A	B	C	D	E	F	G	H	I
47	913101	32	1	.20	4	6	7.00	4	14

MTH	YEAR	PET	PRECIP	P - PET	APWL	ST CHANGE	AE	RATIO	STORAGE	DAYS/STRESS
11	32	2.64	4.09	1.46	-5.54	1.46	2.64	1.00	3.11	0.00

TABLE 21

the program, making the other search procedures inoperative.

The sample printout in Table 20 shows some of this procedure. The lines on Table 20 show:

Line 1. The station number, location, elevation and name.

Line 2. That a 1:1 confidence limit of achieving $0.50E_o$ is assumed. This set of assumptions could be varied to suit the livelihood system being studied.

Line 3. Soil moisture assumptions, in this case 7.00" of available soil moisture.

Lines 4 & 5. Monthly estimates of average potential evapotranspiration.

Lines 6 & 7. There are data for 37 years.

Lines 8 to 20. The proportion on the 37 years of monthly data that satisfy the conditions specified in 2 above.

The second page of printout (Table 21) shows mean monthly rainfall, and provides a key to data to be printed and punched out after each season's analysis. These data for each station-season form the basis of maps of cropping success, days of moisture stress, months the season began, months of severe moisture stress, and so forth. The maps can show these data as overall probabilities based on the full run of years, or for particular years one wishes to study, say the drought of 1960.

The Energy Water Budget, Season By Season

Analysis. The sample printout (Table 22) shows the analysis for a sequence of three years giving, in order by rows: month and year, potential transpiration, precipitation, the difference between precipitation and potential transpiration, accumulated potential water loss (a measure of soil matric suction which governs the amount of storage change in soil moisture), change is soil moisture storage, actual evapotranspiration, a ratio measuring "success" as the proportion of expected or normal yield in a good year, soil moisture storage, and days of stress.

PET (potential transpiration) is the potential crop (or bare soil) evapotranspiration. It is the E_o for the month multiplied by the E_t/E_o coefficient appropriate for the stage of the crop cycle. As can be seen, the season begins in November in 1948, but in December in 1949.

The ratio is an estimate based on Glover's work, of the amount by which expected yield is decreased by a short fall of needed moisture in a given month -- e.g., a short fall in March, 1949, of 2.16" of the needed 4.50" for PET destroyed the crop (reduced the yield to zero percent of expected yield). At present this measure is very crude and needs much further research; in the end it may prove to be an intractable problem, for yields are so responsive to management (weeding, use of fertlilzer, etc.) that it is difficult to define the idea of expected yield.

The number of days of moisture stress in a month is estimated as follows:

$$D_s = d\left[1 - \frac{AE}{PET}\right]$$

Where: Ds = number of days with moisture stress

d = number of days in the month

AE = the actual evapotranspiration of that month

PET = the potential transpiration of that month

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MTH	YEAR	PET	PRECIP	P - PET	APWL	ST CHANGE	AE	RATIO	STORAGE	DAYS/STRESS
11	48	2.64	4.57	1.93	-5.07	1.93	2.64	1.00	3.33	0.00
12	48	4.78	6.93	2.15	-2.91	2.15	4.78	1.00	5.47	0.00
1	49	5.71	1.69	-4.02	-6.94	-3.67	5.37	.90	1.80	1.85
2	49	6.47	6.10	-.37	-7.31	-.13	6.23	.96	1.67	1.06
3	49	4.50	1.61	-2.89	-10.20	-.73	2.34	0.00	.95	14.90
4	49	2.62	11.81	9.19	-1.01	6.05	2.62	1.00	7.00	0.00
5	49	2.66	5.28	2.62	0.00	0.00	2.66	1.00	7.00	0.00
6	49	2.70	1.50	-1.20	-1.20	-1.20	2.70	.96	5.80	.01
7	49	2.89	1.22	-1.67	-2.87	-1.70	2.82	1.00	4.10	0.00
8	49	2.89	2.60	-.30	-3.17	-.30	2.89	1.00	3.80	0.00
9	49	2.91	2.56	-.35	-3.52	-.30	2.80	.96	3.50	.56
10	49	3.07	5.47	2.40	-1.12	2.40	3.07	1.00	5.90	0.00
11	49	2.64	2.05	-.59	-1.71	-.60	2.64	1.00	5.30	0.00

	A	B	C	D	E	F	G	H	I
47	913101	48	11	0.00	5	6	7.00	3	18

MTH	YEAR	PET	PRECIP	P - PET	APWL	ST CHANGE	AE	RATIO	STORAGE	DAYS/STRESS
12	49	2.66	6.73	4.07	0.00	1.70	2.66	1.00	7.00	0.00
1	50	5.14	3.31	-1.83	-1.83	-1.80	5.11	.96	5.20	.19
2	50	5.39	1.93	-3.46	-5.30	-2.60	4.53	.68	2.60	4.49
3	50	6.76	11.46	4.70	-.59	4.40	6.76	1.00	7.00	0.00
4	50	4.19	9.76	5.57	0.00	0.00	4.19	1.00	7.00	0.00
5	50	2.66	4.09	1.44	0.00	0.00	2.66	1.00	7.00	0.00
6	50	2.70	.94	-1.75	-1.75	-1.80	2.70	1.00	5.20	0.00
7	50	2.89	0.00	-2.89	-4.65	-2.25	2.25	.54	2.95	6.90
8	50	2.89	1.34	-1.56	-6.20	-.80	2.14	.38	2.15	8.09
9	50	2.91	1.54	-1.38	-7.58	-.55	2.09	.38	1.60	8.53
10	50	3.07	3.03	-.04	-7.62	-.00	3.03	.96	1.60	.40

	A	B	C	D	E	F	G	H	I
47	913101	49	12	.68	3	6	7.00	2	5

MTH	YEAR	PET	PRECIP	P - PET	APWL	ST CHANGE	AE	RATIO	STORAGE	DAYS/STRESS
11	50	2.64	4.72	2.09	-4.91	2.09	2.64	1.00	3.69	0.00
12	50	4.78	7.09	2.30	-2.61	2.30	4.78	1.00	5.99	0.00
1	51	5.71	4.65	-1.06	-3.67	-2.59	5.71	1.00	3.40	0.00
2	51	6.47	7.76	1.28	-2.39	1.28	6.47	1.00	4.68	0.00
3	51	4.50	6.30	1.80	-.59	1.80	4.50	1.00	6.48	0.00
4	51	2.62	4.88	2.26	0.00	.52	2.62	1.00	7.00	0.00
5	51	2.66	8.39	5.73	0.00	0.00	2.66	1.00	7.00	0.00
6	51	2.70	.51	-2.19	-2.19	-2.20	2.70	1.00	4.80	0.00
7	51	2.89	0.00	-2.89	-5.08	-2.10	2.10	.38	2.70	8.50
8	51	2.89	3.19	.30	-4.78	.30	2.89	1.00	3.00	0.00
9	51	2.91	1.30	-1.61	-6.40	-.95	2.24	.54	2.05	6.89
10	51	3.07	8.15	5.08	-1.32	4.95	3.07	1.00	7.00	0.00

	A	B	C	D	E	F	G	H	I
47	913101	50	11	1.00		6	7.00		0

TABLE 22

In the examples shown here, the crop in March 1949 during the fifth month of the season experienced 15 days of stress and the crop failed. It would be more accurate to describe these 15 days as stress-day equivalents. The shortfall in moisture needed was 2.16", which is the equivalent to what the plant would transpire in 15 days (0.144 inches/day). It makes little difference whether one thinks, then, of 15 days in which the plant roots actually could not extract a drop of moisture, or of a longer period (up to 31 days) in which some considerable and increasing portion of the mositure needed by the plant for its physical survival was not supplied.

It should be emphasized that "days of stress" are not simply days without rain. They are days when a plant is in true physiological difficulty and unable to extract from the soil the moisture it needs for transpiration which is the way it controls its internal temperature. The 7.00 inches soil moisture assumption provides ample moisture in most months when precipitation is less than potential transpiration. It takes only a few days of stress, however, to cause irreversible damage and reduce yields.

At the very end of the program is a summary of the station (Table 23). In this instance it shows for the 35 seasons analysed, the number of days of moisture stress for each month of the 6 month crop season, as well as the average number of days of stress and their standard deviations.

The line: 47 913101 AVG. RATIO .63 S.D. .4 tells the avarage or overall success of getting a normal yield at this place. All this information is card punched automatically and used in making maps. Present map making capability includes maps for part or all of Tanzania of the following types:

1. Average success.
2. Standard deviation of success.
3. Success of individual years.
4. Most frequent month of season commencement.

MTH	YEAR	PET	PRECIP	P - PET	APWL	ST CHANGE	AE	RATIO	STORAGE	DAYS/STRESS
1	67	2.85	4.92	2.07	-4.91	2.07	2.85	1.00	2.79	0.00
2	67	4.85	2.56	-2.30	-7.23	-1.09	3.64	.54	1.70	6.98
3	67	5.63	3.43	-2.20	-9.43	-.55	3.98	.38	1.15	9.11
4	67	6.28	3.31	-2.98	-12.41	-.50	3.81	0.00	.65	11.81
5	67	4.25	5.87	1.61	-10.80	1.61	4.25	1.00	2.26	0.00
6	67	2.70	.20	-2.50	-13.30	-1.72	1.92	.38	.54	8.65
7	67	2.89	.12	-2.78	-16.07	-.23	.34	0.00	.31	27.32
8	67	2.89	.87	-2.03	-18.10	-.11	.98	0.00	.20	20.50
9	67	2.91	7.28	4.37	-13.73	4.37	2.91	1.00	4.57	.00
10	67	3.07	7.44	4.37	-9.36	2.43	3.07	1.00	7.00	0.00
11	67	2.64	10.83	8.19	-1.17	0.00	2.64	1.00	7.00	0.00
12	67	2.66	1.50	-1.16	-2.33	-2.30	2.66	1.00	4.70	0.00
1	68	2.85	1.65	-1.20	-3.53	-1.20	2.85	.96	3.50	.01

	A	B	C	D	E	F	G	H	I
47	913101	67	1	0.00	4	6	7.00	4	37

35
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0
35
3 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 13 0 0
0 0 0 0 0 0 0 0 0 0 7
35
1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 2 4 0 1 0 5 0
0 0 1 7 0 0 0 0 12 2 9
35
10 0 11 3 0 0 5 1 0 0 6 0 7 1 0 0 0 1 0 0 0 0 5 0
2 5 5 4 0 0 0 0 4 9 12
35
0 0 9 0 0 0 0 0 0 2 0 0 0 0 12 0 0 15 0 0 0 0 0 0
0 0 3 6 0 0 0 0 9 5 0
35
0 0 0 0 0 0 0 0 0 14 0 0 0 0 20 0 0 0 0 0 0 0 0 2
0 0 0 0 0 0 0 0 0 0 9

47 913101AVG. RATIO .63 S.D. .4

AVERAGE DAYS OF STRESS = 0.00 STANDARD DEVIATION = 0.00 FOR MONTH 1 OF THE SEASON

AVERAGE DAYS OF STRESS = .68 STANDARD DEVIATION = 2.52 FOR MONTH 2 OF THE SEASON

AVERAGE DAYS OF STRESS = 1.55 STANDARD DEVIATION = 3.11 FOR MONTH 3 OF THE SEASON

AVERAGE DAYS OF STRESS = 2.53 STANDARD DEVIATION = 3.51 FOR MONTH 4 OF THE SEASON

AVERAGE DAYS OF STRESS = 1.76 STANDARD DEVIATION = 3.79 FOR MONTH 5 OF THE SEASON

AVERAGE DAYS OF STRESS = 1.33 STANDARD DEVIATION = 4.29 FOR MONTH 6 OF THE SEASON

TABLE 23

5. Most frequent month of lowest ratio.

6. Problem months - Calendar month with lowest ratio (e.g., February). Analysis limited to agriculturally significant months.

7. Problem months - Month of season with lowest ratio (e.g., 4). Analysis limited to agriculturally significant months.

8. Average number of days of moisture stress in season.

9. Average number of days of moisture stress in individual months of season.

10. Standard deviation of days of stress in season.

11. Standard deviation of days of stress in individual months of season.

APPENDIX A

BUREAU OF RESOURCE ASSESSMENT AND LAND USE PLANNING

DROUGHT PERCEPTION AND ADJUSTMENT

1. Is this a good (hard) place to be a farmer? Why?
2. How have the rains been this year?
3. What happens if the rains are late? If they do not come?
4. Do the rains fail often? How often?
5. Where is it that the rains are bad? Good?
6. If the rains fail, what can a man do?
7. If there is not much rain, does it make any difference how a man cultivates?
8. What do you think of using irrigation?
9. When there is a drought, what is the reason for it?

APPENDIX B

DROUGHT PERCEPTION AND ADJUSTMENT

1.(a) Is this a food or hard place to be a farmer?

(b) Is the land higher up the mountain better or worse for farming? (cite names of places)

(c) Is the land further from the mountain better or worse for farming? Why is this?

2. How have the rains been this year?

3.(a) What happens if the rains are late?

(b) What happens if they do not come?

4.(a) Do the rains fail often?

(b) How often?

5.(a) Where is it that the rains are bad?

(b) Where is it that the rains are better than here?

(c) How do the rains here compare with those higher on the mountain?

(d) How do they compare with those lower on (or away from) the mountain?

6.(a) If there is a drought, what is the reason for it?

(b) If the rains fail, what can a man do?

7. If there is not much rain, does it make any difference <u>how</u> a man cultivates (i.e., does he change his technique of farming)?

8. If there is not much rain, does it make any difference to <u>what</u> a man cultivates (does he plant different crops)?

9. If there is not much rain, does it make any difference <u>where</u> a man cultivates?

10. What differences occur in the way in which people farm depending on whether they live at a high, middle, or low level on the mountain? What differences are there in types of crops, methods of farming, timing of operations, etc.?

	High Level	Middle Level	Low Level
Crops			
Methods			
Timing			
Other			

11. Why are there differences?
12. Which is most important for good farming in the Ulugurus -- soil or rainfall?
13. In this village what is the best time for planting the following?

    Maize

    Rice

    Millet

    Other crops
14. Do you usually manage to plant at the best time? If "no," what are the problems of planting at the best time?
15. Have you ever used irrigation (any form of water control for cultivation)?

    If so, what type? (describe)

    What do you think of using irrigation?