RESPONSE FARMING IN RAINFED AGRICULTURE

J. Ian Stewart

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Research colleagues have contributed in many important ways to the development of response farming. Their names, titles, contributions and relevant publications may be seen in Appendix B. To all of the above the writer owes a deep debt of gratitude.

Vegetables in the Pink City a decade ago. The need has grown and will be still greater tomorrow. Jaipur, India. February, 1978.

FLASH: Response Farming Enters Computer Age

In effect, this book is a 20-year progress report on the state of development of a new approach to farming in highly variable rainfall zones. Termed Response Farming, the approach depends on a seasonal rainfall prediction at the start of each new rainfall/cropping season, coupled with advice on modifying cropping systems/practices in accordance with the predicted rainfall and rainy season characteristics.

But developments at this moment are accelerating, largely due to completion of programming of the initial version of a new computer software package for specialized analyses of rainfall records and other weather parameters. Collaboration between me and programmer Michael Adams began in June 1987. On February 12, 1988, this manuscript first went to the printer. The next day Michael delivered the new computer program. Two days later I embarked for a month's consulting in Jordan, at the behest ot the USAID Mission in Amman. My assignment was to initiate Response Farming research within the USAID funded Jordan Highlands Agricultural Development Project (JHADP).

With the aid of the new program, the analyses completed in just 26 days were equivalent to all of the analyses presented in this book. Further, the new line of research was begun not only in the JHADP, but was also introduced to researchers in the German (GTZ) Zarqa River Basin Project, the Australian Dryland Farming Project, the University of Jordan and the Jordan University of Science and Technology.

The computer program still requires written documentation and an instruction manual, so is not ready for widespread distribution just yet. Just the same, this advance clearly marks the end of the slow development era and the beginning of the rapid development phase. I believe the outlook is very promising indeed.

Ian Stewart

A SMALL RAINFALL FABLE

Accepting that seasonal rainfall prediction is not presently very precise, the question is how much precision can be attained, and how valuable is that to the farmer? To assist in putting this question into a farmer's perspective, let us play a quick little game.

Imagine you farm a block of land which is irrigated by permanent sprinklers covering the entire area. Like rainfall, they are either on or off and all water received is evenly distributed. Each year your watermaster gives you either one unit of water, or two units or three units, with no advance information as to which it is to be. When you ask for information he replies that he also does not know. He simply turns on the tap according to what comes down his main pipeline.

As the years pass you find this situation to be quite frustrating because there are important differences between the ways you would proceed with one, two or three units of water supply, if only you knew which to expect. When you plead with him once more, he says *"Look, all I know myself at the start of each year is one of two things: I know you will get one or two units but not three, or I know you will get two or three units but not one. Now, how important is that?"*

Harvesting Barley in Marathassa Valley, Cyprus. May, 1963

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SECTION I - INTRODUCTION

CHAPTER 1

Initial Words on Response Farming and the Focus of the Book

Response farming focuses on water, and on farm management with respect to water. The concept is that improved information about water supply prospects, and about expected impacts of alternative actions which might be taken, will equip farmers to more closely meet their goals. This information is required by all farmers everywhere, but the writer believes the greatest need at this time is in rainfed agriculture - specifically in semiarid areas of the developing world. Accordingly, this initial book about response farming will address that situation.

The subject matter presented is technical by nature, but is also inherently interesting and even exciting for all who have a deep interest in self-help development in agriculture, as well as the scientific community, and hopefully others. Accordingly, an attempt has been made to present technical aspects of the subject in understandable graphical forms and language while maintaining accepted scientific standards. This poses a danger of being too technical on the one hand and not exacting enough on the other. Or, worse, simultaneously too boring and too racy. Let's hope otherwise.

Recent research advances have produced a new capability for coping with seasonal rainfall variability in semiarid regions of the developing world. The resulting methodology, termed response farming, works in two steps. Prior to each growing season, a forecast is made concerning expected season rainfall amount, its duration and intensity index (amount/duration). The farmer then modifies his pre-plant and planting time decisions so as to maximize crop yields and returns per unit of expected rain. A second improved forecast, say 30 days after crop germination, guides adjustments of fertilizer rates (upward if rains are good) or plant populations (downward if rains are poor).

The advances have been in three types of studies:

1. Rainfall record analysis to identify suitable crop types and cultivars for production in a given location, made possible by advances in research on crop water balance mechanisms and crop water production functions.
2. Prediction of season rainfall characteristics to provide pre-plant and planting time guidance to farm decisions as above.
3. Simulation modelling of impacts on crop water use and yield (i.e., crop water balances and water production functions), caused by modifying practices -- notably fertilizer rates and plant populations.

The most recent and more unique portion of the research is that on prediction of season rainfall characteristics. The approach to prediction was evolved in Kenya in 1980 and was not tested outside of Kenya until 1985. For most readers this will be the initial introduction to this part of the research and to the package termed response farming. On the other hand, research by the author and colleagues on crop water requirements, water balances and water production functions began in 1967, and a number of publications on these topics are listed in Appendices C and D. It is for this reason that the book concentrates largely on rainfall prediction research, with examples from 20 locations in eleven countries of North America, the Near East, East and West Africa and the Asian Subcontinent.

CHAPTER 2

A Looming Crisis in the Developing World

Declining Per Capita Food Production and Quality of Life in Developing Countries

Presently, some developing countries are in crisis, with inadequate food production and declining quality of life. Additional countries appear to be headed the same direction. Many ideas have been advanced about the nature of the problem, its causes and possible solutions. And clearly, in different locations different factors are dominant. It is not the province of this book to debate these issues. Instead, some aspects of the overall problem will be presented which are addressable to some degree by the response farming approach.

The writer believes the crisis situation, both presently and in the near future, is rooted in the unprecedented rates of population expansion we are experiencing. It is not that the world has too many people per se, but that we are unable to provide adequately for the present doubling of the world population every 25 years or so. A few relevant points follow:

1. The great majority of all people are in the developing countries, and most farm for a living with rainfall as their sole water supply.
2. The families are large and the farms are very small.
3. Cash resources and/or credit are extremely limited and often nonexistent, however worthy the purpose.
4. Population increases, like present populations, are mostly in the rural areas, placing extreme pressure on the land in two ways. First, population per unit of land is swelling in established agricultural communities, resulting in ever increasing demand for greater production per hectare just to maintain present standards, however low. Secondly, waves of migrants are moving into ever drier regions. These are the recurrent drought zones where, paradoxically, each new wave establishes a poorer farming community than the last, and simultaneously removes the best available grazing lands from pastoral peoples and their animals - a double tragedy.

The Food Crisis of the Sixties and the Green Revolution

The last major food crisis was met and conquered by the Green Revolution of the 1960s, which returned India from the brink of starvation and prevented a number of other countries from reaching that point. That success is commonly credited to visionary strides in plant genetics, and the credit is well deserved. However, to successfully meet the new challenge, it is essential that we acknowledge some additional truths about the old one.

The green revolution was made possible by three key aspects rather than one. These are:

1. Genetic advances, primarily in the basic food grains.
2. Widespread irrigation development which assured that water shortages would not limit yields of the improved plants.
3. Massive infusions of chemical fertilizers as well as herbicides, pesticides, etc., required to attain high yields, but which previously were not cost effective due to the lack of an assured water supply.

Post Green Revolution Developments

The Sahelian zone of West Africa has suffered diminished food production on a per capita basis since the early 1970s. Although exacerbated by population growth, there is also a physical reason (documented here in the West Africa portion of the Technical Section). Rainfall throughout the region declined dramatically in 1971 and has not since returned to earlier levels.

Ethiopia starved in 1984 and is presently plunging back into the same situation with the failure of the 1987 rains. Lack of rain in Ethiopia threatens Egypt too, because water levels in Lake Nasser behind the great Aswan Dam essentially depend on flows in the Blue Nile. India once more is reeling under severe and widespread drought conditions, but for the present has ample food stocks. However, farsighted leaders fear for the future because nearly all waters available for irrigated agriculture are now developed.

There is hope in Africa and India and elsewhere for a second green revolution. This hope is nurtured by stunning advances in bioscience since the sixties. Plant geneticists are now heavily invested in the promising new realm of biotechnology. Genetic changes can now be greatly speeded up, and even engineered to order.

Priorities for the Second Green Revolution

Out on the land the problem of water supply remains since the new green revolution is required in rainfed areas where irrigation can play little if any role. No one foresees genetic changes which can bring about high crop yields in low rainfall years. And no one shows willingness to underwrite the costs of inputs such as fertilizers which would enable high yields in high rainfall years, but would be wasted in low rainfall years. Thus, the genetic promise for the needed second green revolution may be stymied. This poses a major danger to those countries which are most in need.

In the crisis of the sixties, we understood how to handle the water and soil fertility constraints. Therefore, the green revolution became a success when the application of new concepts in plant breeding overcame the genetic constraint. For the crisis presently looming, we basically understand how to handle the genetic and fertility constraints. However, it is the writer's belief that the second green revolution will succeed only when new concepts are employed to overcome the water constraint.

SECTION II-A -- TECHNICAL
VARIABLE RAINFALL AND RESPONSE FARMING

CHAPTER 3

The Water Constraint in Low Resource Agriculture in Semiarid Areas

General Comments on the Water Constraint

Recent advances in our understanding of rainfall as a resource in crop production have shed light on two facets of the water constraint - its nature and the requirements for successful management within its confines. The bad news is that the water constraint is far more complex than a case of too little rainfall. This is reflected in present crop yields and returns which are far below the levels that actual rainfall amounts could support - even in semiarid areas.

The good news is that today we possess the needed historical records, research tools and computing power to sort through the complexity and give farmers the information they need to greatly increase their yields and returns per unit of rainfall received. Additional good news is that the information farmers require is simple - simple in its content, simple to transmit to both farm advisers and farmers, and simple for the latter to absorb and apply.

Identifying and Defining Agriculturally Relevant Rainfall/Cropping Season Parameters

The water constraint is rooted in the variability and unpredictability of seasonal rainfall characteristics. Rainfall amount is the parameter usually discussed, but when crop production is the goal, it is useful to divide rainfall amount into two component parameters. These are season duration and intensity. Duration is defined as the number of days from onset of the rains to the final rain date. Intensity (actually an intensity index) is the average rainfall per day - amount divided by duration. With these definitions, one sees that season rainfall amount is he product of duration times the intensity index.

For clarity, definitions are also required for season itself, and for the date of onset and final rain date. Furthermore, the definitions must be fitted to the purpose of the analysis. For example, when a rainfall record is evaluated for overall crop production potential, the season (each year separately) is the period of time which begins on the date of onset and ends on the final rain date. When the analysis is for production of a specified crop(s), the season begins either on the date of onset of the rains or the crop germination date, whichever is later, and ends on the final rain date or crop maturation date, whichever is earlier.

The definition applied to date of onset of the rains may change with the purpose of the analysis and with localized agricultural realities, but in all cases will be based on early season rainfall requirements to safely launch a new crop. In most cases the definition will specify a minimum amount of rainfall stored in the surface soil as the signal for onset. A simpler definition, suitable in some circumstances, would say that onset occurs when total rainfall reaches or exceeds a specified amount within a specified number of days. With these definitions or others, the purpose is always to insure that, as of the date of onset, there is sufficient water in the soil to germinate the seed of the crop in question and maintain the new seedlings until further rains are assured (with a high level of probability).

The definition of final rain date also may change to meet particular needs and circumstances, but must always satisfy the same production-related criterion. The final rain date denotes the last rainfall to effectively augment the crop water supply. An example might be the last rain in excess of one millimeter prior to a specified ending date. Another might be the date when, adding backwards in time from a specified ending date, total rainfall equals or exceeds 10 mm. The latter example would prevent misunderstanding in the situation where rainfall essentially ceases very early, but ineffective small showers occur perhaps a month later, toward the usual time the season ends.

Variability in Rainfall Season Parameters

The five key factors which characterize a rainfall season for crop production have been identified as the onset and final rain dates, rainfall amount, duration and intensity. Let us begin with rainfall amount since that has been the focus of the majority of published studies. It should be noted that most analyses deal only with total annual rainfall - its variability and probabilities of attaining specified amounts. Often such figures bear little relevance to the season rainfall enjoyed by crops in the locality. Here, the discussion will be confined to cropping season rainfall.

Season rainfall amount is notoriously variable in most locations in the world. Typically, it may range from a low around 1/3 of the long term mean to a high of approximately double the mean. Thus, many rainfall records show that the wettest season may produce about six times as much rainfall as the driest season. Variation of this magnitude is both daunting and confusing to farmers whose very lives depend on their making rational decisions about types of crops to be planted, levels of inputs to purchase and specific practices to follow.

However, the great variability in rainfall amount is divided - often something like 50-50 - between its two component parameters, which are season duration and intensity. With reference to the latter, the highest average rainfall per day in any season in the record is often found to be approximately three times the lowest average rainfall per day, roughly half of the variability found in rainfall amount. Similarly, the duration of the shortest season in the record is often only half or even less that of the longest season, accounting for the rest of the variability in rainfall amount.

The remaining parameters which describe a rainfall/cropping season are the date of onset and the final rain date. The date of onset is of particular interest for two reasons. The first is that (by definition) it occurs at the start of the season, before on-farm decisions must be finalized. The second is that it is highly variable, and therefore potentially a predictor of rainfall amount, duration and/or intensity, all of which occur later. If so, it may serve to guide farming decisions for the season at hand. Detailed discussion of the nature, accuracy and usefulness of predictions based on date of onset will follow in appropriate sections.

Typically, the date of onset varies over a time period of approximately half the maximum duration of the season. An example might be a monsoonal area in which onset can occur at any time in the first two months of a possible four month season. In a Mediterranean area, onset may vary over the first four months of a possible eight month rainfall season. If, for the sake of illustration, we assume the rains stop (final rain date) on the same date every year, then the duration of the monsoon season in our example would vary from about 60 to 120 days, while the Mediterranean season duration would vary from 120 to 240 days. And every bit of the variation in both cases would be explained (in fact caused) by variation in the date of onset.

The truth is somewhat different from the above, because there is also variation from one year to another in the final rain date. This causes season duration to be dependent on both the date of onset and the final rain date. But variability of the final rain date is generally over far less a time period than that of the date of onset. In practical terms this means that variation in the date of onset explains most, but not all, variation in season duration. More on prediction later.

The True Nature of the Water Constraint

It was stated earlier that the water constraint is rooted in seasonal rainfall variability and unpredictability. The nature and degree of the variability has just been discussed. Predictability is next, but first it is time to clarify the real nature of the water constraint in semiarid rainfed agriculture.

The tremendous variability means recurrent drought, with increasing frequency as one moves to lower rainfall zones. It is important to note there are also many fair, good and, infrequently, even excellent rainfall seasons in these same zones. But no one knows when to expect which kind of season, i.e.,predictability is nil at present. Thus the risk of failure, certainly of the more desired crops, is high, occurring, say, four or even five seasons in ten on average. And the risk is unavoidable, locked in so to speak, by the inability to predict.

The result is extreme caution on everyone's part - not only the farmer, but his advisors who assist in formulating his strategy, and also would-be creditors who could fund the purchase of inputs to reach higher yield levels in better rainfall seasons. They do not do so; their money would be lost too often with virtually no hope of repayment.

The inevitable consequence of these circumstances is what the writer terms "1-ton agriculture". This means the average seasonal production of basic food grain crops rides along somewhere below, but approaching, one metric ton per hectare (892 lb/ac). This yield level is set not by shortage of water, but instead by the natural regeneration rate of soil fertility - in the absence of chemical fertilizer. The irony of this is that in virtually any rainfall zone where farmers can survive at all, these yield levels are far below the potential set by the average rainfall.

The inherent core of this scenario is incessant poverty laced with periods of famine. With increasing population in these areas we may expect still worse. Unfortunately, this is not a bad dream, but is the actual situation on an ever broadening scale.

CHAPTER 4
Response Farming: The Proposed Intervention

The General Approach and Notes on Usefulness

Two approaches to overcoming the water constraint present themselves. The more obvious one is to take control of the water supply and dispense it through irrigation schemes, but that is ruled out for this discussion. The remaining alternative is prediction of expected rainfall behavior, season by season, coupled with responsive management of the cropping system. The overall goal is to maximize crop yields and returns per unit of rainfall received. Considering the different farm activities required to achieve this, it is more useful to express the goal in two parts. The first is to maximize the fraction of total rainfall actually used by crops - termed evapotranspiration - or, conversely, to minimize the fraction wasted. Secondly, we wish to maximize crop yields and returns per unit of water evapotranspired.

When in place in the field, the response farming program is essentially an information program, providing localized information about expected rainfall behavior in the approaching season and about how best to proceed in the light of the rainfall forecast. The latter information will be offered at two levels. The first is a generalized level which simply points the directions decisions should take. Experienced farmers will already possess this knowledge. The second level of information will be in the form of detailed recommendations for decision making on all relevant (water supply related) questions for production of specific crops important to the locality. The new recommendations will resemble those made today and will flow from the same research sources. The difference is they will not be the same every season as if average rainfall prevailed. Instead, they will be modified each season in accordance with actual rainfall expectations.

No suggestion is intended that the forecasting system will achieve perfection. The expectation is that the forecasts will be sufficiently accurate to reduce the economic and basic food supply production risks to levels accepted in more dependable water supply areas. The effect should be improved decision making on both ends of the rainfall scale. In better rainfall seasons, credit for purchasing inputs can be injected into the system with a high degree of confidence. This will enable the higher yields and returns required to break the poverty syndrome and provide the cushion needed for low rainfall seasons. And when low rainfall is anticipated, concentration can be focused on assuring the family food supply with minimum cost and risk.

In addition to serving farmers, information developed using this methodology can benefit other programs as well. Examples include:

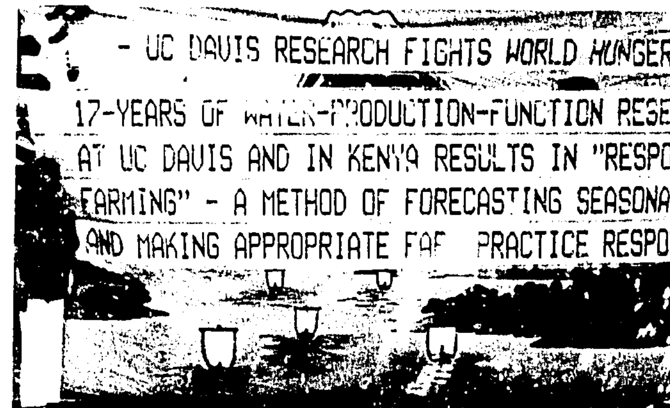
1. Early warning and crop yield forecasting for national food planning/food security programs.
2. Detection and warning of heightened threats of flooding and/or soil erosion.
3. Crop insurance programs.
4. Planning for and controlling hydropower generation.

Response Farming Origins and Research Aspects

It was at the University of California at Davis (UCD), from 1966 to 1977, that the writer and colleagues carried out early research on crop water production functions and crop water balance relationships. These are the first two principal components of the new methodology.

However, Kenya is where the response farming package came together. In late 1977 the writer joined the U.S. Department of Agriculture to extend the UCD research into the low resource, rainfed agricultural setting of the recurrent drought zones of eastern Kenya. The project continued through 1983, sponsored by the U.S. Agency for International Development and the Government of Kenya, the latter represented by the Kenya Agricultural Research Institute.

There, in research aimed at development of optimal cropping systems for different rainfall zones, it became evident that no single system could be optimal, or even nearly so, in the highly variable rainfall conditions encountered from year to year at any particular location. This realization led to a search for predictability in the rainfall records, and the concept of a flexible cropping system governed by rainfall predictions made as early as possible prior to each cropping season. Thus research into rainfall predictability, specifically for crop production purposes, became the third research component of the package.



Robbie Stewart, WHARF Founding Director, Picnic Day, UC Davis. April 1984.

The fourth and final component of response farming research is modelling the impacts of farmers' management decisions on crop water utilization and consequent yield. Certain management decisions have received particular research attention because of their overriding importance to both water use efficiency and to cost effectiveness in farming. These are a. plant population (numbers of plants per hectare), as influenced by seeding rates, row and plant spacings, and by thinning in the early growing period, and b. chemical fertilization, which is essential for higher yields when the rains warrant the investment - but wastes precious capital and sometimes may actually harm crop yields when rains are poor and the best possible minimal yields are desperately required for survival of the farmer and his family.

Both plant population and fertilization lend themselves to manipulation to conform with actual rainfall conditions early in the growing cycle, say 30 days after germination. For example, plant numbers can be reduced if rains are found to be in the lower part of the predicted range. Or fertilizer, especially nitrogen, can be augmented if rains are in the upper part of the expected range. These actions are important aspects of the response farming strategy. Our own research and the great amount of published literature on these topics must be modelled in order to provide farmers, first, with rainfall predictions and, second, with information on the most effective responses to make to those predictions. That is the essence of response farming.

Veihmeyer Hall, UC Davis — Home to Water Science section of the Department of Land, Air and Water Resources — where research toward the Response Farming development began in September, 1966.

CHAPTER 5

Rainfall Prediction to Guide Seasonal Farm Decisions

Prediction Requirements for Farm Development versus Seasonal Cropping Guidance

It is the great variability in weather, both short term and long term, which creates the incessant demand for predictive information. A key issue for agriculture in this regard is seasonal variability of rainfall. Both deficient and excess rainfall periods can create serious management problems. Irrigation farmers are concerned because their water supplies ultimately depend on rainfall - one of the most variable and most important weather factors. Rainfed farmers have the same concerns, but even more strongly and in every cropping season because they lack the water supply and flood control buffering features provided by irrigation developments.

Long term rainfall probabilities are of particular interest when agriculture is being developed in a region. Designers of dams and drainage structures rely heavily on these types of data to assure their works will withstand the strains of all but the rarest rainfall events. Development works on individual farms, including levelling, bench or contour terracing, etc., for control of soil erosion or to drain excess water or other purposes, as well as construction of small irrigation dams, ponds, etc., are also based on long term probabilities. Consequently, calculation and publication of this type of rainfall information has received a great deal of attention.

Development of a region for agriculture, and of individual farms in the region, is in essence a one-time activity which must consider all the long term variability in climate. However, producing a crop on a certain field in the current rainfall season raises a host of different considerations. More precise information about expected weather, rainfall in particular, would be extremely helpful to the farmer at the start of the season and in the early part of the season when basic decisions are being made.

The problem is this: Long term rainfall probabilities do not satisfactorily address farmers' questions about how to maximize production and returns per unit of rainfall in the approaching season.

One reason is that long term probabilities, by their nature, cover all rainfall contingencies. As noted earlier, seasonal rainfall amounts typically range from as great as two times normal to as little as 1/3 normal. Rainfall which is near twice normal generally poses a danger of crop water-logging and soil erosion. Rainfall below say 60% or 70% normal means yields of crops normally grown in the locality may be disastrously low and all rainfall must be retained and utilized. Correct decisions to handle these two extremes may be diametrically opposed.

A second reason is that long term rainfall probabilities do not deal with variability in either the duration or average daily rainfall intensity of the season. Yet these are critical factors when deciding which crops and cultivars to emphasize in the season's plantings, and whether to plant before the onset of the rains or after.

Onset Relationships for the Approaching Season, to Quantify Possible Ranges of Rainfall Behavior and Probabilities Within the Ranges

Our knowledge of expected seasonal rainfall characteristics is no longer confined to long term rainfall probabilities. The discovery in 1980 that the amount of rainfall in the coming season as well as its duration and intensity (index) are all linked to the date of onset of the rains(as defined for cropping purposes) has profound practical implications. It means the generally accepted dogma that, in each new cropping season, farmers face the possibility of a recurrence of any type of season which may have occurred in the recorded history of the location is false. The truth is they face only a portion of the historical range of occurrences and that portion can be readily defined for them as each new season approaches prior to their land preparation and planting operations.

The way it works is simplicity itself. Seasons having early onset, i.e., early with respect to the historical record of onset dates, are of relatively longer duration and produce amounts of rainfall in the upper portion of the historical range. Late onset seasons are the opposite. They are relatively short in duration and fall in the lower portion of the range of rainfall amounts.

The foregoing paragraphs raise some obvious questions:

Q: Is it really so simple? Is it universally true that early seasons are relatively longer and produce more rainfall than late seasons?

A: Studies of rainfall in 18 countries of Africa, Asia, the Near East and North America all agree on the simple linkage described between onset and season duration. In the case of rainfall amount, the linkage is generally looser but is present in every case examined, save one. Studies by the author in Sri Lanka in August and September, 1987 have revealed the first exception found anywhere. The N.E. monsoon in the dry zone (Maha Illuppallama) over the 1905-85 period has produced as much rainfall, on average, in late (short duration) seasons as in early seasons. These rains are more intense and produce more runoff. This unusual phenomenon helps to explain the centuries old tradition in the island of catching runoff waters in reservoirs (village "tanks") which is then used to irrigate and extend the growing season.

Q: If this simple relationship is so widespread and so potentially useful, why hasn't it been discovered and applied long ago?

A: It has been - at least the strong dependency of season duration on date of onset has. In the author's experience, the farmers of India, Jordan and West Africa all have long traditions of changing the crops they plant (more precisely, the crops and varieties they emphasize in their planting) if onset of the rains is delayed beyond certain dates. The change is from longer maturity crops/varieties with relatively high water requirements to shorter term cultivars which are less demanding and often less desired, but which offer more food security.

In India, both farmers and scientists have noticed the season duration relationship and the latter have carried out research with the goal of providing improved guidance to farmers as to how to respond to late onset conditions. However, such research has been severely limited by restricted availability of detailed, long term rainfall data, and even more by the massive computational requirements of this type of study. Today's ready access to the power of computers makes it possible for the first time in history to organize and analyze rainfall records by the thousands, as must be done in order to develop guidelines for individual farming communities.

Q: Exactly how reliable are these onset relationships and to what degree can they provide useful guidance to farmers - and for what types of decision making?

A: The nature and accuracy of predictions we are presently capable of making forms the major part of this book. Detailed examples are presented for a number of different sets of conditions in locations around the world. These include California, the Mediterranean region, East Africa, West Africa and the Asian Subcontinent.

Responding to Rainfall Predictions: Alternative Farm Management Decisions

Examples of important pre-plant and planting time decisions which are influenced by farmers' expectations of rainfall amount, duration and intensity index include:

1. Land preparation and tillage oriented toward retention of all rainfall, e.g.,blocked, flat furrows or small basins, versus measures to affect drainage of excess rainfall from the land, such as sloping furrows.
2. Choice of higher water requirement market or food crops, with particularly desirable traits and large potential yields, versus lower water requirement crops which offer insurance for the family food supply.
3. Choice of intercropping two or more crops in the same field, known to be advantageous with adequate rainfall, versus monocropping to insure at least subsistence level production if rainfall should be low.
4. Planting in narrow rows with high seed and initial fertilizer rates to maximize production with high rainfall, versus wide rows and reduced seed and fertilizer rates for more assured and cost effective food production with limited water.
5. Dry planting prior to the onset of the rains, versus planting after the soil contains sufficient water to germinate and succor seedlings through possible early season dry spells.

SECTION II-B -- TECHNICAL

Predictive Behavior of Seasonal Rainfall -- Illustrative Examples Around the Globe

CHAPTER 6

Davis, California Rainfall Behavior: An Introductory Example

The 100-year rainfall record at Davis, California - the home of WHARF and UCD - provides a fitting initial example of rainfall behavior with respect to date of onset for cropping purposes. Figure 1 presents 100 years of rainfall occurrences in a scatter diagram which, due to its appearance, is termed a "rainfall flag." This type of representation emphasizes the importance of the date of onset for cropping purposes - wheat production in this instance.

The date of onset is a key concept in the response farming methodology, because it forces the rainfall analyst and those providing guidance to farmers to pay attention to the same rainfall factors the farmer is concerned with - the amount of crop extractable water stored in his soil at planting time (most particularly the amount stored in the surface soil at the time of seedling germination) and all subsequent rainfall prior to the maturity of his crop. Other rainfall is of no direct interest for the current crop season.

The precise definition of the date of onset for a specified crop and locality requires some study of the local conditions. Major considerations include soil water-holding capacity and normal depth of seed placement, the expected evaporative conditions of the atmosphere in the planting and seedling periods, the pattern of early leafing and water use by the particular crop, and the length of dry spells to be expected after the initial rains - as revealed by the detailed rainfall record.

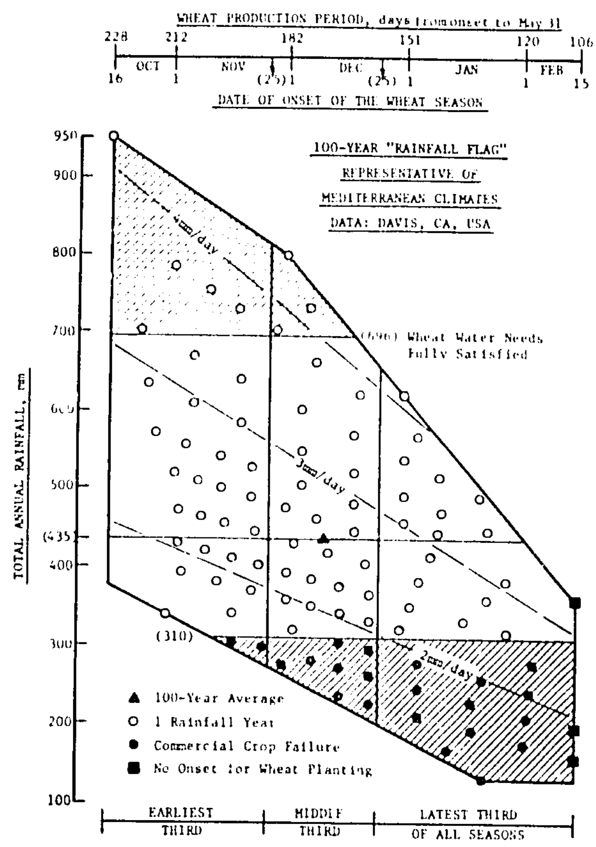
In the Davis example, onset is defined as 30 mm (1.2 in) of water stored from the new rains in the surface soil. Depending on the early rainfall pattern and evaporation losses between rains, this amount of storage could accrue in one day, a few days, or a longer period. This requires a small water balance program for determination of the date in each year of record.

Diverting for a moment, the practical determination of onset at the farm level will be made easy. Either a trained advisor will announce the onset of the rains publicly (radio, TV, farmer meetings, etc.) or an individual may have a device, such as a box of soil with a glass side, marked at the level representing onset. In fact, at the farm level, all response farming activities will be easily implemented by uneducated farmers. This will be clarified as we proceed.

The explanation of Figure 1 is somewhat lengthy because, at least for most readers, many new ideas are being introduced at once. **Subsequent examples will introduce additional factors which will be readily understandable provided the information in Figure 1 is understood.** Therefore, later explanations and discussions will be more brief.

FIGURE 1

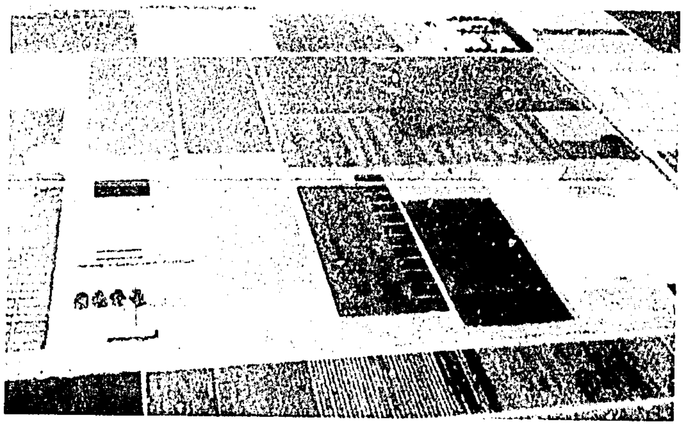
"Rainfall Flag" representation of probabilities for rainfall amounts, wheat growth periods and average daily rainfall intensities, all as related to date of onset of the rainy season for wheat production.



The following 11 items explain Figure 1 in detail:

1. Figure 1 is a graph drawn to look something like a drooping flag. It contains 100 circles and squares, each representing total rainfall amount and the date of onset for wheat production in one of the past 100 years. The triangle in the center of the flag represents the average of all years. Note that the rainfall year in Mediterranean climates is taken to be July 1 through June 30, because rains begin in the fall, and continue through the winter and spring of the next year.

2. There are two important scales on the graph, one upright and the other horizontal across the top. The upright scale, which looks like the "flagpole," shows total annual rainfall in millimeters (mm). (To convert to inches, an easily memorable relationship is 100 mm = 4 inches). On the upright scale we see that the average rainfall at Davis is 435 mm (17.1 in), but



Water Science experimental fields, UC Davis. July 1972.

rainfall in a year has been as little as 130 mm (5.1 in) or as much as 950 mm (37.4in).

3. The most important horizontal scale near the top is that labelled "Date of Onset of the Wheat Season." If we look at that scale directly above the triangle in the middle of the flag, it indicates that the average date of onset is Dec 10. However, the extremes of the scale show that onset may be as early as Oct 16 or as late as Feb 15. The dates of onset are divided into three time periods each representing a third of all past onsets. These divisions are shown on the lower scale and by the vertical lines within the flag. The earliest third of onsets contains 33 years of record, the middle third 34 years and the latest third, the remaining 33 years.
4. Now the "droop" in the flag takes on more meaning. It shows that all of the rainfall seasons which started early were in the upper part of the rainfall range while all of the late starting years were in the lower part of the range. In other words, a correlation exists between annual rainfall amount. and the date of onset of rains adequate for safe planting of wheat.
5. The topmost scale labelled "Wheat Production Period" shows another correlation of interest to wheat farmers. The wheat crop will become mature approximately May 31 whether it is planted in November or January. But if the rains begin earlier, not only is the growing time longer, but, since the rainfall expectation is greater, the yield expectation is also greater. The scale shows the number of days from onset of the rains until May 31. The range is great, from 228 days for onset on Oct 16 to as little as 106 days for onset on Feb 15.
6. Within the flag are three sloping lines labelled 4, 3 or 2 mm/day. They represent the average daily rainfall amount from onset until May 31. This is calculated simply by dividing total rainfall (flagpole) by the days in the wheat production period (top scale). For example, the average rainfall is 435mm and average production period is 173 days (onset Dec 10), resulting in an average intensity of 435/173 = 2.5 mm/day. (The careful reader may note that the above calculation is not quite fair, because part of total annual rainfall is outside of the wheat production period. In Mediterranean climates, roughly 90% of the rain is within the season, so the actual average intensity for wheat at Davis is about 0.9 x 2.5= 2.25 mm/day. Other examples in this book will deal primarily with cropping season rainfall rather than annual rainfall. In this first example, total annual rainfall is used purposely so the information developed may be compared directly to published rainfall probabilities.)
7. Continuing with rainfall intensities, the figure shows that later onset seasons tend not only to have less rainfall, but less rainfall per day. This creates still more stress in the crop because evaporative rates, and therefore daily water requirements of the crop, rise sharply after February and continue rising even while rainfall is slowing or stopping altogether.
8. Figure 1 may be used to look at probabilities of annual rainfall. Since 100 years are represented, all that is needed is to lay a ruler across the figure at any rainfall level of interest and count the data points above the ruler to determine the probability (%) of getting that much rainfall or more. For example, there are 46 data points above the mean line at 435 mm. The probability of getting average or above is 46%. Or, the probability of getting less than average is 54%. Usually rainfall averages are even more distorted downward because they tend to be made up from relatively more low rainfall years and fewer high rainfall years. Therefore a more useful statistic for assessing the agricultural potential of a location might be the median which indicates half of the seasons are higher and half lower.
9. Rainfall probabilities are more directly useful when they are related to potential for production of one or more crops of interest. This requires a knowledge of water balance and water production function relationships - in other words, a relation between rainfall and actual crop water use, and a second relation between crop water use and yield. These are complicated topics which will receive some but not full treatment in this book.

Meteorological station in Water Science experimental fields, UC Davis. July, 1971.

Figure 1 relates total annual rainfall to potential wheat production. In particular, two lines are drawn across the figure indicating that **a.** 696 mm of annual rainfall will fully satisfy wheat water requirements, and **b.** the crop will be an economic failure if annual rainfall is 310 or less. These lines are only illustrative because it is not possible to draw them definitively. The actual values vary with many factors, a few of which are the percentage of annual rainfall which actually occurs in the growing season (or is stored in the root zone), the soil depth and water holding capacity, the evaporative rates during the growing season, the price ratios between product and inputs, and others. Still, it is useful to draw such lines provided they are based on reasonable assumptions, because they show the general nature of the situation if not all the correct detail.

As an example, suppose in a given case the land is sloping and, due to runoff, 800 mm of total rainfall is needed to satisfy wheat water requirements. Or, the land is superb and only 600 mm are required. In either case we would see in the figure that water requirements are only satisfied with early onset of the rains, and never with late onset. The same is true for the economic crop failure point which would depend a lot on the farmers' circumstances as well as total rainfall, etc. If this occurred at 400 mm or 200 mm instead of 310 mm, the figure would still show the nature of our situation - which is that the probability of failure with early onset is low, and with late onset, is high.

Still the reader should know that the lines in Figure 1 are drawn with a considerable underpinning of actual research data. The wheat water requirement at Davis is 470 mm - measured for four years in the large lysimeters at UCD by W.O. Pruitt and J. Hatfield. Since only about 90% of annual rainfall is in the wheat season, the effective requirement in Figure 1 is immediately increased to 470/.90 = 522 mm.

A second increase in the effective water requirement for wheat in the figure derives from water balance studies in rainfed agriculture in Kenya which indicate that approximately 75% of season rainfall is typically used by the crop on rolling lands like those used for dry farmed wheat in the Davis area. Thus 522/.75 = 696 mm (27.4 in) - the rainfall figure assumed to fully satisfy wheat water requirements in Figure 1.

The economic failure line drawn at 310 mm (12.2 in) represents a wheat yield of 2,000 kg/ha, roughly 30 bushels per acre. The water production function assumed is as follows:

$$Y = 12.32\,R - 1820$$

where Y is the potential wheat yield, as limited by water only, expressed in kg/ha.

and R is annual rainfall, expressed in mm.

This is a straight line function which indicates that 148 mm of rain (1820/12.32 = 148) is required to begin grain production, after which each mm of rain is associated with production of 12.32 kg/ha of wheat until the rainfall requirement of 696 mm is reached. Maximum potential yield assumed is approximately 6,750 kg/ha (about 100 bu/ac). As previously noted, this function again assumes 90% of rainfall in the wheat season, and 75% utilization by the crop.

10. Continuing to assume that 696 mm of rainfall permits maximum yield of wheat and 310 mm marks the economic failure level, one may now calculate rainfall probabilities of direct interest to wheat growers in the Davis area. To do this the range of possible rainfall amounts is divided into four groupings.

    These are:

    i. **Rainfall greater than 696 mm,** indicating maximum yield but also possible problems with soil erosion or crop loss from waterlogging due to excess water.

    ii. **Rainfall above average,** ranging up to full satisfaction of wheat water requirements, i.e., 436-696 mm.

    iii. **Rainfall below average but above the economic failure level** (311-435 mm).

    iv. **Rainfall below the failure line,** i.e., 310 mm or less.

    Laying a ruler across Figure 1 at rainfall levels of 696, 435 and 310mm, and counting the data points, shows an 8% probability of maximum yield and excess water, a 38% probability of above average production but less than maximum, a 29% probability of below average production but still profitable, and a 25% probability of failure due to rainfall less than 311 mm. Note that the black square on the far right of Figure 1 at a rainfall level of 360 mm has been included with the failure group below 311 mm. This was a year when adequate onset conditions for planting wheat never occurred.

11. The rainfall probabilities presented above are comparable to those often published, in that all years are considered together, implying that any approaching year (or wheat season) could be like any of the years in the past, except that some conditions are more probable than others. Figure 1, however, shows that this is simply not true. If onset were to occur on the earliest date in the record (Oct 16) the probabilities for that particular year would be vastly different from the overall probabilities. And with each day that passes without onset after Oct 16, the probabilities shift again -- downward, as shown in the figure. A practical example of how this works and how better information about rainfall expectations might be provided to farmers, will be presented in Figure 2 and Table 1.

William O. Pruitt, Member, WHARF Professional Advisory Council, walking toward large floating lysimeter where experimental wheat harvest nears completion, UC Davis. June, 1977.

Figure 2 first groups all 100 years together next to the rainfall scale on the left. This is comparable to published rainfall probabilities which now may be recognized as simply the "flagpole," with the informative "flag" wrapped tightly around it. Next, in a sense, the flag is unfurled, revealing three different rainfall ranges and three different sets of probabilities, associated with the three onset periods. For convenience, the different sets of probabilities are displayed in Table 1. In Figure 2 it may be seen that if onset occurs by Nov 25 (say Thanksgiving), the probability of failure has dropped to 2/33 or just 6%, instead of the overall figure of 25%. And these failures are not as dismal as failures with later onset. On the other hand, if onset is after Dec 25 (Christmas), the probability of a maximum crop is zero while the chance of failure, including dismal failure, has shot up to 46%, approaching one year in two

A farmer armed with this knowledge would want to alter his game plan if Christmas arrived without onset of the rains. He might wish to forget wheat and fallow his land, or switch to an alternative crop. If he plants wheat he likely would reduce his seed rate and certainly should reduce his fertilizer usage. But he would not be con-

TABLE 1 - DAVIS, CALIFORNIA, USA:

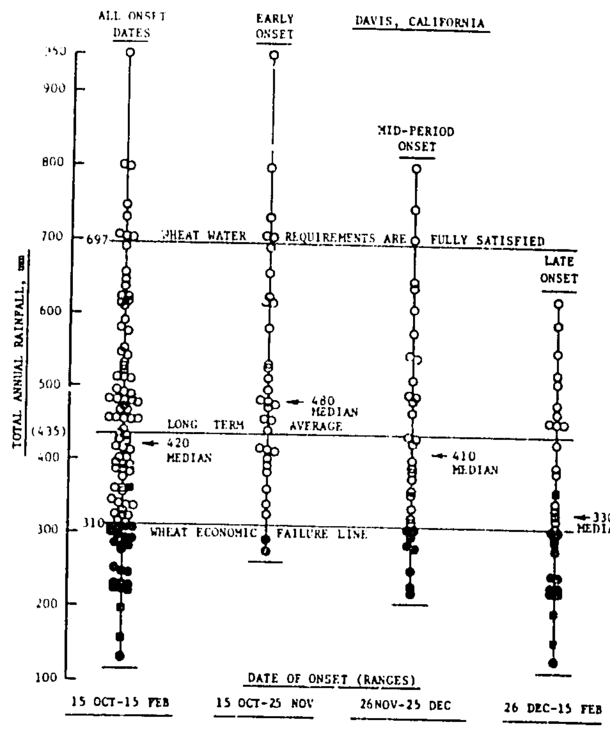
100-year rainfall probabilities as they relate to wheat production potential, compared to probabilities for three groups of years within the 100-year record, differentiated by dates of onset of the rainy period. Derived from Figure 1.

			- - - - - - PROBABILITIES, % - - - - - -			
			WHEAT YIELD & RAINFALL(mm) EXPECTATIONS			
ONSET PERIOD dates	TOTAL YEARS no.	AVERAGE RAINFALL mm	EXCESS WATER 950-697	ABOVE AVERAGE 696-436	BELOW AVERAGE 435-311	ECONOMIC FAILURE 310-130
(ALL: Oct-Feb*)	(100)	(435)	(8)	(38)	(29)	(25)
EARLY: to Nov 26	33	513	15	52	27	6
MIDDLE: 27 Nov-Dec 25	34	435	9	32	35	24
LATE: Dec 26 Onward	33	344	0	30	24	46

*No onset 3 years in 100 (included in failures)

FIGURE 2

Davis, California: 100 years of annual rainfall, showing the overall range of occurrences on the left, followed by three reduced ranges -- differentiated solely on the basis of date of onset for wheat production purposes. See text for discussion.



cerned with special land preparation to assure drainage of excess water. Rather, he would till in a manner to catch and retain every drop of rain.

These are just a few examples to begin to illustrate the far reaching possibilities of improving farm management by providing farmers with the new rainfall information - new in the sense that it embodies a higher level of predictability than previously available, and new in its direct linkage to production of specific crops. The following section will amplify this approach in terms of applications in developing countries of the Mediterranean region.

Before proceeding, it may be useful to point out that the examples to be presented are from a number of countries in different parts of the World. They form a progression, with each building on what has gone before, and each introducing new aspects of the response farming approach. Clear understanding of earlier examples will be essential for understanding later ones. Thus a brief recapping of the essential points about Figure 1 may be in order. The key elements are:

1. Each datum point represents one year of rainfall history, showing the total amount of rainfall which occurred, and the date of onset - the first date when conditions became right for seeding and starting a crop of wheat. The rainfall amount is shown on the vertical

scale on the left and the date of onset is shown on the horizontal scale at the top of the figure.

2. All data points are enclosed by a boundary line, making the whole scatter diagram look like a flag dropping away from the vertical scale on the left, which resembles the flagpole. One quickly sees that the highest rainfall years are near the flagpole, which means onset was relatively early. The lowest rainfall years are those at the drooping end of the flag, related to late onset.

3. A second horizontal scale at the top, labelled "Wheat Production Period", shows the number of growing days in the season, from planting and germination at onset to physiological maturity on May 31. This shows that early onset seasons are of longer duration than are late onset seasons.

4. Dashed lines within the flag indicate average rainfall intensities throughout the growing season. Higher intensities are near the top boundary of the flag and lower intensities are in the lower part of the flag. The intensities are easily calculated for any year, simply by dividing rainfall amount by the number of days duration of the season. At Davis, earlier onset seasons not only have more rainfall and longer duration, but also higher average intensities than do late onset seasons.

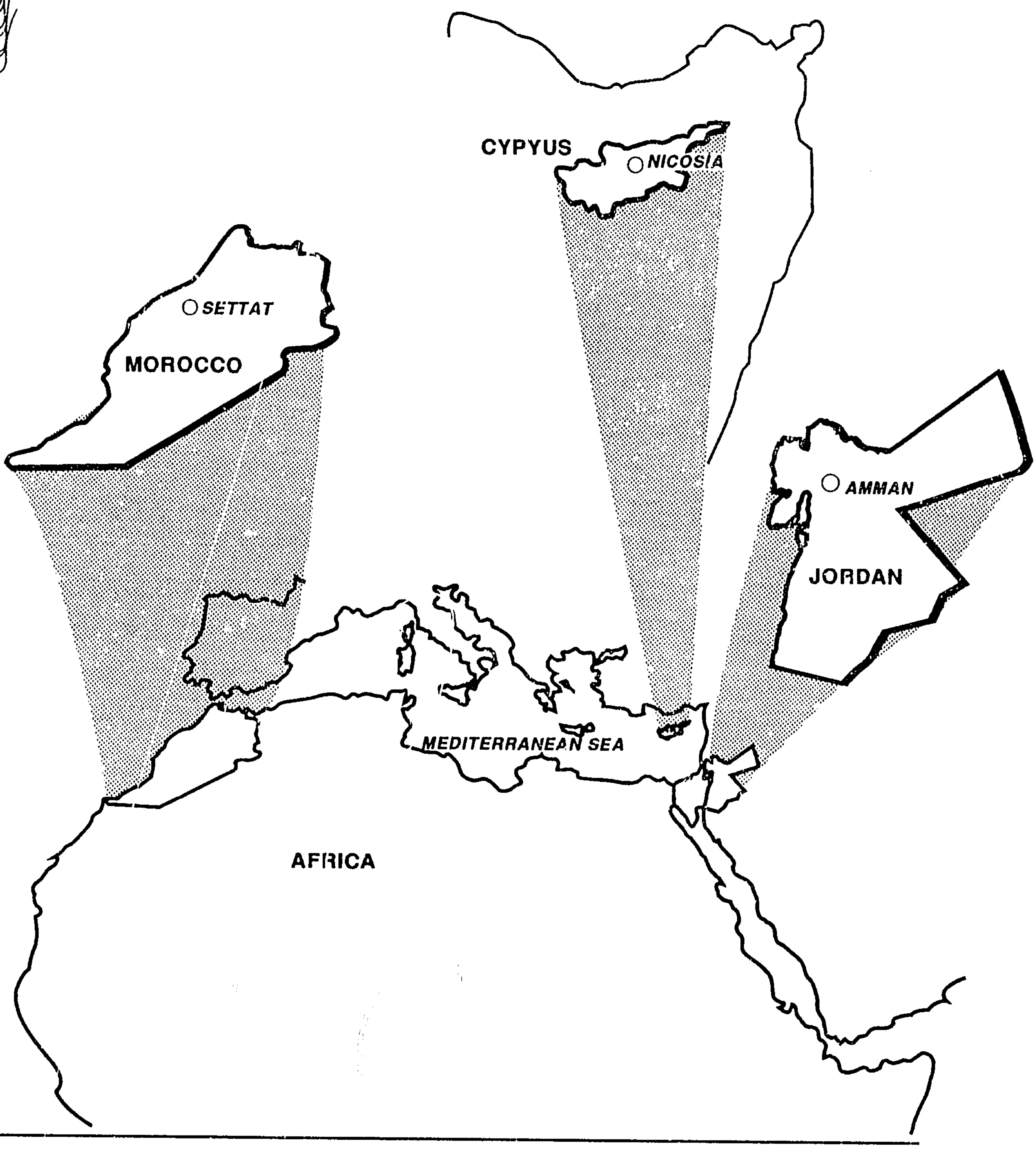
5. Figure 1 covers exactly 100 years of rainfall record so each year equals one percent of all occurrences. Therefore a ruler laid across the figure horizontally at any rainfall level of interest will indicate the probability (%) of receiving that much rain or some greater amount. Simply count the data points above the ruler to determine the probability. Note that the same determination could be done with a 50-year record, counting each year as two percent, or a 20-year record counting each year as five percent.

6. Horizontal lines across the flag suggest linkages between rainfall amounts and potential wheat yield levels. The lines are based on research on **a.** water production functions which relate potential crop yields to actual crop water utilization, and **b.** water balance calculations relating actual crop water utilization to gross water supply - in this case to annual rainfall.

7. Vertical lines through the flag in Figure 1 divide it into three sets of years, based on different dates of onset. Thus, one may view the probabilities of reaching different wheat yield potentials separately for years with early onset versus mid-period versus late onset years.

With the above reminders, we will now proceed to show examples in the Mediterranean region. They are similar to the Davis example but will introduce new aspects.

TECHNICAL SECTION II-C
THE MEDITERRANEAN: WEST TO EAST TRANSECT



CHAPTER 7
Producing the Staff of Life

Wheat the Common Crop

Throughout the Near East region, rainfed agriculture is dominant, occupying 88% of the total cultivated land in eleven countries studied in depth by the Food and Agriculture Organization of the United Nations (FAO, 1982). In nearly all of these countries, wheat is the principal rainfed crop. Therefore, the majority of analyses in this section are made with respect to wheat production. However, a number of other crops are discussed and compared in connection with traditional agriculture in Jordan.

Defining the Rainy Season for Wheat Production

As in the Davis example, the date of onset is defined as the first day when accumulated soil water reaches 30 mm or more. Runoff losses are assumed to be zero, so a 30+ mm rain in one day meets the criterion for onset. However, if the 30 mm must be accumulated over a period of two or more days, then appropriate evaporation losses are applied, making the total rainfall required more than 30 mm. This requires simple water balance calculations based on knowledge of how evaporation from the soil surface proceeds in different wetting/drying sequences. The end of the season is taken as May 31 when wheat in the region is physiologically mature and can no longer gainfully utilize water.

Yields of rainfed wheat in the FAO study cited above were found to be low, less than 1.0 t/ha, and only 57% of available cropland in the rainfed sector was being planted in any given year. The present study develops information to attack both of these problems. Guidance can be provided to farmers for reduced-risk selection among alternative crops to plant, and for improving their levels of inputs, particularly fertilizers, to more closely match rainfall levels for yield maximization per unit of water.

Rainfall Characteristics at Selected Wheat Production Sites

Long term daily rainfall records were obtained from three wheat production sites which form a transect across the Mediterranean Basin. The first record is from Settat, Morocco, supplied by courtesy of Dr. Darrell Watts, Leader, USAID/INRA Dryland Agriculture Applied Research Project. The second record is from Nicosia, Cyprus, courtesy of the Cyprus Meteorological Department, and the third is from Old Amman Airport, Jordan, courtesy of the Water Authority of Jordan. Long term average rainfall figures for the three selected locations are shown in Table 2 by months as well as annually.

It is simple coincidence that the three selected sites in

TABLE 2

Long term mean rainfall (mm) at three selected wheat producing locations in the Near East region, monthly and annual

SITES	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	YEAR
Settat	8	44	50	68	64	67	50	45	17	3	0	0	416
Nicosia	10	26	35	75	69	48	36	20	18	11	2	6	356
Amman	0	6	30	52	66	57	52	16	4	0	0	0	283

Table 2 decline in normal rainfall amount as one proceeds from Morocco in the west to Jordan in the east. Different selections might reverse or change this order. However, it is of direct interest to note that rainfall in the main part of the rainy season (Dec, Jan, Feb, Mar) is nearly equal at all three sites, being 249, 228 and 227 mm respectively. Thus there is a decline in both early and late rainfall as one proceeds from west to east.

The analyses to be presented incorporate the following definitions:

1. The wheat production period is the number of days from onset through May 31.
2. The duration of the rainy period is the number of days from onset to the last date before June1 when rainfall equals or exceeds 1.0 mm.
3. Wheat season rainfall amount is the total from onset (including accumulated soil water on the date of onset) to the last rainfall before June 1.
4. Wheat season rainfall intensity is the average amount of rainfall per day in the wheat production period. It is determined by dividing wheat season rainfall amount (3 above) by days in the wheat production period (1 above).

Figures 3, 4 and 5 show "rainfall flags" from Morocco, Cyprus and Jordan respectively, similar in nature to the example from Davis, California (Figure 1). An important difference is that the vertical scale has been changed from total annual rainfall to total wheat season rainfall, excluding rainfall before onset and following wheat maturation.

Changes have also been made in the rainfall levels which correspond to wheat yield levels of greatest interest. Horizontal lines in Figures 3, 4 and 5 are drawn at 205 mm, 335 mm and 625 mm. These lines separate the rainfall scale into four categories which are explained on the right side of the figures. For example, the lowest category termed "subsistence failure" refers to rainfall levels below 205 mm and wheat yields of 300 kg/ha or less. The reader will recognize that judgement is involved in the selection of these numbers. They are based on 9 years of published rainfall and wheat yield data for several Districts of Amman, Irbid and Balqa Governorates of Jordan, and on the local perception that 300 kg/ha or less constitutes failure. It should be noted also this relates to production without the use of commercial fertilizers, herbicides or other such inputs.

The higher rainfall categories with separations at 625 and 335 mm refer to commercial wheat production using fertilizers, etc, and are derived from the previously noted lysimeter research by W.O. Pruitt and J. Hatfield, at UC Davis on wheat water requirements (unpublished) and from water production function research by the author.

Wheat water requirements at Davis, California were found to be 470 mm (maximum evapotranspiration). Assuming 75% efficiency of water use, this translates to 625 mm of rainfall. Greater rainfall is assumed to be excess to needs and possibly an erosion or waterlogging hazard.

The water production function assumed for rainfed commercial wheat in these examples is as follows:

YIELD (kg/ha) = 10.1 RAIN (mm) - 1350

At 625 mm rainfall, this function indicates a maximum wheat yield of 4,962 kg/ha or approximately 5 t/ha. At 335 mm rainfall the indicated yield is 2,033 kg/ha or approximately 2 t/ha. As in the Davis example (Figure 1), this is assumed to be the lowest yield level which will be profitable in commercial production.

CHAPTER 8

Morocco

Figure 3 presents a "rainfall flag" for Settat, Morocco, based on 36 years for which data are available over the period 1935/36 to 1981/82. As at Davis, California, the range of onset dates is great, spanning the period from Oct 7 to Jan 30 inclusive. Vertical divisions in the flag show 1/3 of onsets occur by Nov 5, with another 1/3 by Dec 12, followed by the final 1/3. In the latter group there was one year in which onset conditions suitable for wheat planting never occurred.

FIGURE 3

Ranges of wheat season rainfall totals and intensities, related to date of onset. Settat, Morocco. (Average annual rainfall 416 mm)

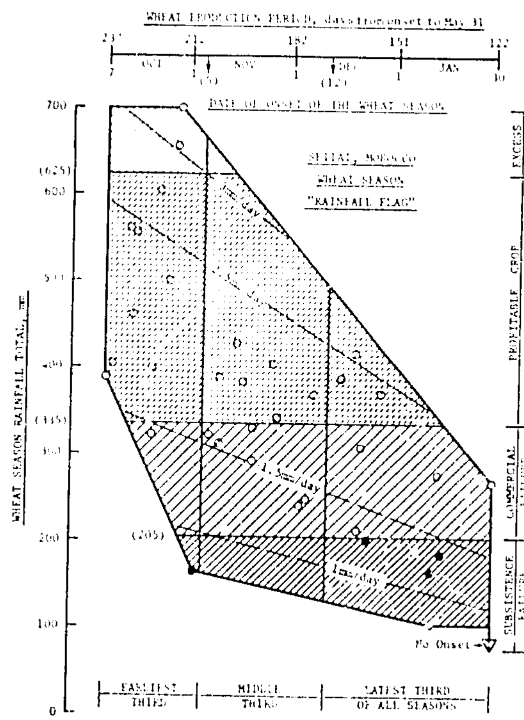


Figure 3 shows clearly that high probabilities of successful wheat production are associated with early onset of the rains, while the opposite is true when onset is late. In the latter case, even successful crops would produce only moderate yields, indicating farmers would be well advised to curtail additions of costly inputs or even to switch out of wheat to an alternative crop, or to leave the land fallow.

Table 3 for Settat is similar to Table 1 for Davis. It initially shows the overall long term median wheat season rainfall and probabilities of achieving the different rainfall and wheat yield levels categorized in Figure 3. The same information is then shown separately for the early onset years, the middle onset years and the late onset years.

TABLE 3 - SETTAT, MOROCCO:

Probabilities for wheat season rainfall and grain yield for all years - versus probabilities in three subsets of years differentiated by date of onset (See Fig. 3).

DATE OF ONSET FOR WHEAT PRODUCTION	MEDIAN WHEAT SEASON RAINFALL mm	- - CROP & RAINFALL PROBABILITIES, % - - PROFITABLE CROP >335mm	COMMERCIAL FAILURE 335-206mm	SUBSISTENCE FAILURE <206mm
ALL ONSET DATES	[355]*	[53]	[30]	[17]
EARLY: Until 5 Nov	480	84	8	8
MID-PERIOD	336	50	50	0
LATE: 15 Dec on	239	25	33	42

* Average annual rainfall is 416 mm.

Table 3 shows that Settat, Morocco farmers really operate in three distinct rainfall regimes instead of the single regime described currently. Fortunately, we can now readily distinguish which rainfall pattern applies in the season at hand. Just this much information about their water supply prospects would allow them to greatly improve their decision making. Or, we can take the next step and also provide farmers advice on how they might best proceed to respond to their improved rainfall information.

Rabat, M rocco. March, 1985.

Dr. Darrell Watts (r), Head, INRA/MIAC Dryland Farming Applied Research Project, explains wheat experiments to the author. Aridoculture Center, Settat, Morocco. April, 1985.

CHAPTER 9

Cyprus

Figure 4 presents a "rainfall flag" for Nicosia, Cyprus similar to that shown for Settat, Morocco (Figure 3). The Nicosia flag is based on 42 years of record from 1937/38 to 1978/79, with no data missing. The range of onset dates is essentially the same, from Oct 5 to Feb 1 inclusive, but with some tendency for later onset. The figure shows the early 1/3 of onsets are by Nov 14, the middle 1/3 from Nov 15 to Dec 14 and the late 1/3 thereafter. As in Settat, one year had no onset.

Average rainfall intensities in Nicosia tend to be a little below those at Settat, as the lower overall rainfall would suggest. Intensities also tend to decline with later onset as was seen for Settat. The implication of this is that later starting seasons may also be expected to have more and longer dry spells within the rainy period.

Table 4 shows the same information for Nicosia as Table 3 for Settat. However, the probabilities of successful commercial production are only good (57%) at Nicosia if onset is early. And with late onset, the probability of subsistence failure has risen to 50% or one year in two. Farmers having this information would undoubtedly wish to insure their family food supply with alternative crops or perhaps off-farm employment.

TABLE 4 - NICOSIA, CYPRUS

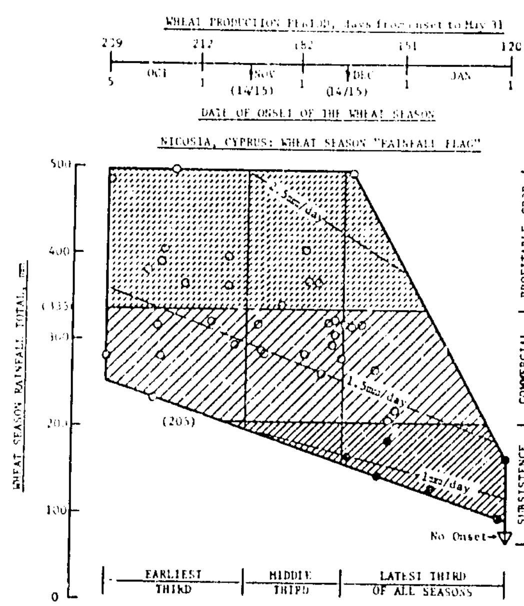
Probabilities for wheat season rainfall and grain yield for all years -- versus probabilities in three subsets of years differentiated by date of onset (See Figure 4).

DATE OF ONSET FOR WHEAT PRODUCTION	MEDIAN WHEAT SEASON RAINFALL mm	- - CROP & RAINFALL PROBABILITIES, % - - PROFITABLE CROP >335mm	COMMERCIAL FAILURE 335-206mm	SUBSISTENCE FAILURE <206mm
ALL ONSET DATES	[313]*	[31]	[52]	[17]
EARLY: Until 15 Nov	364	57	43	0
MID-PERIOD	314	29	71	0
LATE: 15 Dec on	196	7	43	50

* Average annual rainfall is 356 mm.

FIGURE 4

Ranges of wheat season rainfall totals and intensities, related to date of onset. Nicosia, Cyprus. (Average annual rainfall 356 mm)



Rock of Romiou where Aphrodite, Goddess of Love and Beauty, was born of the foam off the coast of Paphos, Cyprus. July, 1962.

Friendly ladies watch while the author tries his hand at harvesting barley. Marathassa Valley, Cyprus. May, 1963.

Figure 5 shows the same information for the lower rainfall regime at Amman, Jordan. In Jordan, onset of the rains is somewhat later, with the earliest date being Nov 6 and the latest Feb 18. This is based on 46 years of record in the period from 1937/38 to 1983/84. Data for one year are missing and in four years there was no onset for wheat.

Average daily rainfall intensities at Amman tend to be relatively lower, mostly between 1 and 2 mm/day, whereas Nicosia is mostly above 1.5 mm/day and Settat mostly between 1.5 and 2.5 mm/day. Since Amman has the highest evaporative rates of the three locations as well as the lowest average rainfall intensities, the wheat water stress in most years would be relatively greater than if water amount were the only difference among the three locations.

Table 5 for Amman is similar to Tables 3 and 4. As would be expected, the lower rainfall at Amman reduces the probability of successful wheat production below that at the other two locations. Planting wheat at Amman in late onset seasons is foolhardy, since the expected failure rate for subsistence is 80% or four years in five.

TABLE 5 - AMMAN, JORDAN:

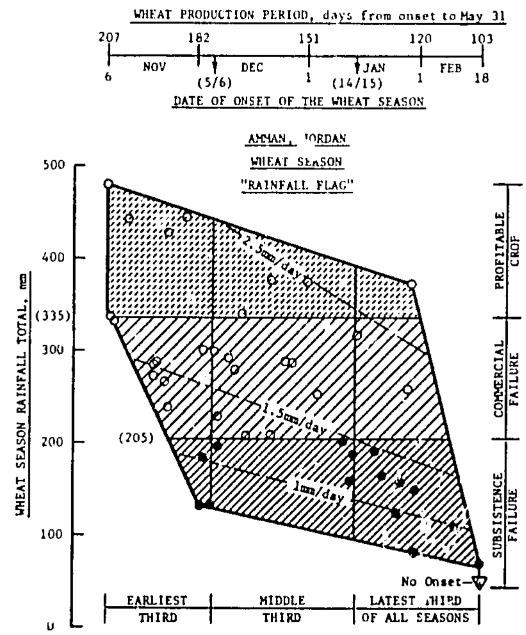
Probabilities for wheat season rainfall and grain yield for all years - versus probabilities in three subsets of years differentiated by date of onset (See Fig. 5).

DATE OF ONSET FOR WHEAT PRODUCTION	MEDIAN WHEAT SEASON RAINFALL mm	- - CROP & RAINFALL PROBABILITIES, % - - PROFITABLE CROP >335mm	COMMERCIAL FAILURE 335-206mm	SUBSISTENCE FAILURE <206mm
ALL ONSET DATES	[245]*	[20]	[39]	[41]
EARLY: Until 5 Dec	287	33	47	20
MID-PERIOD	265	19	56	25
LATE: 15 Jan on	123	7	13	80

*Average annual rainfall is 283 mm.

FIGURE 5

Ranges of wheat season rainfall totals and intensities, related to date of onset. Amman, Jordan. (Average annual rainfall 283 mm)



Azraq Oasis in the steppe desert east of Amman, Jordan — a favored home to Lawrence of Arabia. November, 1985.

Young olives near Irbid in the northern highlands of Jordan. March, 1985.

CHAPTER 11

-- A Case Study for Jordan --
Response Farming Alternatives to Maximize Crop Yields and Returns

Adjusting Planted Area According to Date of Onset and Early Season Rainfall

Jordanian cereal farmers traditionally practice some of the tenets of Response Farming. For example, a recently published United Nations Food and Agriculture Organization study of rainfed agriculture in the Near East region describes how wheat and barley farmers in Jordan delay planting until they have assessed the early rains, then adjust the planted area accordingly. With high rainfall they expand the planted area and with low rainfall they contract it (FAO, 1982).

The author used crop data gathered and published by the Arab Organization for Agricultural Development (AOAD, 1977, 1978) and available rainfall data (Water Authority of Jordan, 1985, 1986) to study this response by cereal farmers to early rainfall, and found they were judging the rainfall prospects nearly perfectly. Table 6 shows how wheat and barley hectarage in Irbid, Balqa and South Amman Governorates varied with rainfall over the 9-year period from 1968/69 to 1976/77.

TABLE 6

Wheat and barley hectarage planted in relation to annual rainfall in Irbid, Balqa and South Amman Governorates, Jordan.

RAINFALL YEAR	TOTAL RAINFALL, mm	TOTAL PLANTED AREA WHEAT & BARLEY, ha
1968/69	562	55,760
1969/70	409	39,480
1970/71	542	52,490
1971/72	457	46,770
1972/73	265	26,550
1973/74	564	41,620
1974/75	350	33,700
1975/76	359	38,270
1976/77	356	34,970

Data Sources: AOAD (1977, 1978); Water Authority of Jordan (1985, 1986).

Table 6 shows that Jordanian cereal farmers are already taking the first step in Response Farming. When onset of the rainy season for wheat or barley production is delayed, they plant a lesser area. They do this because experience has taught them that late onset means little or no profit, and an enhanced probability of total failure. Their goal in planting wheat at all in these circumstances is to cover the family's basic food needs. The durum wheat they grow is a dietary staple and cannot be purchased in the market because only soft wheat is imported.

Selecting Alternative Crops Based on Probable Yields and Economic Returns

The next question is what should be planted on the land, if anything, when rainfall is not satisfactory for wheat? Farmers may be helped to find answers to this type of question by combining improved rainfall information like that in Figure 5 with water production functions which show how different crops will produce under the range of rainfall conditions which accompany seasonal variation in date of onset. An example of how this could be done to assist Jordanian cereal farmers in low to medium rainfall zones follows.

The same data sources cited above were used to develop yield response functions, i.e. water production functions relating yields to rainfall, for seven different crops grown using traditional practices in low to medium (to 400 mm or 15.75 in) rainfall areas of Irbid and Amman Governorates. Crop yield data utilized are based on representative sampling at the District level in the years 1969 to 1975 inclusive (Amman South) and 1969 to 1977 (Irbid East). Annual rainfall data are those published for selected stations within the districts. Despite the roughness of these data, the relationships found are surprisingly good as shown in Table 7.

TABLE 7

Water production functions relating yield (Y,kg/ha) to total annual rainfall (R, mm) in the low to medium (to 400 mm) rainfall areas of Irbid and Amman Governorates.

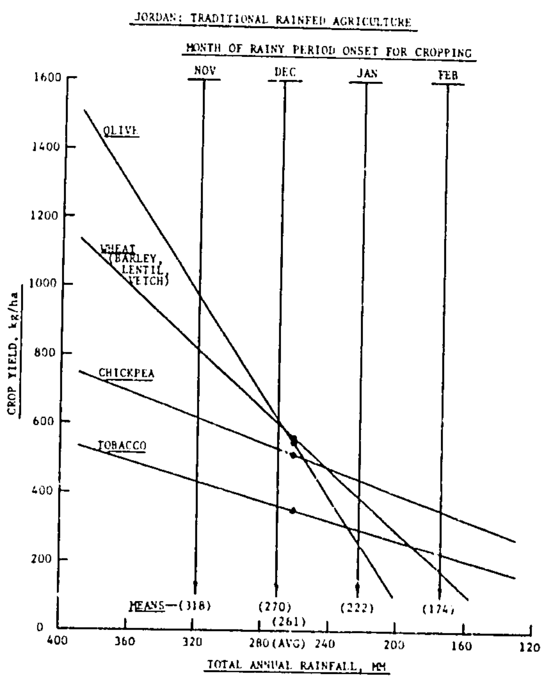
WHEAT	$Y = 4.45R - 602$	$n = 16$,	$R2 = .85$
BARLEY	$Y = 4.54R - 598$	$n = 16$,	$R2 = .61$
LENTIL	$Y = 4.21R - 553$	$n = 16$,	$R2 = .75$
CHICKPEA	$Y = 1.83R + 33$	$n = 16$,	$R2 = .25$
VETCH	$Y = 4.43R - 643$	$n = 16$,	$R2 = .91$
TOBACCO	$Y = 1.41R - 16$	$n = 16$,	$R2 = .39$
OLIVE	$Y = 7.44R - 1397$	$n = 9$,	$R2 = .64$

The crops listed in Table 7, apart from wheat and barley, are lentil, chickpea, vetch, tobacco and olive. The latter, being a tree fruit, is obviously not a late season alternative for wheat. Technically speaking, tobacco could be an alternative crop, but due to governmental control cannot actually be used that way. Nevertheless, it is interesting and instructive to see how olive and tobacco compare to the cereals and other crops in terms of both yields and economic returns in different rainfall circumstances.

Figure 6 compares expected yields from the different crops, and for each crop shows how the yields vary with differing rainfall expectations which accompany changes in the date of onset from year to year. The rainfall figures shown represent averages from three meteorological stations in Amman South (Old Amman Airport) and Irbid East Districts (Ramtha and Rihab). Rainfall at these three stations is similar with an overall long term average of 261 mm (10.3 in).

FIGURE 6

Comparison of water production functions for crops grown in the period 1969-77 in the low to medium rainfall zones of Amman and Irbid Governorates, Jordan. Data from AOAD, (1977, 1978) and Water Authority of Jordan, (1985)



However, as seen in Figure 6, average rainfall in years with onset in November is relatively high at 318 mm (12.5 in) falling thereafter to 270 mm (10.6 in) for December onsets, 222 mm (8.7 in) for January onsets and 174 mm (6.85 in) for February onsets. Crop yield expectations fall accordingly. For example, average wheat yields in years with November onset should be 813 kg/ha, but only 172 kg/ha if onset is in February. A possible alternative is chickpea which averages only 615 kg/ha in November onset years but remains at 351 kg/ha with February onset. Table 8, derived from Table 7 and Figure 6, presents further information which could be helpful to farmers in selecting alternative crops.

Another way to compare alternative crops, if they are to be marketed, is to express their expected yields in terms of their gross values. This is done in Figure 7 and Table 9 which are similar to Figure 6 and Table 8 except that crop yields have been multiplied by their respective prices at the farm gate as of November, 1985 when the study was made. Note that expected gross returns are expressed in Jordanian Dinars (JD) per hectare. At that time, one JD was valued at $2.68 (U.S. Dollars). Note that since one hectare equals 2.47 acres then JD 1.00/ha is nearly the same as $1.00/ac.

Table 8

Yield expectations as related to date of onset of the rains, for traditionally managed rainfed crops in the transition zone between relatively well watered highlands and arid desert in Irbid and Amman Governorates, Jordan.

		---Mean Yield Expectations, kg/ha----				
		----Onset Months & Rainfall Means----				
Crop Category	Crop Type	Nov-Feb (261mm)	Nov (318mm)	Dec (270mm)	Jan (222mm)	Feb (174mm)
Cereal Grains	Wheat	(559)	813	600	386	172
	Barley	(587)	846	628	410	192
Grain Legumes	Lentils	(546)	786	584	382	180
	Chickpea	(511)	615	527	439	351
Forages	Vetch	(513)	766	553	340	128
Annual, Cash	Tobacco	(352)	432	365	297	229
Perennial, Fruit	Olives*	545	969	612	255	0

* Figures shown are averages of all years. Due to strong "alternate bearing" characteristics of olives, average yields will be relatively higher than shown in even years and lower in odd years.

FIGURE 7

Comparison of gross returns from six crops, based on production levels related to variation in the date of onset of the rains. Low to medium rainfall zones of Amman and Irbid Governorates, Jordan. Prices as of Nov., 1985.

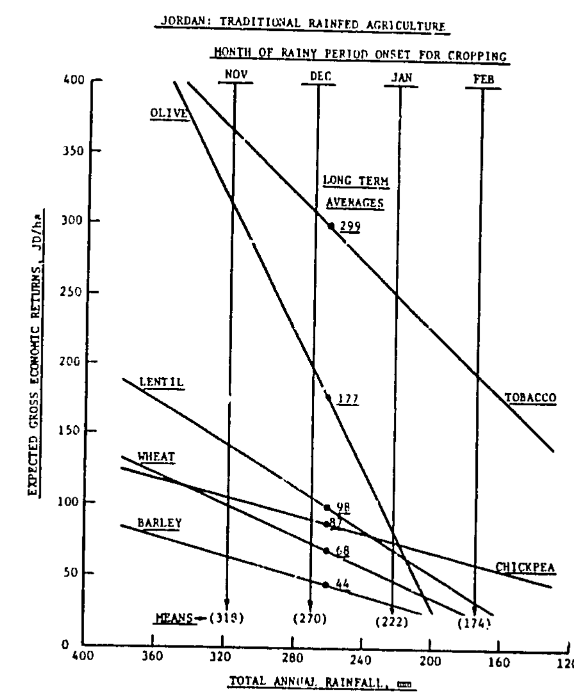


Figure 7 shows tobacco has the greatest value at all rainfall levels up to 400 mm where olive nearly equals it. However, in this particular rainfall regime with a long term average of 261 mm, tobacco should have a long term average value (price steady) of 299 JD/ha versus a value of 177 JD/ha for olive. These are by far the most valuable of the seven crops, and might be permanently substituted for wheat if circumstances permit. However, as earlier mentioned, these crops cannot serve as last minute sub-

Table 9

Variation in expected gross returns from rainfed crops with differing dates of onset of the rainy season. Traditional management in transition zones of Irbid and Amman Governorates, Jordan, with long term mean rainfall of 261mm.

Crop Category	Crop Type	--Mean Gross Returns Expected, JD/ha[1]-- ----Onset Months & Rainfall Means---- Nov-Feb (261mm)	Nov (318mm)	Dec (270mm)	Jan (222mm)	Feb (174mm)
Cereal Grains	Wheat	67	98	72	46	21
	Barley	44	63	47	31	14
Grain Legumes	Lentils	98	141	105	69	32
	Chickpea	87	105	90	75	60
Forages	Vetch	62	92	66	41	15
Annual, Cash	Tobacco[2]/	299	367	310	252	195
Perennial, Fruit	Olives	177	315	199	83	0

1. Commodity prices as of November, 1985.
2. Tobacco production is licensed and subsidized by the Government, with the overall payment totalling in the range of 700-1000 fils/kg. Figures in the Table are based on 850 fils/kg.

stitutes when the onset of the rains is delayed.

It is often stated that barley yields more than wheat when water is limiting; Table 8 shows this to be true, but only barely. However, the price of wheat in the present example is well above the barley price. Hence, Figure 7 shows expected market returns from barley are well below those from wheat at all rainfall levels. Vetch, a high quality forage crop, has virtually the same production function and price per unit weight as wheat, hence is not shown on either Figure 6 or Figure 7. It would be a suitable substitute for wheat only in the instance the farmer specifically wanted to produce forage rather than grain.

The water production function for lentil is like that for wheat, but the unit price is higher. Therefore gross returns are higher at all rainfall levels. If lentil were substituted for wheat, it should be decided on economic grounds rather than an expectation of low rainfall. However, lentil can be successfully planted after it has become too late for wheat, so may be substituted when onset is very late.

Finally there is chickpea, which offers an excellent alternative to wheat when rains are late. Figures 6/7 and Tables 8/9 show chickpea performs relatively well in low rainfall conditions, surpassing the other grain legumes, cereals and forages in the example area if onset of the rains is in January or later. Chickpea also commands a good price and produces greater per hectare returns with January or later onset. Another point is that chickpea is planted in March or April after the decision not to plant wheat is finalized. Altogether, chickpea is in many instances a desirable substitute for wheat when rains are late.

TECHNICAL SECTION II-D

AFRICA: RESPONSE FARMING FOR RECURRENT DROUGHT ZONES

CHAPTER 12

East Africa: Kenya

Rainfall Record Requirements to Establish Prediction Criteria

In 1980 the original finding was made that seasonal rainfall amount and duration are linked to date of onset. The first analysis was based on just 16 years of daily rainfall data from the Katumani National Dryland Farming Research Station, Machakos District, Eastern Province, Kenya. Shortly after, nine additional years of data were made available and new analyses completed. The findings were virtually unchanged (Stewart, 1980; Stewart & Hash, 1982).

The indication was, and still remains, that relatively short term rainfall records, say 10-15 years minimum, can provide the information required for a Response Farming program. Of course, longer records are preferable, but short records are still useful.

Spatial Variation in Rainfall Prediction Criteria

Further verification was gained by extending the analysis to nine other locations in Eastern Province, five of which have much longer rainfall records, beginning in the 1926-31 period. (Kashasha, 1982; Stewart & Kashasha, 1984). These analyses encompass an area of some 13,000 km^2 (5,000 mi^2) in Machakos, Kitui and Kajiado Districts, in which there is a wide range of climatic conditions associated with elevation changes, including average annual rainfall ranging from a high above 1,000 mm (about 40 in) to a low to 500 mm (about 20 in). These analyses have made it possible to assess both similarities and differences in how regional rainfall behaves in various localities.

Kenya's Two Rainfall Seasons

Rainfall in the Eastern Province of Kenya is mostly monsoonal, occurring in a bimodal pattern. The two seasons peak in intensity in November and April. The "short rains" (colloquial usage) approach from the north with onset in late October or November, tapering off in December. Convective rains follow in January and February, ranging in amount from zero to high levels in some years. They may be of importance either by extending the short rains season, or by effectively providing an early onset to the second season, called the "long rains", which approach from the south. The long rains (or southern monsoon) arrive in March or April and taper off in May with no significant rainfall thereafter.

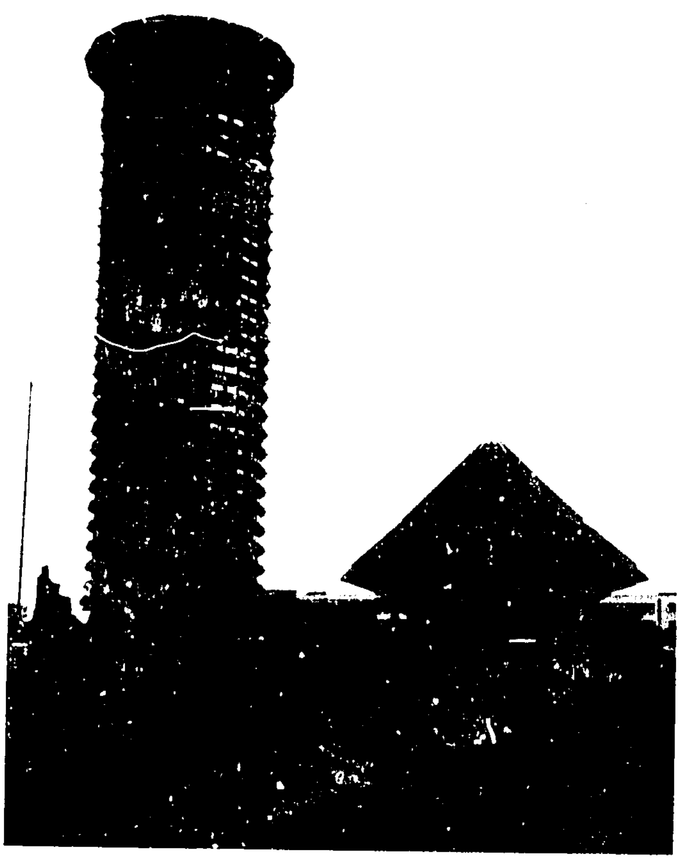
It is in the farmer's interest to plant the long rains crops in February, if convective rains store sufficient water in the soil to germinate and succor the seedlings through the dry spells which may be expected prior to establishment of the monsoon. Such considerations enter in to the definition of onset which may differ for different cropping enterprises or localities.

Examples shown are for the long rains season at Katumani, the short rains season at Ikutha, Kitui District, and both seasons at Kajiado where a considerably longer record is available. Kajiado is also the driest location analyzed, with average annual rainfall totalling 504 mm (19.8 in). Identifying and descriptive information about these three locations is presented in Table 10.

TABLE 10 - EASTERN PROVINCE, KENYA:

Three rainfall stations in the recurrent drought zones of Machakos, Kitui and Kajiado Districts.

Station Number	Name of Locality	Latitude	Longitude	Elevation (m)	Rainfall Record	Mean Annual Rainfall(mm)
9137089	Katumani NDFRS	1°35'S	37°14'E	1,575	1957-83	701
9238006	Ikutha Agriculture Station	2°04'S	38°11'E	732	1957-79	699
9136039	Kajiado District Office	1°50'S	36°48'E	1,737	1931-80	504



Kenyatta Conference Center, based on "boma" architecture, Nairobi, Kenya. February, 1977.

Maize, the Favored Food Crop

The most desired food crop in the region is maize (corn), despite the rather low rainfall and the worldwide reputation maize has for suffering greater yield loss from a given water stress than most other crops. A mitigating factor in Kenya has been the development by breeders of Katumani Composite B maize, which has particular adaptations fitting both the rather low temperature and rainfall conditions in Eastern Province.

Katumani maize is capable of delaying tasseling and silking if stressed for water, and of maturing early if stress is later in the season. Normal maturity is 120 days but the writer has experienced a range from 85 to 137 days in trials under different temperature and rainfall conditions. Farmers of that area will grow maize if they believe there is reasonable hope of getting even a subsistence level yield - because their first purpose is to feed the family, and only secondarily to market the remainder. For this reason, the analyses presented as examples here are based on maize production.

Additional Food Crops

Despite the above, it must be stressed that many crops with greater stress tolerance are also grown in this area by the same farmers, and there are drier areas where no maize is attempted. Other grain crops grown are grain sorghum (many types and maturities) and millet. Beans of several types are very popular and are often intercropped with maize or other crops.

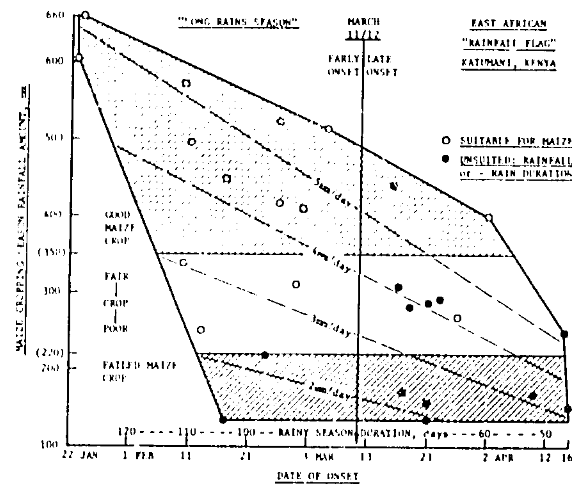
A Rainfall Flag for the Long Rains Season at Katumani

Figure 8 presents a scatter diagram representing 27 years of rainfall for maize production in the long rains season at Katumani. The figure is drawn in the form of a rainfall flag similar to those for the Mediterranean region, but with reference to maize production rather than wheat. Cropping season rainfall averages some 340 mm, but ranges from 133 mm to 660 mm as shown on the vertical scale. Horizontal lines at 350 mm and 220 mm establish three categories of seasons, roughly denoting expected maize yield levels. Above 350 mm a "good" crop is expected, dropping to "fair" then "poor", and finally to the "failure" level with 220 mm of seasonal rainfall. Stewart & Faught, (1984) show detailed production functions for maize (and beans) in Eastern Kenya, and the influences of plant population and soil fertility on the functions. Thus, although the categorization in Figure 8 is approximate, it is reasonable based on research findings.

Farmer standing in his Response Farming trial plot of maize and beans, Kimutwa, Machakos District, Kenya. "Long Rains" season. April, 1982.

FIGURE 8

How season rainfall amount, approximate rainy period duration, average daily rainfall intensity and suitability for maize production relate to date of onset of the "long rains." Katumani National Dryland Farming Research Station, Machakos, Kenya, 1957-83.



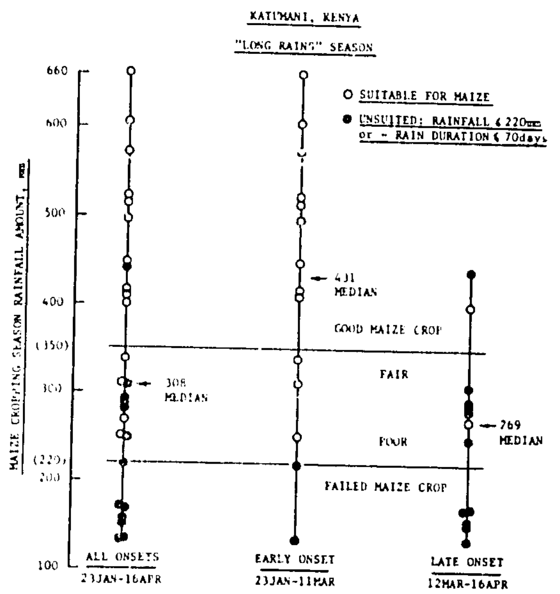
The lower horizontal scale in Figure 8 labelled "Date of Onset" shows actual occurrences in the 27-year record from as early as January 23 to as late as April16. A vertical line separates onset dates up to March 11 (termed early onset) from those after that (late onset). The placement of the line is arbitrary, designed to separate generally satisfactory maize seasons from those generally not satisfactory.

The reasons for unsatisfactory seasons are two-fold. First, there is failure from too little rainfall as noted above, which occurs much more frequently in late onset seasons. Second, there is failure due to too short a duration of the rainy period, which for production of 120 day maize, is here judged to be 70 days or less. Figure 8 shows that only two of thirteen late seasons would have produced satisfactory crops. Five would fail for lack of rainfall and six from too short duration. Note that the scale labelled "Rainy Season Duration" is only approximate because the final date of rainfall changes as does the date of onset. Therefore, the lines showing intensity, e.g., 4 mm/day, are also approximate.

Figure 9 is another way to present the information seen in Figure 8. It quickly shows that while failure is possible with early onset, the great majority of failing seasons (and few successes) are those with late onset. Figure 9 summarizes the probabilities of attaining good,

FIGURE 9

Separation of historical range of maize growing season rainfall amounts into two ranges based on date of onset. Blackened circles (•) indicate seasons unsuited to maize production, due either to deficient rainfall or too short a rainy period. Katumani NDFRS, 1957-83.



fair/poor or failing maize yields - first for all years together i.e., without regard for date of onset, then for early onset years versus late onset years.

The results, shown in Table 11, are dramatic. The overall probabilities indicate a success rate of 52% (37% good plus 15% fair/poor) versus 48% failure - roughly 50-50. This makes maize production a very risky gamble, so that one would be very hesitant to invest in costly inputs such as fertilizers. Without fertilizers, however, only low yields are possible even when rains are good. This is a basic dilemma faced by smallholders the world over. It further means that even if the farmer wishes to gamble, no one - not even his government - is willing to join in that gamble by extending credit to purchase the inputs. Thus, the poverty syndrome continues in better rainfall years when it could be broken.

However, the gamble or risk is very much lessened in early onset seasons. Table 11 shows a 64% probability of a good maize crop, or nearly two seasons out of three. Additionally, there is a 22% probability of a fair to poor, but still "successful" crop. The probability of failure is reduced to 14%, or about one season in seven.

When onset is late the probabilities are reversed - the risk of failure is a high 84%, or roughly five seasons out of six. Quite obviously, maize should not be recommended as a principal food crop at Katumani in long rains seasons beginning after March 11. If March 12 dawns without onset of the rains the farmer should shift to "plan B", meaning primarily that he should reapportion the crops he grows to downplay or eliminate maize, and favor grain sorghum, millet, beans, etc, in accordance with his desires, the local markets, or other factors. Further rainfall analyses to evaluate risks in growing alternative crops in late seasons will help farmers make these decisions.

TABLE 11 - KATUMANI, KENYA, "Long Rains":

Relationship of date of onset to seasonal rainfall amount, and consequent maize yield levels. Probabilities (%) of good, fair to poor or failed maize crop, shown first for all years together, then separately for early versus late onset years.

CROPPING SEASON ONSET PERIOD	PORTION OF RAINFALL RECORD No. Years	PROBABILITIES, %: RAINY PERIOD DURATION > 69 DAYS — GOOD CROP (>349mm)	FAIR/POOR (221-349mm)	FAILED MAIZE CROP — RAIN AMT (221mm	DURATION (70 days
ALL ONSET DATES, 23 Jan-16 Apr	[27]	[37]	[15]	[26]	[22]
EARLY ONSET, by Mar 11	[14]	64	22	14	0
LATE ONSET, 12 Mar on	[13]	8	8	38	46

Dry Planting Versus Waiting for Onset: A Major Decision

An important question for rainfed farmers, and one which continues to receive much research attention around the world, is whether to "dry plant" before the rains begin, or wait for onset and then plant. There are a number of advantages and disadvantages either way. However, the analysis shown for maize at Katumani in the long rains provides a clear answer in favor of waiting for onset, in the opinion of the writer.

Table 11 shows why this is so. Planting before the rains means, in effect, that the date of onset is ignored, and the risks are as seen for onset dates in the upper line of the table, i.e., 48% failure. This is too great a risk for needed use of inputs, so the poverty syndrome is maintained.

A second reason favoring waiting for onset to plant maize in the long rains at Katumani was mentioned previously. Early germination of the crop may be activated by relatively light convective rains (locally termed "grass rains"), which may then be followed by a dry period in which the seedlings die. Waiting for sufficient rain to satisfy properly defined onset conditions (whether convective or monsoon rains) will obviate this risk.

However, it should be emphasized that other analyses for different crops, seasons or locations may show dry planting to be as viable an option as waiting for the rains, or even preferable. A case in point is also at Katumani. Suppose March 12 arrives without onset and the farmer decides to plant grain sorghum and millet instead of maize. He should then dry plant because of the following changes in the situation:

1. When the rains come they will be the monsoon and there will be no "false start" followed by a long dry spell. The rainfall record confirms this.

2. The crops now to be grown will have lesser water requirements than does maize, and greater water stress tolerance. The principal risk is shifted from amount of rainfall per se to the length of the rainy period, which is effectively shortened by a day each day onset is delayed, and, if seeds are not already planted, with each day germination is delayed there-after.

Short Rains Decisions: Dry Planting and Early Season Adjustment of Plant Populations and Fertilizer Rates

Similarly, maize in the short rains season at Katumani might just as well be dry planted provided this is what the farmer wishes, and provided he has the power required to prepare the land which is dry and hard prior to the rains. The reasons are the same as those above - the short rains are not preceded by convective rains and the monsoon tends to start with a vengeance so there is rarely any significant dry spell early on to wither the seedlings. And as the season's name implies, the rainy period may be rather limited, so every day counts in producing a maize crop. Probabilities for rainfall amounts and maize yield levels are shown in Table 12, and provide further information about the question of planting before or following onset of the rains.

TABLE 12 - KATUMANI, KENYA, "Short Rains":

Relationship of date of onset to seasonal rainfall amount, and consequent maize yield levels. Probabilities (%) of good, fair to poor or failed maize crop, shown first for all years together, then separately for early versus late onset years.

CROPPING SEASON ONSET PERIOD	PORTION OF RAINFALL RECORD No. Years	---- RAINFALL & CROP YIELD ---- PROBABILITIES, % GOOD CROP (>349mm)	FAIR/POOR (221-349mm)	FAILED CROP <221mm
ALL ONSET DATES, 16 Oct-23 Nov	[27]	[41]	[41]	[18]
EARLY ONSET, by Nov 2	[14]	64	15	21
LATE ONSET, 3 Nov on	[13]	15	70	15

Table 12 shows that maize yield level probabilities in the short rains at Katumani differ greatly between early onset and late onset seasons, but the difference is not in the failure rate which remains roughly the same at all onset dates. Therefore, dry planting does not increase the risk of failure. However, the chance of a good crop is very high if onset is early (64%), falling to a low of 15% with late onset. This is a case where early season management of plant population and fertilizer rates becomes very important, with judgements to be based first on the date of onset and then on actual 30-day rainfall amount.

A Rainfall Flag for the Short Rains at Ikutha

Ikutha Agriculture Station in Kitui District has the same annual rainfall as Katumani, but somewhat less in the short rains, averaging about 295 mm versus 350 mm at Katumani. In regard to the prospects for growing maize, this makes the date of onset still more critical, as will be discussed with relation to Figure10 and Table 13.

TABLE 13 - IKUTHA, KENYA, "Short Rains":

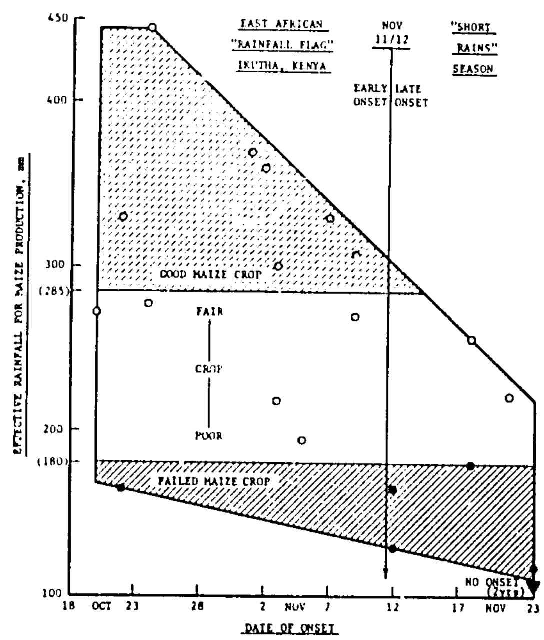
Relationship of date of onset to maize season "effective rainfall" and resulting crop yield levels. Probabilities (%) of good, fair to poor, or failed maize crop are shown first for all years together, then separately for early versus late onset seasons.

CROPPING SEASON ONSET PERIOD	PORTION OF RAINFALL RECORD No. Years	------PROBABILITIES, %------ EXPECTED RAINFALL/MAIZE YIELD CATEGORIES GOOD CROP >285mm	FAIR/POOR 181-285mm	FAILURE <181mm
ALL: 20 Oct-23 Nov	[21]	[33]	[34]	[33]
EARLY: by 11 Nov	[13]	54	38	8
LATE: 12 Nov on	[8]	0	25	75

Figure 10 takes the rainfall analysis one step further. The first example - for Davis, California - illustrated how total annual rainfall is related to date of onset. The other Mediterranean climate examples changed the relationship to total crop season rainfall (wheat), as did the Katumani, Kenya examples for maize. Now the Ikutha example shows "effective rainfall" on the vertical axis of the figure. This is defined as the amount of rainfall which the maize crop should have actually utilized in each season in the record, or in technical terminology, the crop evapotranspiration (ET).

FIGURE 10

How maize season "effective rainfall" relates to expected production, and how both relate to date of onset of the "short rains". Ikutha, Kitui District, Kenya, 1957-79.



The estimation of ET by a specific crop in a given location in past rainfall seasons requires water balance calculations. These must consider the evaporative conditions of the atmosphere as well as rainfall, the crop leafing and rooting patterns as they affect rates of water utilization and soil water extraction respectively, soil slopes, depths and water holding capacity, and additional factors if higher levels of accuracy are sought.

The water balance calculations for Ikutha, and for Kajiado to follow, were described and carried out by Kashasha (1982), and were the same as were used initially by the writer in developing the response farming method (Stewart, 1980). They are simplified calculations such as others have used (Frere and Popov, 1979) aimed at a moderate level of accuracy, but sufficient for planning purposes in situations where there are many unknowns.

As a rule of thumb, the water balance calculations in Kenya indicated that effective rainfall ranges around 80% of total season rainfall. The assumption made was that no rainfall ran off the cropped field, so the 20% not used by the crop either percolated below the root zone (exceeded the water storage capability of the root zone soil) or remained in the soil at season's end because it arrived too late to be utilized.

Therefore, the criteria for maize crop yield levels in Figure 10 are changed from those in Figures 8 and 9. For example, a good crop here requires 285 mm of effective rainfall rather than 350 mm of total season rainfall.

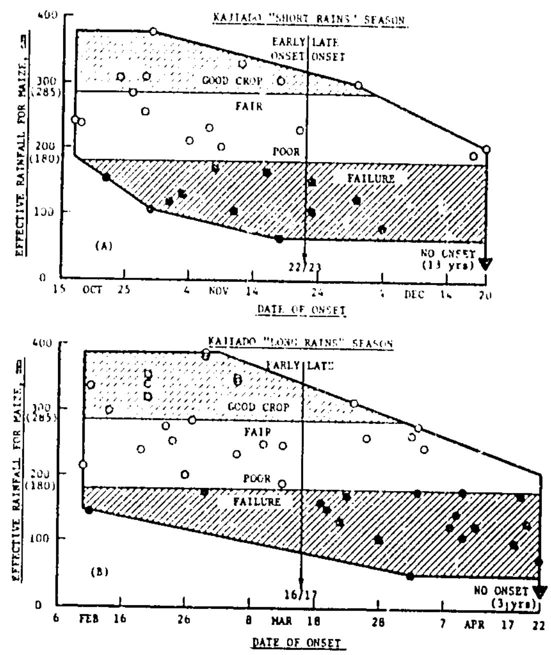
Figure 10 reemphasizes a point made in the previous example. The figure displays the findings from a 21-year rainfall record, with 13 years termed early and only 8 years termed late. The dividing line is arbitrary, being based mostly on perceived differences in the risks of failure, or probabilities of success, in the particular enterprise - which in this case is maize production. The placement of the dividing line could be quite different when discussing another crop.

The fact is that each day onset is delayed the probabilities of success lessen slightly. There is no practical way to convey that information in meaningful fashion to uneducated smallholders. However, anyone who is capable of living off the land is also capable of understanding that we operate on plan A if the rains begin by November 11 (Figure 10), but if they don't, as of November 12 we switch to plan B.

The first line in Table 13 shows that overall odds are evenly split between a good crop (33%), a fair to poor crop (34%) and failure (33%). But a radical shift occurs between early and late onset seasons. Early seasons have a 54% probability of a good crop with only 8% (one year in 12 or 13) chance of failure. With late seasons there is no chance of a good crop, and failure is expected in three out of four years. Clearly, less water demanding crops should be substituted for maize in late seasons.

FIGURE 11

How maize season "effective rainfall" relates to expected production, and how both relate to date of onset of the short rains (A) and long rains (B) seasons, respectively. Kajiado, Kajiado District, Kenya, 1931-1980



Kajiado Rainfall Flags — Both Seasons

The final example representing the recurrent drought zones of Kenya is Kajiado with average annual rainfall of only 504 mm (19.8 in), including both the short and long rainy seasons. There are those who will object to any discussion of growing maize in such a dry climate. Nevertheless, the farmers of Kajiado also prefer to eat maize and they grow it. The writer believes this should be their prerogative, but we should provide them the best advice possible on when and how to successfully grow the crops they wish to, and when they must emphasize alternative crops for their own survival.

The Kajiado rainfall record dates back to 1931, so is considerably longer than those from Katumani or Ikutha. However, it provides essentially the same information for guidance of farm decision making. This is encouraging because many regions of developing countries have rainfall records only over a limited time span.

As in the Ikutha example, Figure 11 relates effective rainfall for maize production to date of onset of the rains - in this instance both the short and long rains. One difference seen immediately in Figure 11A is that the onset period at Kajiado in the short rains extends to December 20, whereas the last date of onset at both Katumani and Ikutha was November 23 (Table 12 and Figure 10). (Additionally, onset conditions for maize were not met in 13 of 41 years of record for the short rains at Kajiado.) The dividing line for early versus late onset is drawn between November 22 and 23, and Table 14

TABLE 14 - KAJIADO, KENYA, "Short Rains" and "Long Rains" Seasons:

Relationship of maize season "effective rainfall" and resulting crop yield levels to date of onset of the rainy period. Probabilities (%) of good, fair to poor, or failed maize crop are shown first for all years together, then separately for years with early versus late onset.

CROPPING SEASON ONSET PERIOD	PORTION OF RAINFALL RECORD No. Years	PROBABILITIES, % — EXPECTED RAINFALL/MAIZE YIELD CATEGORIES: GOOD CROP >285mm	FAIR/POOR 181-285	FAILURE <181mm
SHORT RAINS				
ALL: 17 Oct-20 Dec	[41]	[15]	[24]	[61]
EARLY: By 22 Nov	21	24	38	38
LATE: 23 Nov on	20	5	10	85
LONG RAINS				
ALL: 10 Feb-22 Apr	[45]	[22]	[31]	[47]
EARLY: By 16 Mar	21	43	47	10
LATE: 17 Mar on	24	4	17	79

shows the late season failure rate rising to 85%.

Early onset in the short rains at Kajiado occurred in 21 of the 41 years- approximately half. In these years a good crop could have been produced 24% of the time - one year in four. Failure would be expected 38% of the time - four years in ten. Commercially this is not tenable, but a farmer desirous of putting maize on his table could devote a small block of land to it in early seasons and achieve his aim in six out of ten such seasons.

The long rains season at Kajiado offers distinctly better prospects for maize production, provided again that plantings are restricted to early onset seasons. Figure 11B shows early onset until March 16, with 21 of 45 years of record starting by that time - nearly half of the years, as in the short rains. The improved prospects are more clearly seen in the lower portion of Table 14. The failure rate expected in early onset long rains seasons is a low 10%, indicating a 90% success rate from the standpoint of family food supply. And at a higher level a good crop could be gotten four years in ten (43%).

CHAPTER 13

West Africa: Niger

General Climatic Features

The monsoon arrives in higher rainfall areas of the southern Sudano-Sahelian zone of West Africa in late April, May or June, then moves northward reaching the drier latitudes verging on the Sahara Desert in July, August or early September. The pattern is unimodal (single season) with recession or withdrawal of the monsoon generally in late September or early October, but sometimes -- especially in recent years in drier locations - in August. Virtually all annual rainfall is within this season, with little or no rainfall in other months.

Evaporative rates and temperatures in Sub-Saharan West Africa are considerably higher than in the recurrent drought zones of East Africa, which are at higher elevations. Hargreaves and Samani (1986) indicate that evaporation rates (Class A pan equivalent) at Niamey, Niger average about 7.9 mm/day in the June-July-August onset period. Temperatures through the growing season average about 29°C (84°F).

By way of comparison, Stewart and Faught (1984), using pan factors developed by Kaila (1983), show Katumani, Kenya evaporative rates (Class A pan equivalent) to be about 6.1 mm/day during the onset period for the short rains, and about 6.5 mm/day during the long rains onset period. Temperatures in both growing seasons average around 20°C (68°F).

Therefore daily crop water requirements are generally much higher in West Africa than in Kenya (East Africa). This tends to be compensated for by greater rainfall intensities in West Africa. For example, Figure 8 shows intensities at Katumani mostly in the range of 2-5 mm/day, with extremes approaching 1 mm/day or 6 mm/day. This section will show, for two quite different rainfall zones of Niger, intensities ranging from 4-7 mm/day, with extremes somewhat higher and lower. With reference to those lower intensities, some extremely interesting findings on the climatic shift since 1971 will be presented and discussed.

Typical small farm near Niamey, with clumps of pearl millet stubble on the fields of sandy soil. January, 1987.

Rainfall Relationships at Niamey

The first example comes from Niamey, the capital of Niger, located in the southwest corner of the country along the Niger River somewhat east of the border of Burkina Faso. Figure 12 shows the rainfall occurrences in the 30-year period from 1954-1983. This is not the entire record available for Niamey, but it is the period of special interest for this presentation, for two reasons:

1. It matches the period of record available from Bouza, Niger which is the other West Africa example to be discussed in detail. This permits direct comparisons of the two locations. Niamey is the wetter site with average annual rainfall for the 30 years of 567 mm (22.3in), while Bouza is drier with 416 mm (16.4 in).
2. In 1971 (arguably, as early as 1968), a major reduction in rainfall took place throughout the Sahelian zone. For 50 years before that the rainfall averaged markedly higher. To include that entire period would distort the averages in a way which would mask the effects of the recent climatic shift. The 30- year record creates a reasonable balance, with 17 years before the climatic shift and 13 years after.

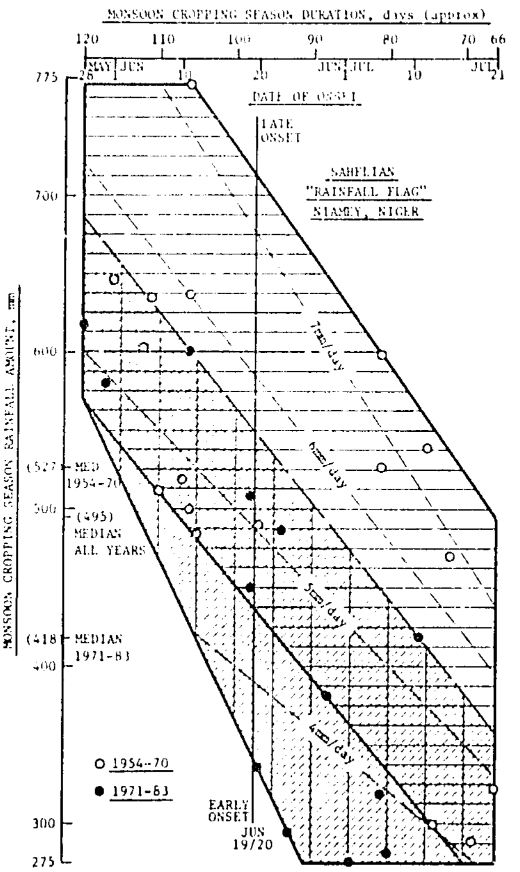
Figure 12 is not crop specific, so relates seasonal rainfall amount to date of onset of the monsoon. The major food crop in the area is pearl millet, although many other crops, and cultivars with differing maturities, are grown. Onset is defined as 40 mm of rainfall stored in the surface soil - a somewhat stringent requirement based on the high evaporation rates and temperatures, and a particular problem in the Sahelian zone of blowing sand which can kill young seedlings.

The final seasonal rainfall date in this instance is identified by summing daily rainfall backward in time from the last rainfall event in October (November rainfall seldom occurs and is not considered for this purpose) until a total of 10 mm or more is reached. That date is taken to be the final rain date in the season for practical purposes. This procedure avoids the problem of, say, reasonable rainfall to Sept 10, then nothing until Oct 20 when a final rainfall of 2.0 mm occurs. Effectively, this would be outside of the cropping season.

As in previously discussed locations, the final rain date changes from year to year, but less than the date of onset. Figure 12 displays a horizontal scale at the top labelled Monsoon Cropping Season Duration, which means number of days from onset to final rain date inclusive. Due to the changes in final rain date, the durations shown are approximate as noted in the figure.

FIGURE 12

30-year relationships of monsoon rainfall amount, duration and intensity to date of onset: Niamey, Niger. Note effects of climatic shift from 1971 onward.



For the same reason the intensities are also approximate when related to any given data point, but are correct overall and are representative.

Onset Relations at Niamey and Recent Changes in Rainfall Behavior

The Niamey rainfall in Figure 12 may be viewed as a single record, as has been the case in all earlier examples, or as two separate records, one from 1954 to 1970 and the other from 1971 to 1983. We will do both, starting with the view that it is a single record. This means the open circle and blackened circle data points are each representative of one year in the record and are all to be viewed equally. The shading in the lower portion of the flag is to be ignored and the whole is to be seen as one.

From this overall viewpoint, Figure 12 provides an excellent example of the ways seasonal rainfall characteristics are impacted by date of onset. It is clear that the range of expected rainfall amounts, as well as the duration of the rainy period, both diminish with each day onset is delayed. Table 15 provides details on median values of the agriculturally pertinent characteristics, first for the 30-year record as a whole, then as if it were two separate records - one confined to years which in fact had early onset, and the other with late onset years.

The first line in Table 15 provides an overall look at Niamey rainfall. It shows that onset may occur as early as May 28 or as late as July 21, a span of 55 days. The median date in this range is Jun 20. The final rain date (not in the table) has a lesser range, and more importantly, a strong tendency to cluster around the median date of Sep 26. The median cropping season rainfall amount is 494 mm (19.4 in), ranging from as little as 275 mm (10.8 in) to as much as 771 mm (30.4 in). Median duration of the rainy period is 99 days, but the actual duration has ranged from 71 to 154 days. This will be dealt with shortly in more detail. Intensity of rainfall at Niamey has a median value of 4.68mm/day, with a range from 3.02 to 8.08 mm/day.

However, if we divide the Niamey rainfall record into two records, simply on the basis of whether onset occurs by Jun 19 or after, major differences are revealed in all of the season characteristics of interest to the farming community. These differences may be seen in the second and third lines of Table 15 which contain characteristics of early versus late seasons respectively.

First we see the median rainfall amount in early seasons is high (590 mm or 23.2 in), while that of late seasons is very low (351 mm or 13.8 in). To the farmer this means emphasis on different crops and different levels of inputs. It means different land preparation and tillage practices, probably different row spacings and certainly different plant populations.

Next we see the median season duration is much longer (113 days) in early seasons than late ones (82 days). This again calls for emphasis on different crops and cultivars with different maturities. Rainfall intensities at Niamey have also been higher (median values) in early than late seasons, by nearly one millimeter per day, being 4.91 mm/day (0.19 in/day) in early seasons versus 4.07 mm/day (0.16 in/day) in late seasons.

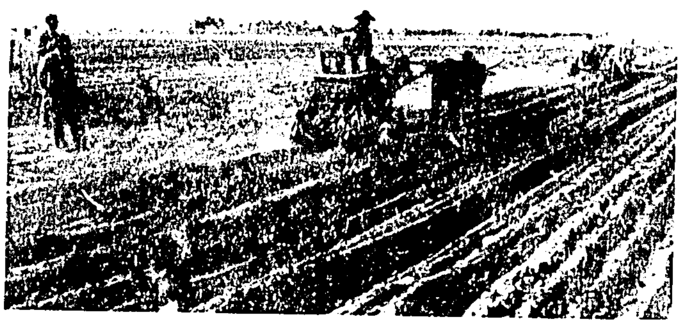
TABLE 15 - NIAMEY, NIGER:

Median values of monsoon cropping season rainfall characteristics, including date of onset and consequent rainfall amount, duration and intensity. Presented first for all years*, then for early onset versus late onset years.

		MONSOON CROPPING SEASON RAINFALL			
		MEDIAN VALUES			
NO. YEARS	ONSET PERIOD	ONSET (date)	AMOUNT (mm)	DURATION (days)	INTENSITY** (mm/days)
30	ALL, May 28-Jul 21	6-20	494	99	4.68
14	EARLY, to Jun 19	6-10	590	113	4.91
16	LATE, Jun 20 on	7-06	351	82	4.07

* 30 year record from 1954 to 1983 inclusive.

** Intensity from actual data, not calculated from median amount/duration.



Appropriate technology in the form of ox-drawn farm implements mounted on a wheeled tool bar — under development at the ICRISAT Sahelian Center, Niamey, Niger. January, 1987.

Returning to Figure 12, the lower, shaded portion of the flag is seen to contain all of the data points representing more recent years from 1971 onward. Earlier years (1954-1970) are in the unshaded portion of the flag and also the upper part of the shaded area. (In effect there are two separate flags which overlap each other.) The two flags each show clear relationships between farm-relevant rainfall characteristics and date of onset. In fact each of these relationships is stronger than when considering the whole as a single record. The important point made by the separation into two records is that yesterday's rainfall (1954-70) was markedly better in every respect than today's rainfall (1971 on). This has continued true since 1983 but precise data are not available at this writing.

Rainfall Reduction in the Sahel: A Long Cycle?

Many researchers have studied the apparent climatic change in Sub-Saharan Africa illustrated in Figure12 and have published their concepts of what has happened. Some believe it is a permanent change and others think it represents cycling which is normal in light of the history of the area. The writer shares the latter view, but believes the cycle is a long one - possibly the 100-year cycle shown to have held sway over Nile River flows for the past 300 years (Author Unknown).

The Nile cycle reaches its low point approximately 10 years after the turn of the century, e.g., 1910, 2010, and its high point some time in mid-century. The Niamey rainfall from 1905-1921 was low like the present, but seven of the 17years of data in this period are missing, making it impossible to be sure just how low. However, it seems plausible that the Sudano-Sahelian zone may be following the Nile cycle, and if so, we are presently well into the down slide. In that case, conditions will get worse before they get better again and the great majority of today's farmers in that area will not see better conditions during their farming careers. The writer believes therefore, that the shaded area of Figure 12 represents Niamey rainfall both for today and effectively for tomorrow. The information provided to farmers about their rainfall, and the recommendations on how best to respond to the information, should be based on the post-1970 period until a clear shift upward has been experienced for a few years at least.

Table 16 is similar to Table 15, but covers only Niamey rainfall as it used to be, i.e., prior to 1971.

Table 17 characterizes Niamey rainfall as it is today, and as it is expected to remain, at least through the near future.

Summary of Changes in Niamey Rainfall Since 1970

- Whereas average annual rainfall over the 50-year period 1921-70 was 594mm (23.4 in), and in the more recent 17 years of that period (1954-70) was 603mm (23.7in), it fell to 504 mm (19.8 in) in the 13-year period 1971-83. The significance of this change is elaborated below.
- There has been a general shift toward later onset of the monsoon of approximately 11 days, from a median date of June 12 in the pre-1971 period to June 23 thereafter.

TABLE 16 - NIAMEY, NIGER:

Yesterday's situation - median values of monsoon cropping season rainfall characteristics, including date of onset and consequent rainfall amount, duration and intensity. Presented first for all years from 1954-70 (17 years), then for early onset years (9) versus late onset years (8).

		MONSOON CROPPING SEASON RAINFALL			
		MEDIAN VALUES			
NO. YEARS	ONSET PERIOD	ONSET (date)	AMOUNT (mm)	DURATION (days)	INTENSITY** (mm/days)
17	ALL, Jun 01-Jul 21	6-12	519	107	5.16
9	EARLY,to Jun 16	6-10	603	112	5.16
8	LATE, Jun 17 on	7-12	480	76	5.44

* Intensity from actual data, not calculated from median amount/duration.

TABLE 17 - NIAMEY, NIGER:

Today's situation - median values of monsoon cropping season rainfall characteristics, including date of onset and consequent rainfall amount, duration and intensity. Presented first for all years from 1971-83 (13 years), then for early onset years (7) versus late onset years (6).

		MONSOON CROPPING SEASON RAINFALL			
		MEDIAN VALUES			
NO. YEARS	ONSET PERIOD	ONSET (date)	AMOUNT (mm)	DURATION (days)	INTENSITY** (mm/day)
13	ALL, May 28-Jul 11	6-23	418	93	4.20
7	EARLY,to Jun 23	6-19	508	105	4.66
6	LATE, Jun 24 on	7-04	306	84	3.45

* Intensity from actual data, not calculated from median amount/duration.

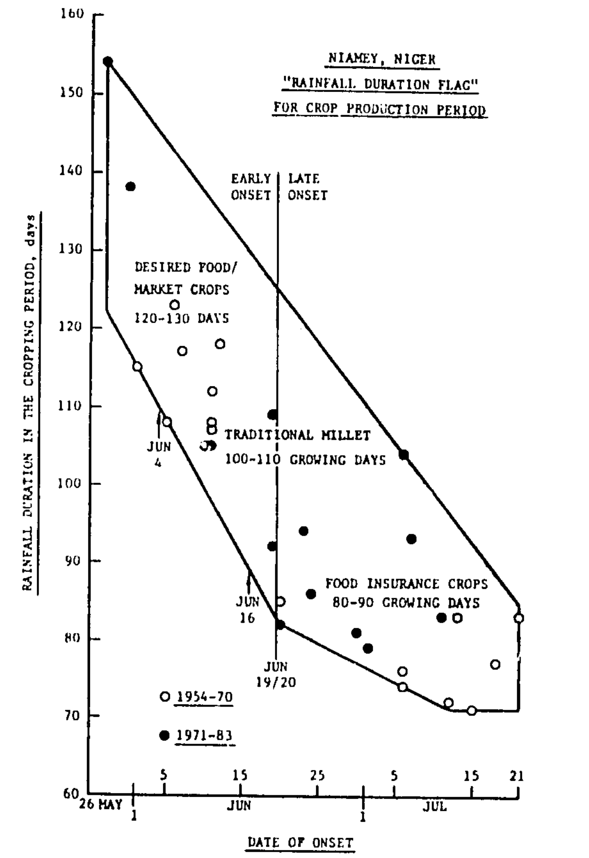
- The shift to generally later onset dates suggests weaker starts to the monsoon, and thus greater difficulty in meeting satisfactory onset conditions for safely planting crops.
- Compounding the above problem is a slight tendency for earlier recession of the monsoon, from Sep 26 before 1971 to Sep 24 thereafter. This coupled with later onset has reduced the median rainy period duration from 107 days before 1971 to 93 days in recent years.
- Though the average season has been shortened since 1971, the relative drop in rainfall amount for cropping has been even greater, and median values of intensity have fallen sharply, from 5.16 mm/day before 1971 to 4.20 mm/day thereafter. (The above are generalized comments without reference to effects of early versus late onset in the two sets of years being discussed.)
- The effect of the climatic change on early onset seasons is important, but not dramatic. In the present period onset is a bit later, resulting in a reduction in rainy period duration of one week (median), from 112 to 105days. There is a corresponding and relatively larger reduction in amount of cropping season rainfall in early seasons, from 603 mm to 508 mm, which has reduced median intensity from 5.16 mm/day to 4.66 mm/day.
- Late onset seasons have suffered much more from the climatic change, not simply in relative terms but in absolute reduction in rainfall amount. Prior to 1971, late seasons differed from early seasons only in duration. Late seasons were short but had intensity indices as high or higher than early seasons. In the period from 1971 onward, late seasons have been somewhat earlier in onset and therefore of somewhat longer duration than before, but both total rainfall and average intensity have declined catastrophically. Median late season rainfall amount used to be 480 mm but now is only 306 mm. The former average intensity of 5.44 mm/day has declined to only 3.45 mm/day. These facts mean that the traditional ways of farming in late seasons require radical change, just for the sake of survival. Because the traditions were developed in the better rainfall period from 1922 to 1970, the need presently is to provide farmers with the new rainfall information and what to do about it - particularly in the 50% of seasons which start late.

Rainfall Duration versus Date of Onset — a Strong Relationship

In most instances, rainy period duration correlates with date of onset much better than does rainfall amount. Sivakumar (1987) has quantified the duration relationship for 57 locations in Niger (including Niamey) and Burkina Faso. In each case the rainfall records used were more than 25 years long, ranging from 26 to 78 years. Thirty of the stations analyzed are in the Southern Sahelian zone, of which 27 are in Niger and 3 in Burkina Faso. This is

FIGURE 13

Duration of Monsoon cropping season rainfall, as related to date of onset. Illustrative example of crop and cultivar selection based on this relation.



the drier area with mean annual rainfall from 330 to 640 mm (13.0 to 25.2 in). Throughout this zone the correlations are excellent, with coefficients (r) ranging from 0.81 to 0.95. An additional 27 stations in the Sudanian zone of Burkina Faso have higher rainfall means from 650 to 1160 mm (25.6-45.7 in). Here the correlations are somewhat less, but still very good. All are statistically significant at the 1% level with correlation coefficients ranging from 0.52 to 0.90.

Stewart (1987) finds virtually the same correlation between duration and date of onset at Niamey as does Sivakumar (op cit). This is of interest because Sivakumar used somewhat different criteria for both date of onset and final rain date. Additionally, he analyzed 78 years of record while the writer analyzed only 30. The relationship developed by Stewart is presented in Figure 13 in the form of a "rainfall duration flag." An example of how information of this type can be interpreted to assist farmers in selecting crops and cultivars to emphasize in seasons with different onset dates is based on the figure.

The first thing to notice in Figure 13 is that the years before 1971 and the more recent years all fall nicely into the same pattern - unlike Figure 12 where they effectively form two different flags (albeit overlapping). The change which took place at Niamey in 1971 therefore, was in the amount of rainfall and in the onset dates, but not significantly in the final rain dates. Figure 12 shows the change in amount of rainfall relative to onset date. Figure 13 shows that onset dates since 1971, except for two in May, are clustered in the middle of the period from June 11 to July 11. Pre-1971 onsets tend to cluster both earlier and later than that, from June 1-12 and from July 6-21, with only one of the 17 years between (June 20). Whether or not the new tendency for onset to occur in the mid-June to early July period will persist remains to be seen, because it is not clear whether it is coincidence or has some physical cause.

Using the duration versus onset information to guide farmers requires consideration of **a.** lengths of growing seasons (maturities) of different crops and cultivars in the planning site invironment, **b.** rapidity of planting (number of days it takes to plant following onset), **c.** soil depths and water holding capacities, **d.** crop coefficients for estimation of water requirements and **e.** evaporative rates through the season.

The goal of planning is to select crops/cultivars which will reach maturity either within the rainy period or following the final rain date but before completely running out of extractable soil water. The first question is: What is the assured duration of the rainy period in relation to date of onset?

The minimum duration of the rainy period to be expected on any given onset date is defined by the lower boundary of the flag in Figure 13, which is drawn through all of the lowest data points in the record. Of course the actual duration may range anywhere from the number of days indicated by the lower boundary on up to that indicated by the upper boundary of the flag. However, Figure 13 shows the season durations at Niamey tend to lie in the lower half of the flag. Five years of the 30 years analyzed, (i.e., one year in six) are on the lower boundary, and another five years are within four days of the lower boundary, so the risk of overestimating season duration climbs quickly as one increases the estimate above the minimum.

For sake of illustration, let us assume that planting can be accomplished within five days after onset. We will estimate season rainy period duration to be the lower boundary value plus five days. From germination onward this makes our effective estimate the lower boundary value. Two-thirds of seasons will be of longer duration than estimated and one-third shorter, but only slightly shorter.

If we further assume the soil can and will store sufficient extractable water to meet the minimum needs of the crop in the final 20 days before maturity, then our illustrative case takes the form created by the three shaded bands across the flag in Figure 13. First there is the middle band representing traditional millets around Niamey, which require a growing period of 100 to 110 days.

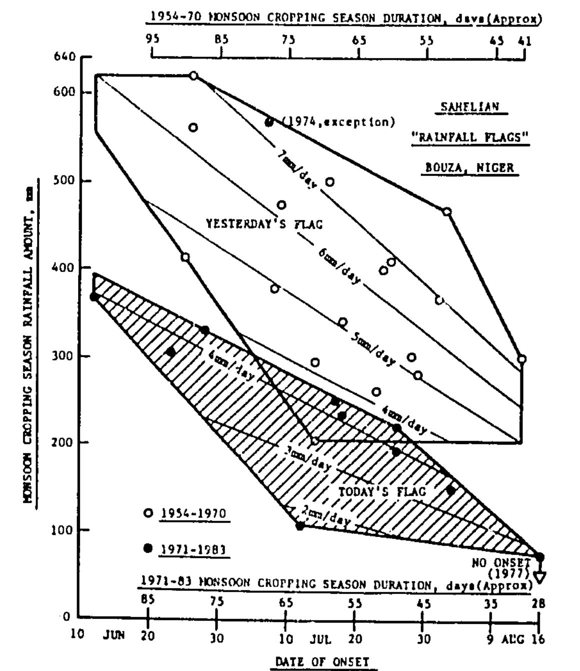
If, in fact, it is 110 days, with the soil holding water for the final 20 days, the rain will not cease until 90 days into the growing period, i.e., 90 days after crop germination. This is conservative because the actual growing period may be anywhere between 100 and 110 days. However, the conservatism is somewhat offset by risking the five planting days. Consequently, if onset of the rainy season occurs later than the date when the lower boundary of the flag equals 90 days duration, traditional millets should be deemphasized and shorter maturity cultivars planted to ensure the family food supply. In our illustration we see this is the case when onset is after June 15.

On the other hand, when onset is quite early and the lower boundary of the duration flag equals or exceeds 110 days (Jun 4 or earlier), the indication is that longer maturity crops can and probably should be grown. Such crops require more water as well as a longer rainy period, but hold the potential for higher yields and more desirability and value in the marketplace, which are needed to break the poverty syndrome.

The illustration just presented of crop selection based on the duration - date of onset relationship is not intended to be definitive as it stands. It is just one example of a field application of the new information about rainfall. However, little additional information would be required to adapt it for use on the ground in providing guidance to farmers. The principal need is to conform the recommendations to the major soil types of the area, which will differ

FIGURE 14

Two rainfall flags over Bouza, Niger. The upper flag shows how the monsoon season rainfall amount, duration and intensity related to the date of onset prior to 1971. The lower flag (shaded) shows the effects of the climatic shift in subsequent years.



in their depths and water holding capacities. For example a shallow sandy soil would indicate emphasis should be given to shorter term food insurance crops at an earlier onset date than would be the case for a deeper soil with loamy or clayey texture.

Rainfall Relationships at Bouza

The second example for the Southern Sahelian zone is Bouza, Niger - more northerly than Niamey, therefore closer to the Sahara Desert and drier. It illustrates that the impact of the climatic shift at the start of the 1970s is greater, absolutely as well as relatively, in the drier zones of the Sahel. Figure14 shows this point.

In Figure 12 it was seen that the 1971 rainfall at Niamey effectively began a new, and poorer, pattern in the relationship between seasonal rainfall amount and date of onset. On any given onset date from 1971 on, the expected rainfall (compared to 1954-70) has been reduced by an amount ranging from 40 mm (1.6 in) on the earliest date of onset (May 28) to 168 mm (6.6 in) on the latest (Jul 21). The average reduction is 104 mm (4.1 in).

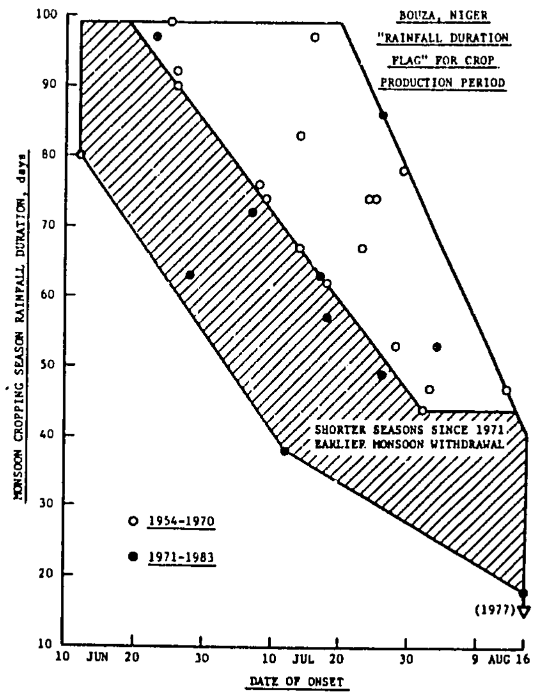
Figure 14 provides the equivalent information for Bouza, but shows a still more startling separation - more nearly complete and of greater magnitude - at the drier location. As at Niamey, the Bouza rainfall flags show that rainfall amount declines with later onset. But the lower shaded area, labelled "Today's Flag," shows that the reduction in expected rainfall (compared to 1954-70) with any given date of onset is severe, ranging from approximately 160 mm (6.3 in) with the earliest onset (Jun 12) to about 170 mm (6.7 in) with the latest onset (Aug 16) for an average of 165 mm (6.5 in).

There are three important differences between Figure 14 and Figure 12. First, the range of dates of onset at Bouza is from June 12 to August 16, markedly later than at Niamey on average. However, onset has been earlier at Bouza in some individual years. Second, the scales showing approximate monsoon cropping season duration at the top and bottom of the figure are not identical. The lower scale, representing "today's" situation, shows that the rainy period duration associated with any given date of onset has decreased by about 10 days as compared with the pre-1971 situation. More detail on this will come with discussion of Figure 15. Third, Figure 14 shows 1974 was an exception at Bouza, in that rainfall was high, near the top of the former pattern. In practical terms this is of little consequence because it stands alone. If several years do this then reevaluation of the situation would be in order.

Figure 15 shows the rainfall duration flag for Bouza, equivalent to that seen in Figure 13 for Niamey. But again there are noteworthy differences. First, the duration of rains at Bouza is much less than at Niamey, ranging from about 20 to 100 days, versus approximately 70 to 150 days at the latter. The average is about 50 days longer at Niamey. Second, the lower shaded portion of Figure 15 shows the climatic shift of 1971 strongly affected season

FIGURE 15

Duration of the monsoon rainy period for crop production, as related to date of onset at Bouza, Niger. Shaded area shows climatic shift since 1971, manifested by earlier recession of the monsoon. Bouza, Niger, 1954-83



duration as well as rainfall amount. Until 1970, all years of record at Bouza were in the upper clear portion of the flag, meaning the expected duration is greater. Since 1971, of the total of 12 years (1971-83, with 1982 missing), eight years have formed a completely different and poorer pattern (shaded) including one year with no onset at all (1977). The other four years remain in the pre-1971 pattern. The practical meaning of this is that since 1971, in two out of every three years, the monsoon has withdrawn from the area approximately 10 days earlier on average than previously.

It is the earlier recession of the monsoon at Bouza which has required two different duration scales for "yesterday's" versus "today's" flags in Figure 14. This shift is also responsible for there being two lines labelled 4 mm/day intensity in Figure 14. And with reference to rainfall intensities, note that they ranged mostly from 4 to 7 mm/day, comparable to Niamey before 1971, after which they have ranged from 2 to 4 mm/day, much less than at Niamey, and, as previously indicated, over a much shorter season.

The inescapable conclusion is that while Bouza was at least a marginal crop production area before 1971, it is no longer suited to that usage. If crops are attempted in today's rainfall conditions, only those grown in seasons with onset by mid-July offer any reasonable hope of satisfactory production.

CHAPTER 14

Broadening the Findings: The Sudano-Sahelian Zone

Relationships of rainfall amount and duration such as those at Niamey and Bouza in Niger are found throughout the Sudano-Sahelian zones. The application of these findings to farm level decision making is further strengthened by the broader, better known climate relationships of the area. Table 18 provides a first look at the broader aspects of the situation and an initial blending of the longer known information with that more recently developed.

TABLE 18

Eleven locations in four countries of Sub-Saharan Africa listed by latitude from the dry north with a late monsoon to the relatively wetter south where the monsoon arrives earlier. Mean annual rainfall to 1970, then for 1971 onward. Ranges of onset dates showing earliest, 50% of years and latest onsets.

LOCATION	NORTH LATITUDE	MEAN ANNUAL RAINFALL, mm		RANGES OF ONSET DATES		
		to 1970	1971 on	EARLIEST	50%	LATEST
Podor(S)**	16°38'	292	156	7-07	8-08	9-21
Ansongo(M)	15°40'	334	(214)*	6-02	7-27	8-27
Kayes(M)	14°26'	749	546	5-21	6-23	7-28
Bouza(N)	14°25'	489	313	6-12	7-18	8-16
Dori(BF)	14°02'	536	455	6-04	7-06	8-13
Nioro(S)	13°44'	875	(590)*	6-08	7-01	7-26
Kolokani(M)	13°35'	848	(724)*	5-11	6-20	8-09
Niamey(N)	13°29'	603	504	5-28	6-20	7-21
Kaya(BF)	13°09'	700	(673)*	4-30	6-15	7-24
Gaya(N)	11°59'	829	774	4-30	6-03	8-01
Boromo(BF)	11°44'	957	975	[illegible]	5-20	5-28

* Estimated using the relations shown in column 4, Table 19.
** Countries are Senegal (S), Mali (M), Niger (N) and Burkina Faso (BF).

Dates of Onset and Rainfall Amounts - Linkages with Latitude

In Table 18 information is shown for 11 locations in Sub-Saharan West Africa, including the two already discussed. Four countries are involved, from Senegal on the west reaching the Atlantic Ocean, eastward through Mali and Burkina Faso to Niger. All 11 locations lie in the belt between 11° and 17°N latitude, above which is virtually rainless desert. The table lists the locations by latitude in descending order from north to south. The northernmost location is Podor, Senegal, at 16°38', and the southernmost is Boromo, Burkina Faso, at 11°44'. These are also the driest and wettest locations respectively, with long term mean rainfall amounts (prior to 1971) of 292 mm (11.5 in) at Podor and 957mm (37.7 in) at Boromo.

The intermediate nine locations have intermediate rainfall, generally increasing with descending latitude. This relationship of annual rainfall to latitude is well known and much documented.

The relation between rainfall and latitude is nearly perfect for 8 of the 11 locations which lie easterly - those in Niger (3), Burkina Faso (3), eastern Mali (1) and northern Senegal (1). More westerly locations in Senegal (Nioro) and Mali (Kayes, Kolokani) follow a similar pattern but with approximately 35-50% higher rainfall at a given latitude.

The mean rainfall figures at all locations prior to 1971 may be seen in column 3, Table 18. Column 4 shows mean rainfall from 1971 onward at seven of the 11 locations for which data are available at this writing - plus estimates for the other four. The seven are based on limited data with 13 years at two sites, nine years at two sites and 12, six and three years, each at one site. These post-1970 rainfall means are not offered as precise values, but simply as representative of the situation now being faced by farmers of the region. As more data become available, improved analyses will be made.

Table 18 also shows the results of additional analyses on the long term rainfall records (all years) as to when onset of the monsoon for cropping purposes has occurred at the 11 locations. Columns 5, 6 and 7 respectively show the earliest dates of onset, the dates by which 50% of all years had onset, and the latest dates. The author is indebted to Dr. Ed Kanemasu and his staff at Kansas State University for providing the rainfall data and for collaborating in the programming and running of these analyses.

Since it is always possible to have a freak onset event which might throw the "earliest" and "latest" onset columns out of line, it is most informative to look at the 50% onset dates in column 6. There we see an almost linear progression of onset, starting early in the south at Boromo and 80 days later reaching Podor in the north. The reader should not infer that this type of progression occurs cleanly each year. These are long term means, and in any given year the progression of the monsoon front can be erratic.

Monsoon Recession and Latitude

The opposite is true of the recession or withdrawal of the monsoon, which (on average) occurs almost simultaneously at all latitudes being discussed. There is a mild tendency for later withdrawal in the south, perhaps four days later than in the north. Thus in 50% of years, the monsoon rains depart the 17th parallel by Sept 24, and the 11th parallel by Sept 28.

Figure 16 provides a graphical representation of the relationship of onset to latitude, based on columns 5, 6 and 7, Table 18. The vertical scale shows north latitude in degrees and minutes, from 11° to 17° inclusive. The horizontal scale is a calendar showing both ordinary dates and Julian dates (days are numbered from one on Jan 1). The onset dates from each of the 11 locations are drawn in at the appropriate latitude, in each case showing the earliest date of onset analyzed from the long term rainfall record, the 50% date and the latest date. The three dates for each location are linked by dashed lines. Each country has a different symbol marking earliest and latest dates.

The shaded area of Figure 16 represents the result of regression analyses in which the three sets of onset dates are related to latitude mathematically. The purpose of the analyses is to enable one to estimate the dates of onset for any other location not analyzed, in the Sub-Saharan zones covered. Estimates of earliest onset dates would be based on the line forming the left side of the shaded area. Fifty percent onset dates would be based on the heavy line up through the middle of the shaded area, while the line on the right side estimates latest onset dates. For example, the three arrows dropped from the 13th parallel in the figure indicate that locations at that latitude should have earliest onset on May 13, 50% onset by Jun 14 and latest onset by Jul 24.

Such estimates are shown for all the parallels of latitude in the last three columns of Table 19. The table also shows estimates of mean annual rainfall at each parallel both before 1971 and from 1971 onward. These estimates derive from the same types of regression analyses

FIGURE 16

Western Africa, Sudano-Sahelian zone: ranges of dates of onset of the monsoon cropping season, shown as a function of latitude. Senegal, Mali, Burkina Faso and Niger.

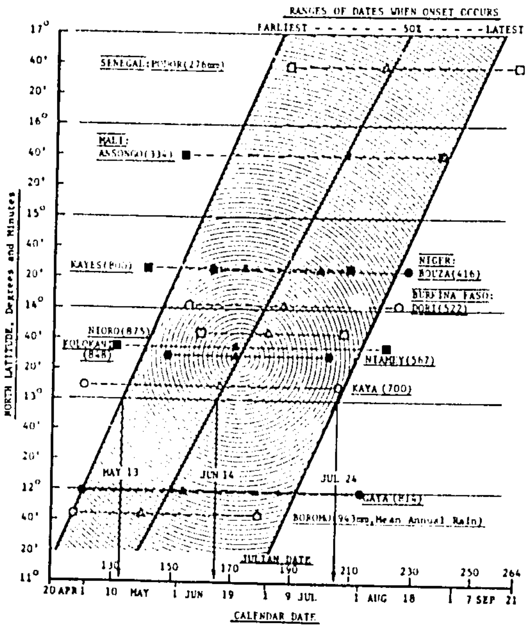


TABLE 19

Generalized values for monsoon cropping season onset date and mean annual rainfall amounts for latitudes 11° to 17°N in Burkina Faso, Niger, eastern Mali and the northernmost area of Senegal. Rainfall amounts are shown to 1970 and from 1971 onward, with percentage reductions of the latter.

LATITUDE NORTH	ESTIMATED RAINFALL, mm PRE-1971	ESTIMATED RAINFALL, mm 1971 ONWARD	% REDUCTION 1971 ONWARD	ESTIMATED ONSET DATES EARLIEST	ESTIMATED ONSET DATES 50%	ESTIMATED ONSET DATES LATEST
17°	177	32	81.9	7-04	8-16	9-16
16°	310	182	41.3	6-21	7-31	9-03
15°	444	331	25.5	6-08	7-15	8-20
14°	577	481	15.1	5-26	6-30	8-07
13°	711	630	11.4	5-13	6-14	7-24
12°	844	780	7.6	4-30	5-29	7-11
11°	977	929	4.9	4-17	5-14	6-27

as were used to draw Figure 16. Rainfall figures used in the analyses are those shown earlier in Table 18.

Accelerated Rainfall Reduction in Drier Latitudes

The estimates of rainfall in columns 2 and 3, Table 19, in turn were used to estimate the percentages by which rainfall has been reduced in this region in the years from 1971 onward. The estimates of percentage reduction in rainfall, seen in column 4, do not form a linear function with latitude, as do rainfall amounts and dates of onset. Instead, we see small reductions of less than 10% in the wetter southern areas, becoming ever greater percentagewise (and also in absolute rainfall amount) as one proceeds to the drier northern latitudes.

Detailed examples of this phenomenon were discussed earlier for Niamey and Bouza, at latitudes 13°29' and 14°25' respectively. Niamey rainfall has fallen from 603 mm before 1971 to 504 mm thereafter - a drop of 99 mm or 16.4%. Bouza, at 489 mm, fell 176 mm to 313 mm, or 36%.

Onset Relations at All Locations: Regression Analysis

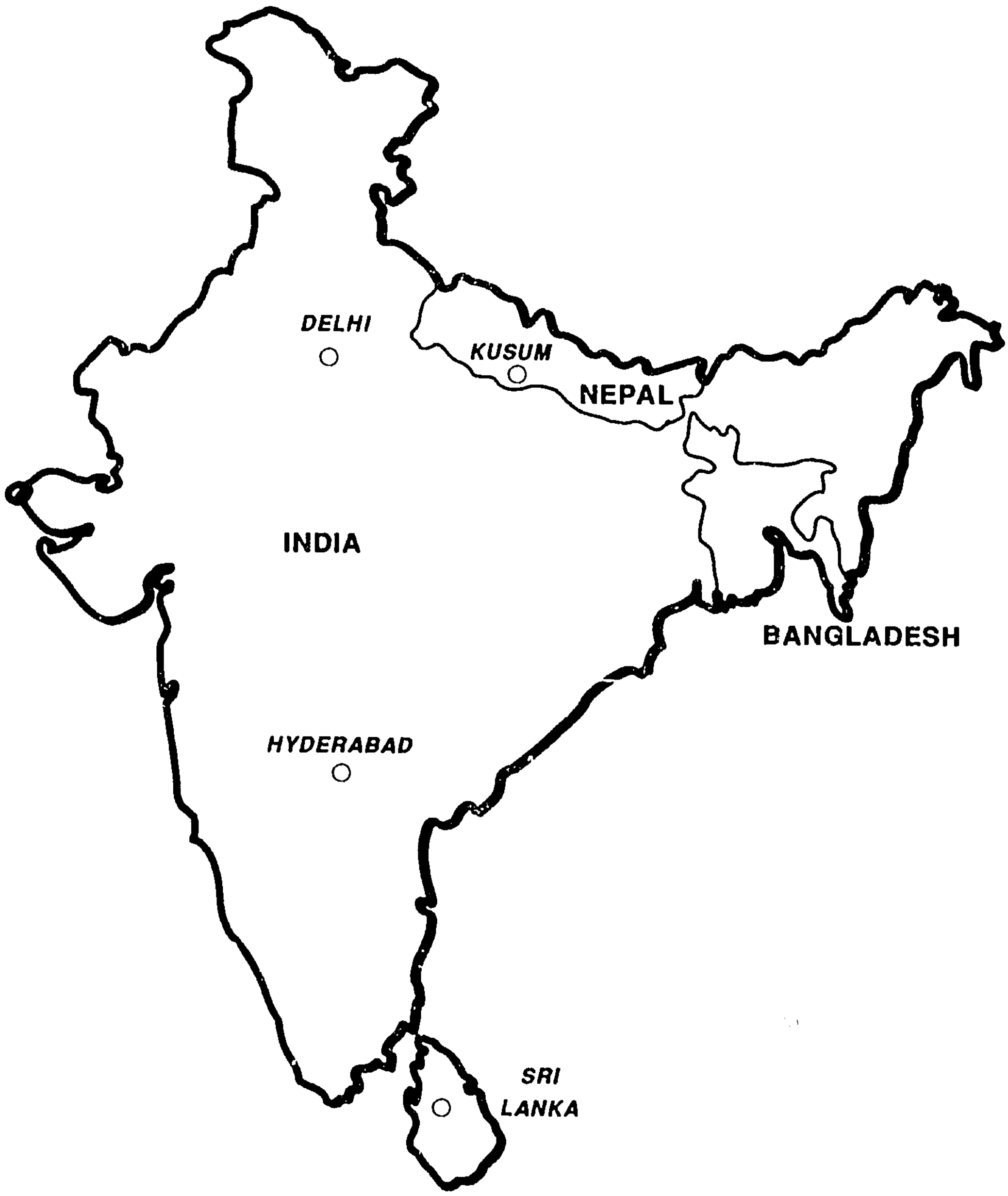
Returning to the relationships of principal interest: Those of (1) cropping season rainfall amount and (2) duration with date of onset are quantified by regression equations for all 11 locations in Table 1, Appendix A. The equation for Niamey and Bouza are determined by the writer's analyses while the others, as earlier noted, were analyzed by Kanemasu and colleagues in collaboration with the writer.

Whenever data were sufficient, the above relationships were analyzed separately for the years prior to 1971 and from 1971 onward. In each case the degree of closeness or fit of the relationship is represented by the coefficient of variation (R^2). The maximum possible value of R^2 is 1.0, meaning a perfect fit. For example, if R^2 were 1.0, one could predict precisely the amount and duration of rainfall to be produced in the season, as of the date of onset. If R^2 is 0.60, the practical meaning is that 60% of the range of past occurrences will not be associated with any given date of onset and only 40% will be.

In Table 1, Appendix A, we see the following:

1. A strong relationship exists between rainfall season duration and date of onset at all 11 locations. This is shown by R^2 values which range from a low of 0.46 in recent years (since 1971) at Bouza, Niger, to a high of 0.85 in years before 1971 at Kolokani, Mali. Statistically speaking, these are all highly significant relationships at the 1% level. Practically speaking, these are all highly useful relationships upon which to base advice to farmers on crop types and cultivars to emphasize in their plantings in different seasons.
2. A less strong but equally valid and useful relationship exists between cropping season rainfall amount and date of onset. Coefficients of variation (R^2) range from a low of .05 at Kaya since 1971 to a high of 0.73 at Bouza since 1971. The latter is an example of an interesting phenomenon. The R^2 values for this relationship have increased markedly since 1971 at five of the six locations where sufficient data are available. The recent mean is 0.51 whereas the pre-1971 mean was 0.24.
3. The relationship between rainfall amount and date of onset is nearly always useful for guiding farm decisions even when the R^2 values are low, because the R^2 shows only how much the historical range of rainfall amounts are reduced at any given date of onset - it does not necessarily reflect important changes in rainfall probabilities within the remaining range. For example, at Kaya, Burkina Faso, before 1971 the R^2 was only 0.12, indicating a reduction in the range of 12%. What it does not show is that the probability of rainfall amount being in the lower one-third of all years, which one might assume is 33 1/3%, is only 12% if onset is early - within the first one-third of all onsets - but is all the way up to 58% if onset is in the last one-third of all onsets. Expressed differently, one very low rainfall year may be expected in every eight early onset years, but nearly six in 10 years of late onset.

TECHNICAL SECTION II-E
THE ASIAN SUBCONTINENT



CHAPTER 15

Nepal

Improving Our Ability to Predict Rainfall

Foregoing sections have focussed on the influence of the date of onset on subsequent seasonal rainfall amount, duration and intensity. The discussions have dealt with the use of date of onset as a predictor of these seasonal rainfall characteristics. Thus in each year or season at any given location, farmers can be guided - as of the date that satisfactory rains appear - in the numerous decisions they must make when planting. These include land preparation and tillage, crop types and cultivars to be emphasized, mixed cropping versus sole cropping, row spacings, seeding rates, initial fertilization rates, weeding practices, etc. All of these and more are influenced by water supply expectations.

There are two distinct ways the above procedures might be further improved. One is to learn how to predict season characteristics more precisely. The second is to learn how to predict earlier in time. This would offer the farmer and his supply system more lead time to prepare for the unique characteristics of the approaching season. The search for ways to predict seasonal rainfall more closely and/or earlier in time is a major research goal of WHARF. The initial finding that the monsoon of the Asian subcontinent may be predictable before onset is presented here.

Two examples are presented. The first is for Kusum, Nepal, located in the mid-western Terai near Dang, close to the northern border of Uttar Pradesh, India. Kusum lies in the upper Gangetic Plain at an altitude of 235 m (770 ft). Map coordinates are 28°01'N latitude and 82°07'E longitude.

Kusum, Nepal: Monsoon Characteristics as Related to Prior Winter/Spring Rainfall

The rainfall record from Kusum spans 28 years from 1957-84. It shows mean annual rainfall of 1474 mm (58 in), which is high compared to the locations discussed earlier, but representative of much of the Terai and inner-Terai area. The monsoon usually arrives in June, but can appear any time from the latter half of May to the first half of July. Final rains are from late September through October. November is almost always totally dry, after which the December-April period (winter/spring) may have rains ranging from zero to 334 mm (13.1 in), according to the record in hand. If we split the year, mean monsoon rainfall (May-November) is 1366 mm (53.8 in) and December-April rainfall is 108 mm (4.3 in).

Robbie Stewart and Dr. Charles Hash, Member WHARF Professional Advisory Council, in Durbar Square, Bhaktapur, Kathmandu Valley, Nepal, 1986.

Both the monsoon rains and the predecessor winter/spring rains are characterized by a relatively few years (approximately one in three) of well above average rainfall with the others below average. Thus, for farming purposes it is more meaningful to refer to medians than means or averages. And in the case of the monsoon, it is relevant to speak of the cropping season from onset to final rain date, rather than to every drop of rain in the May-November period. With these considerations, median rainfall at Kusum is 1200 mm (47.2 in) in the monsoon, and 85 mm (3.3 in) in the preceding winter/spring period.

Pre-Monsoon Rains Predict the Monsoon at Kusum

The important finding leading to earlier rainfall prediction is that the winter/spring rains appear to be a predictor of the character of the monsoon to come. In other words, on May 1, much useful information about the approaching monsoon may be ascertained, based on a simple summation of total rainfall received in the reference rain gauge since the preceding December 1. A fortunate aspect of this early prediction is that it is most accurate for the extreme years - either extremely wet or extremely dry - which are the most worrisome to farmers. Intermediate type years may be more clearly sorted out as of the date of onset.

Using winter/spring rainfall as a predictor is a simple process. The numbers cited here (rainfall amounts) are valid only for Kusum and immediate surrounds. Additional analyses are required to generate predictors for other sites but the process and the types of results are expected to be the same. At Kusum the amount of winter/spring rainfall is divided into three groupings, each implying its own set of characteristics to be expected in the coming monsoon as follows:

1. **Winter/spring rain of 150mm or greater** - this is the wet extreme, the case in two of every seven years. Monsoon characteristics expected are **a.** onset will be early, by Jun 7, **b.** rainfall amount, duration and intensity all will be in the range of normal to extremely high, and **c.** risks of soil erosion from high intensity rains and of crop losses to water logging from excessive rain or duration all will be high, calling for appropriate land

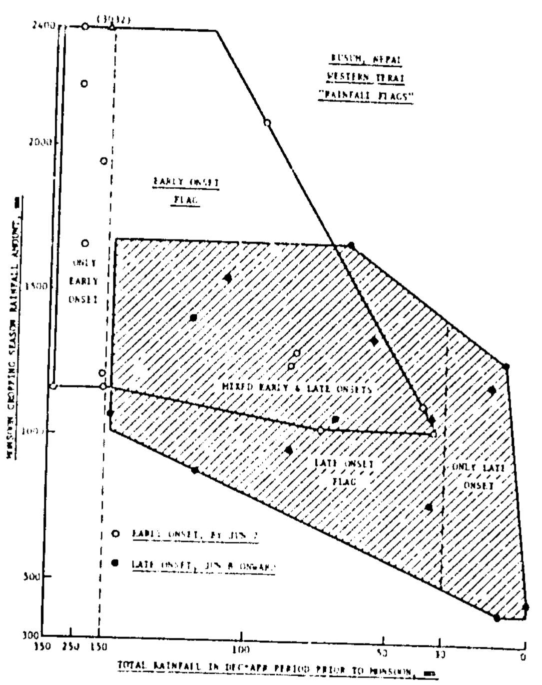
preparation to assure drainage of excess water.

2. **Winter/spring rain of 30 mm or less** - this is the dry extreme, the case in one of every seven years. Monsoon characteristics expected are **a.** onset will be late, after Jun 7, **b.** rainfall amount, duration and intensity will combine to place all of these seasons in the low normal, subsistence or failure categories, and **c.** risks of very low rainfall will be great, with no risk of erosion or waterlogging, so land preparation should stress retention of all rainfall on the cropped field.
3. **Winter/spring rainfall of 31 to 149 mm** - this occurs in four of seven years. Monsoon characteristics expected are less clear but generally central. Whether high central or low central depends on date of onset as will be shown. For the moment, suffice it to say **a.** onset cannot be predicted for this group as early or late; it may be either, **b.** rainfall amounts, durations and intensities cover wide ranges but none stretch to the lowest or highest extremes, and **c.** risks associated with both wet and dry conditions are still present at very low probabilities, but they are clarified, as are the more positive factors on the date of onset (if early) or on June 8 (if late).

Returning to the "rainfall flag" type of presentation, Figure 17 relates monsoon cropping season rainfall amount to the amount of prior winter/spring rainfall. Early and late dates of onset are also shown because winter/spring rainfall is for some years (the extremes) a predictor of both date of onset and rainfall amount. In effect this causes Figure 17 to separate into two overlapping rainfall flags which clearly show the distinctions between early and late onset seasons.

FIGURE 17

May 1 relationships between the winter/spring rainfall just completed and the ranges of onset dates and rainfall amounts expected in the approaching monsoon. Kusum, Nepal (Western Terai)



In Figure 17, early onset years are represented by open circles and are all enclosed within the upper rainfall flag. Late onset years are shown as black circles and are all enclosed in the lower, shaded flag. The two flags overlap in part. The vertical scale shows the amount of monsoon cropping season rainfall, while the horizontal lower scale shows the amount of winter/spring rainfall which preceded the monsoon. The winter/spring rainfall scale starts with zero at the right hand side and becomes greater as one moves to the left. The scale is compressed after reaching 150 mm in order to include the higher levels reached in eight of the 28 years of record.

A dashed vertical line extends upward from 150 mm on the winter/spring rainfall scale, and near the top of this line is a triangle and the number 3032. This was the rainfall level of the wettest season in the record. All others are as shown. In terms of prediction on May 1, the dashed line and the data points show three important findings for years in which the monsoon is preceded by 150mm or more of winter/spring rain:

1. All eight of these years went on to have early onset.
2. All produced at least normal rainfall.
3. Four of the five extremely high rainfall years in the record fell into this group of eight years predicted by high prior rains.

Another vertical dashed line is drawn on the right hand side of Figure 17, extending upward from 30 mm on the lower scale. Again, for prediction on May1, this illustrates three important points:

1. All four years to the right of this line went on to have late onset.
2. The best two seasons produced normal, but not better, rainfall. However, one of these, being so late in onset, was of such short duration that it could only produce subsistence level crop yields. (More on this later.)
3. The other two seasons were the worst in the entire record and were complete failures in terms of producing crops of the area.

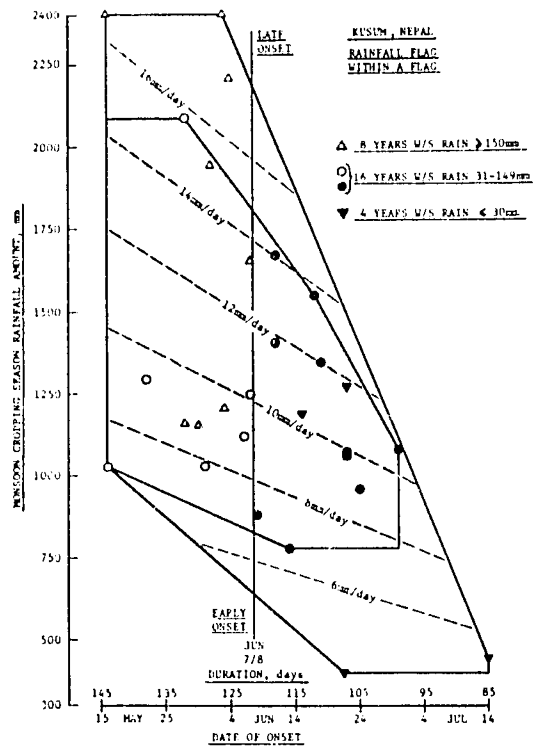
The remaining 16 years of the 28-year record fall between the two vertical dashed lines in Figure 17. This includes the area where the two flags intersect, indicating that when winter/spring rainfall has been moderate (31-149 mm), we cannot predict on May 1 whether onset of the monsoon will be early or late. Additionally we still face a rather broad range of possible rainfall amounts in the coming monsoon, but - and this is important - the real extremes of wetness or dryness are no longer threatening.

The more familiar relationship of rainfall amount with date of onset is seen in Figure 18, which in effect constitutes a flag within a flag.

If one views the outline of the larger flag encompassing all data points, it strongly resembles a number of

FIGURE 18

Monsoon rainfall amount, duration and intensity relationships with date of onset. Data identify three levels of pre-monsoon winter/spring (w/s) rainfall.



examples from other locations. The principal similarities are that the range of rainfall amounts, and the probabilities of given rainfall amounts within the range, change rapidly in negative fashion as onset gets later in time. A difference from earlier examples is the higher rainfall amounts and intensities at Kusum. The latter, for example, range from 16 mm/day to 6 mm/day with a median value of nearly 10 mm/day. This is considerably higher than the Mediterranean or East or West Africa where median intensities are about 2, 4 and 5 mm/day respectively. Nevertheless, despite the higher rainfall and intensities, the basic relation of rainfall to onset remains.

Although each datum point within the flag in Figure 18 represents one year in the 28-year record, years with different characteristics are represented by four different types of symbols - clear circles and triangles pointing upward in the early onset portion of the flag, and blackened circles and inverted triangles for late onset.

The clear triangles with early onset show what happened in the eight years that winter/spring rainfall was 150 mm or greater. If a line were drawn to enclose all of these, it would essentially form a long, upright rectangular box all on the left side of the flag, and taking in the highest rainfall amounts recorded. The assumption is that if, on May 1 of any year in the future, rainfall in the prior Dec-Apr period reaches 150 mm, one can predict that monsoon cropping season rainfall amount and date of onset will fall within that box.

The blackened and inverted triangles with late onset show historical occurrences in the four years when winter/spring rainfall was 30 mm or less. A box around these would form a trapezoid which includes the lowest rainfall amounts and the latest date of onset in the 28 years of record. As above, it is assumed that future monsoons will fall in this box if winter/spring rainfall is below 31 mm. This will be known on May 1 of the year in question, and the farmer may be informed as to the preparations he should make.

This leaves the circles, both clear and blackened, which form the shaded flag within the larger overall flag. This inner flag, like the two boxes above, is known as of May 1 when winter/spring rainfall has been in the intermediate range of 31-149 mm. The shaded inner flag encloses all of the actual occurrences which have followed intermediate winter/spring rainfall. This intermediate category is the most frequent of all - it includes 16 of the 28 years of record, and both early and late (but not the latest) onsets. Once again, it is assumed future monsoons will fall within the shaded flag if winter/spring rainfall is intermediate. On May 1, the farmer armed with just this much knowledge can proceed with his planning, confident that he does not face the worst extremes of either wetness or dryness.

In the case of intermediate winter/spring rainfall, the farmers' knowledge can be further greatly enhanced however, as of the actual date of onset - or on June 8 at the latest when, by definition, onset is late. The nature of the information which can be provided will now be elaborated. A simple summary of the median values of agriculturally important characteristics of the monsoon at Kusum over the 28 years is presented in Table 20. The table first shows overall medians, then the medians ap-

TABLE 20 - KUSUM, NEPAL:

Median values of winter/spring rainfall preceding the monsoon, and of monsoon cropping season onset dates, and rainfall amount, duration and intensity. Presented first for all 28 years of the record, then for seasons which fall in four predicted groupings, identified by winter/spring rainfall, or by early versus late onset.

		PRE-MONSOON	MONSOON RAINFALL			
NO. OF YEARS	ONSET PERIOD	WINTER/SPRING RAINFALL, mm	ONSET DATE	AMOUNT mm	DURATION days	INTENSITY mm/day
		(MEDIAN VALUES)				
28	ALL	65	Jun 7/8	1194	121	9.9
		Four Groupings of Seasons				
8	EARLY	206*	Jun 1/2	1797	136	13.2
6	EARLY*	78	May 29/30	1182	123	9.6
10	LATE*	77	Jun 17/18	1072	111	9.7
4	LATE	9*	Jun 21/22	813	101	8.0

* Predictors

plicable to each of the four categories of years predicted by winter/spring rainfall and date of onset.

Table 20 displays major differences between the first and last groupings, representing rainfall highs and lows respectively, and between these extremes and the overall median values. That these are differences of real importance to farmers is obvious. Less clear is the difference between the two intermediate groupings of 6 early onset and 10 late onset years. However, the table shows only median values which are less informative than the ranges (the figures already presented do that best) and are still less informative than coupling ranges with probabilities.

TABLE 21 - KUSUM, NEPAL:

Minimum rainfall criteria for five levels of crop production (illustrative -- see utilization in Table 2, Appendix A and Figure 19).

- -YIELD LEVELS- -	- - MINIMUM RAINFALL REQUIREMENTS - -		
SEASON* PRODUCTION POTENTIAL	AMOUNT mm	DURATION days	INTENSITY mm/day
MAXIMUM	1800	140	14.7
HIGH NORMAL	1200	120	10.0
LOW NORMAL	900	100	7.5
SUBSISTENCE	700	88	6.0
FAILURE	<700	<88	<6.0

* Season each year is from defined onset date to final rain date, inclusive.

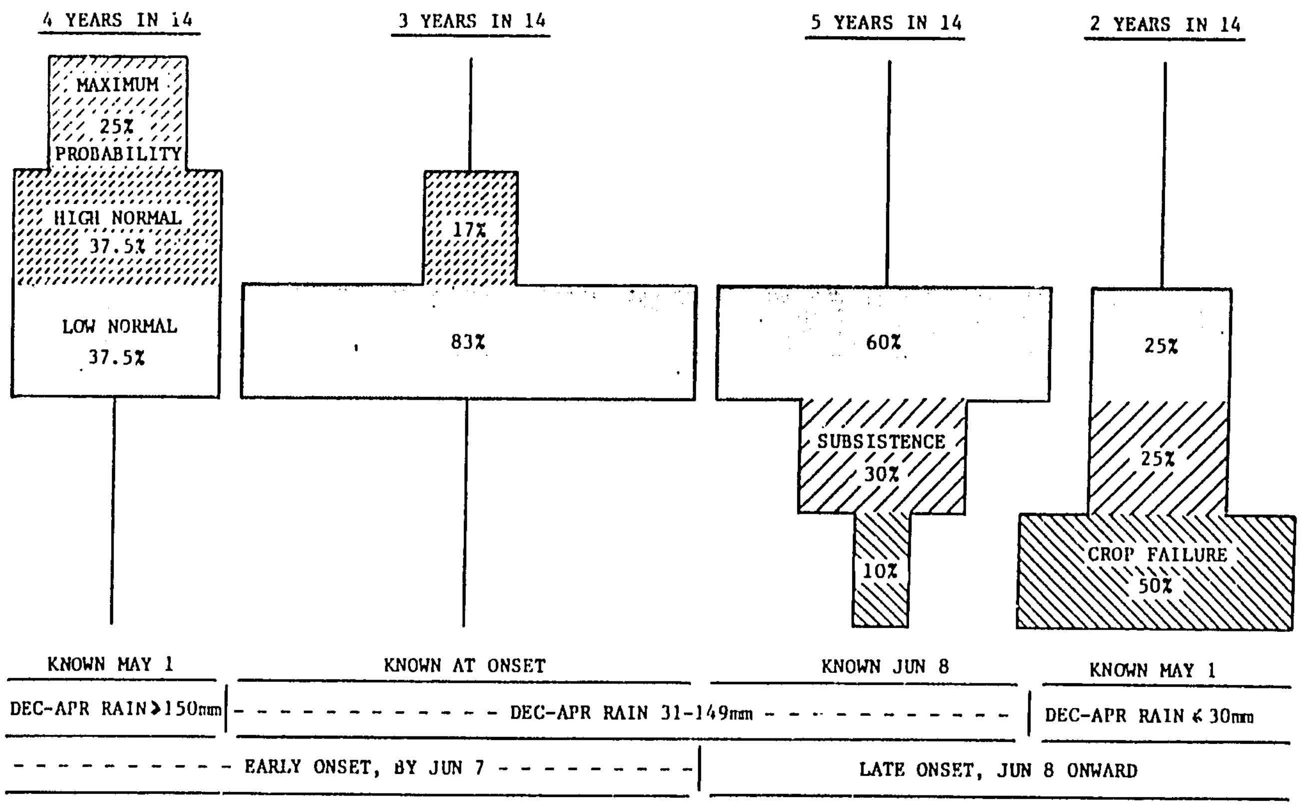
Potential Crop Production in Terms of Rainfall Probabilities

A new approach will now be introduced, which links rainfall probabilities directly to crop production probabilities. This is accomplished by ranking the three key seasonal attributes of rainfall amount, duration and intensity, all based on normal (median) values for the location. The ranking is at five levels as shown for Kusum in Table 21.

The first thing to observe in Table 21 is that season production potential is not linked to any specific crop, but to a hypothetical standard crop, which, in order to yield in the upper half of its potential range in the study location, requires that rainfall amount, duration and intensity all reach or exceed their median values. Since normal is the median rainfall amount, duration and intensity, high normals are all above that. However, at 1.5 times normal rainfall, it is assumed that water requirements of all area crops (rice for example) are satisfied, and that erosion and waterlogging have become potential hazards. The production potential is termed maximum, but measures must be taken to drain excess waters. Low normal is assumed to range from 75 to 100% normal, while subsistence level potential ranges from about 60 to 75% of normal. Below that, failure is assumed.

FIGURE 19 -- KUSUM, NEPAL

Probabilities of monsoon crop production levels in seasons categorized prior to the monsoon: on May 1 if winter/spring rains expecially high or low -- if moderate, categorization is at onset for early seasons, or on Jun 8 for late seasons.



Again the reader is cautioned that the new approaches presented here are just that -- approaches. However, they are thought to hold some real promise for providing answers to major problems not presently being addressed successfully using standard methods. The numbers and percentage rankings, etc., utilized, such as in Table 21 and in the paragraphs above, represent the best judgments of the writer based on experience and research findings presently in hand. Without question, further research will change and improve such numbers. The objectives here are to urge **a.** adoption of new approaches, **b.** utilization of the best information we have in hand for the immediate benefit of the farming community, and **c.** setting in motion widespread research activities aimed at improving the new approaches and their ability to provide helpful guidance.

"Limiting Factors" Govern Sesason Rankings for Production Potential

When assigning a ranking to the production potential of a given season, the approach suggested here utilizes the well known concept of limiting factors. This is a conservative approach which places the season rank in the lowest category in which any one of the three attributes (rainfall amount, duration, intensity) falls.

For example, looking at Table 21, if a season had 1400 mm of rainfall (high normal), an average intensity of 11.9 mm/day (high normal), but the rainy period persisted just 118 days (low normal) - the season is ranked as low normal. This is because it cannot fully support the longer maturity cultivars capable of efficiently utilizing the full amount of rainfall to produce above the normal level.

Detailed Rainfall Record for Kusum

In Table 2, Appendix A, all 28 years of record at Kusum are shown, with the details of their pre-monsoon winter/spring rains, onset dates and monsoon cropping season rainfall amounts, durations and intensities. On the basis of these figures and the criteria seen in Table 21, each season in the record has been assigned a ranking for its production potential. Next the probabilities of each of the five rankings occurring in each of the four predicted rainfall groupings (Table 20) have been calculated. All of the above are summarized in Figure 19.

Early Categorization of the Monsoon at Kusum

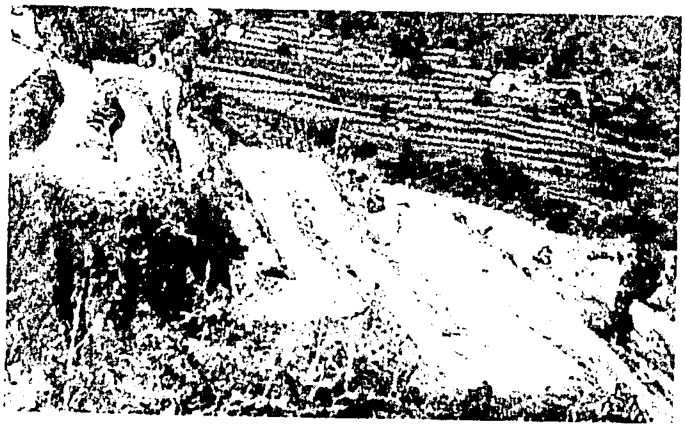
Figure 19 shows the kinds of information which the new analyses and approaches can produce to guide farmers in their decision making prior to and at planting time. In this illustration, each of the 28 years of record at Kusum falls into one of the four production probability patterns pictured. All four patterns are predictable in time for the farmer to take appropriate action. The dates when the prediction can be made are shown in the figure.

The two patterns on the left of Figure 19 represent early onset seasons, none of which historically has fallen to either the subsistence or failure level. The only category in which maximum production has been possible has been those seasons preceded by high winter/spring rainfall. Similarly, the majority of "high normal" production potential seasons were preceded by high winter/spring rainfall, and all had early onset.

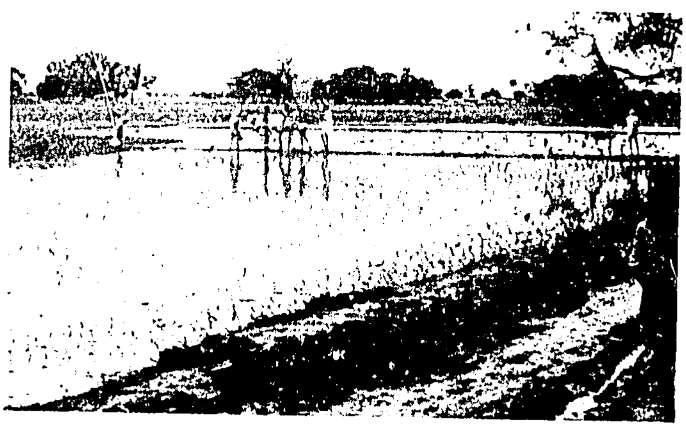
Late onset seasons, represented by the two probability patterns on the right of Figure 19, have never reached either maximum or high normal production potential, and pose clear risks of falling to the subsistence or even failure level. In the case where pre-monsoon rainfall fell below 31 mm, three out of four seasons were at these levels.

Rainfall Prediction to Reduce Risks of Farmers and Suppliers

The information developed and presented for Kusum is useful in the field at two levels. The first is simply to present the farmer with the pertinent prediction and let him react to the situation however he wishes, as dictated by his own experience and knowledge. The same information could be supplied to credit sources, who today in the Third World, generally find the risks of lending to smallholders (to buy fertilizers for example) to be too great - hence credit is not available. Figure 19 makes clear that the risks to farmers and suppliers are very low at Kusum (approaching those of irrigated agriculture) in seasons preceded by high winter/spring rainfall, and for all seasons with early onset if rates of inputs are moderate.



The Rajpath: Torturous highway down the mountain slopes from Kathmandu Valley to the Terai (Upper Gangetic Plain) of Nepal. June, 1968.



Young paddy rice in Chitwan District, Inner Terai, Nepal. July, 1968.

Generalized Response Farming Guides to Assist Farm Decision Making

A second level of application is to accompany the rainfall prediction with Generalized Response Farming Guides to assist farmers in thinking about their responses. Such guides might or might not deal with specific crops by name, depending on the level of information available about specific crop responses to water, and about soils of the area, marketing structures, etc.

The nature of useful but generalized guides is illustrated in Table 3, Appendix A, designed for the four monsoon categories delineated for Kusum. A strategy built in to these example guides is that first priority is given to assurance of the family food supply, after which consideration is given to production for the market. Any other strategy desired could be adopted and the guides modified accordingly.

CHAPTER 16

India, and Two-Station Comparisons

The final example to be presented is that of Hyderabad, India. Hyderabad is positioned in the semi-arid tropical zone of south central India, at 17°27'N latitude and 78°28'E longitude. The rainfall record studied covers the 48-year period from 1937 to 1984, during which mean annual rainfall was 783 mm (30.8 in), ranging from 416-1383 mm (16.4-54.4 in). Mean rainfall in the Dec-Apr period preceding the monsoon averages 52 mm (2.0 in), ranging from zero to 258 mm (10.2 in).

Hyderabad and Kusum: Rainfall Comparisons

Speaking generally, rainfall at Hyderabad is just a bit over half of that at Kusum in the previous example. Some further comparisons are useful for thinking about the rainfall in relation to crop production. Onset of the monsoon at Hyderabad, with a median date of June 21, averages about two weeks later than at Kusum where the median date is Jun 7 (Table 20). Duration of the monsoon at Hyderabad is somewhat longer (128 days versus 121 days), placing the average date of monsoon recession about three weeks later than at Kusum. With Kusum rainfall nearly twice as much and durations not much different, rainfall intensities at Kusum are naturally much greater, with a median of 9.9 mm/day versus 5.3 mm/day at Hyderabad. Before proceeding, some comments about water requirements of crops may prove helpful.

Factors Influencing Crop Water Requirements

Water requirements of crops (maximum evapotranspiration) depend largely on evaporative conditions of the atmosphere. These are also expressed in mm/day so may be compared directly to rainfall intensities. However, crop water requirements are also influenced by the crop type, its stage of growth, and - importantly in rainfed agriculture - the degree of leaf cover the crop attains to intercept sunlight, since it is mostly solar energy that evaporates water from the cropped area and enables crop growth through photosynthesis.

Dancing girl in traditional Rajasthani costume, Jodhpur, India. February, 1978.

Massive stones form distinctive landscape near Hyderabad, India. February, 1986.

The degree of leaf cover is termed leaf area index or LAI, designating the number of hectares of leaves forming a canopy over one hectare of cropped land surface. As a rule of thumb, when LAI reaches 3.0 or greater, the daily water requirement of the crop is maximized. If water is available to meet that need and all other conditions (soil fertility, weed control, etc.) are near ideal, crop yield will also be maximized.

If water is limiting, the farmer can thin his crop in order to reduce the leaf canopy below LAI 3. This reduces both the effective water requirement and, of course, the maximum possible yield per hectare. However each plant left in the field can remain healthy and produce its maximum, whereas, if too many plants are left for the available water supply, none will be healthy and overall yield will be reduced even more.

Fitting Crops to Rainfall at Hyderabad and Kusum

Returning to our comparisons, Hargreaves, et al (1985) show that evaporative rates (ETP rates denoting the water requirements of green grass - the requirements of other crops to be grown may then be related to these) in the principal growing period of the monsoon (June-September) are virtually the same at Hyderabad as in the north of Uttar Pradesh, only a few miles from Kusum. The average ETP near Kusum in this period is 5.2 mm/day, compared to 5.0 mm/day at Hyderabad.

At Hyderabad, median rainfall intensity of 5.3 mm/day just exceeds the ETP rate while the intensity at Kusum of 9.9 mm/day is 90% greater than ETP. This is reflected in the crops grown even though the season timing, length and evaporative conditions are nearly identical in both places.

A key crop at Kusum is paddy rice, grown in flooded fields with maximum evapotranspiration throughout most of the season. In these conditions that means approximately 7.6 mm/day. At Hyderabad a key crop is grain sorghum which, in the peak part of the season will require around 5.5 mm/day, and this can be reduced by thinning to lower plant populations.

Pre-Monsoon Rains: The Initial Predictor at Hyderabad

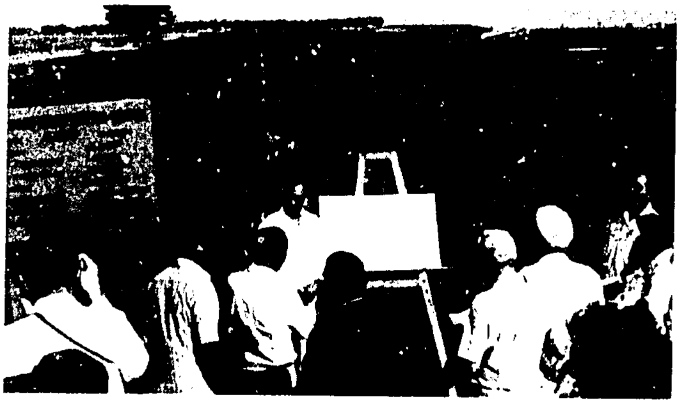
The attributes of the monsoon cropping season at Hyderabad are predictable in much the same way, and at a similar level of accuracy, as at Kusum. The initial predictor is winter/spring (December-April) rainfall prior to the mosoon, but at Hyderabad this prediction is made only at the high end of the rainfall scale. To be explicit, winter/spring rainfall exceeding 81 mm (3.2 in) - which has occurred in nine of the 48 years studied - signals rainfall amount, duration and intensity all in the upper portion of their respective ranges. This is closely comparable to the situation at Kusum when winter/spring rainfall equals or exceeds 150 mm. The principal difference is that high winter/spring rains at Kusum also signalled early onset, which is not true at Hyderabad. High prior rainfall there appears to exclude poor seasons but has no implications for date of onset.

Date of Onset: The Principal Predictor at Hyderabad

For the 39 of 48 seasons which had winter/spring rainfall below 82 mm, there is little or no correlation between those amounts and monsoon rainfall attributes. However, as at all locations discussed in this book, season rainfall amount, duration and intensity are linked to the date of onset. For predictive purposes at Hyderabad, onset is divided into three distinct time periods instead of two. The three periods used as predictors are designated as **a.** early (May 26 to June 10), **b.** middle (June 11-30) and **c.** late (July 1 to August 9).

Four Categories of Seasons Predicted at Hyderabad

Table 22, which is similar to Table 20 for Kusum, shows the median values of the monsoon rainfall attributes at Hyderabad for the entire 48-year record studied, and then for each of the four groupings of seasons defined by the prediction criteria outlined above.



Drs. S. M. Virmani (facing audience, r) and A.K.S. Huda (facing, l), Agroclimatologists, explain grain sorghum experiments which compare yield performance of new genotypes under water stress to scientists from 18 countries during meetings at ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), Hyderabad, India. November, 1982.

TABLE 22 -- HYDERABAD, INDIA:

Median values of winter/spring rainfall preceding the monsoon, and of monsoon cropping season onset dates, and rainfall amount, duration and intensity. Presented first for all 48 years of the record, then for four groupings of seasons identified by winter/spring rainfall, or by onset dates.

NO. OF YEARS	ONSET PERIOD	PRE-MONSOON WINTER/SPRING RAINFALL, mm	MONSOON RAINFALL: ONSET DATE	AMOUNT mm	DURATION days	INTENSITY** mm/day
		(MEDIAN VALUES)				
48	ALL ONSETS: May 26-Aug 09	0-258	6-21	645	128	5.3
		FOUR GROUPINGS OF SEASONS				
9	ALL ONSETS	) 81*	NA	763	131	5.4
8	EARLY: By Jun 10*	(82	6-07	708	134	5.25
21	MIDDLE: Jun 11-30*	(82	6-22	608	128	4.8
10	LATE: Jul 1 Onward*	(82	7-20	573	100	6.2

* Predictors
** Medians from original data - not calculated within the table by amount/duration.

Table 22 shows overall median monsoon cropping season rainfall of 645 mm (25.4 in), persisting 128 days with an intensity of 5.3 mm/day (0.21 in/day). Seasons preceded by high winter/spring rainfall, together with early onset seasons, display higher rainfall amount, longer duration and virtually the same intensities. Seasons with middle period onset have lower rainfall, the same duration and less intensity. Late onset seasons have the least rainfall, by far the shortest durations, but, paradoxically, the highest intensities of all.

The importance of the differences among the predicted groupings in Table 22 is more easily grasped when ranges of values within each of the groupings are seen in addition to the medians. Table 23 presents the ranges, starting with the 48-year record as if no prediction were involved. Rainfall amount runs from a low of 336 mm (13.2 in) to a high of 1229 mm (48.4 in). Duration is from 77 to 174 days and intensities are as little as 2.6 mm/day and as great as 9.4 mm/day. This is the dilemma of Hyderabad farmers today. How does one make all the necessary decisions as to how best to farm in such variable conditions? The lower portion of Table 23 helps to clarify how prediction can ease the decision process.

TABLE 23 - HYDERABAD, INDIA:

Ranges of values of monsoon cropping season onset dates and rainfall amount, duration and intensity. Presented first for all 48 years studied, then for four groupings of seasons identified by high winter/spring rain fall or by onset dates.

NO. OF YEARS	ONSET PERIOD	MONSOON RAINFALL: AMOUNT mm	DURATION days	INTENSITY mm/day
		RANGES OF VALUES		
48	ALL ONSETS: May 26-Aug 09	336-1229	77-174	2.6-9.4
	FOUR GROUPINGS OF SEASONS			
9	ALL ONSETS: W/S) 81 mm	576-1229	113-164	5.1-9.4
8	EARLY: Until Jun 10	562-1084	125-174	4.2-6.5
21	MIDDLE: Jun 11-30	336-1067	101-161	2.6-8.5
10	LATE: Jul 1 Onward	441-783	77-140	3.2-8.6

The first two predicted groupings in Table 23 are similar in their ranges of rainfall attributes but both differ importantly from the lower two groupings (middle and late onset) and from the overall ranges for the 48-year record. For example, rainfall amount was never less than 562 mm in the first two groups, but fell to 336 mm with middle onset and to 441 mm in the late onset group. Similarly, duration never fell below 113 days in the first two groups, even though the first group includes both middle and late onset seasons as well as early onset ones. Intensities in the first two groups also remained moderate to high, never falling below 4.2 mm/day.

In the middle and late onset groupings the ranges are similar except, as expected, late onset seasons are of lesser duration. The impacts of these predictable rainfall differences on probabilities for different levels of potential crop production at Hyderabad are great, as was shown earlier for Kusum in Figure19 and Table 2, Appendix A.

Establishing Standard Criteria for Ranking Monsoon Seasons at Hyderabad

Table 24 establishes criteria for potential production levels for a hypothetical standard crop exactly suited to rainfall conditions at Hyderabad. For example, Table 22 shows median rainfall amount, duration and intensity as 645 mm, 128 days and 5.3 mm/day respectively. These figures, slightly rounded, constitute the minimum requirements for "high normal" crop production potential. Note that the breaking point between low and high normal is here defined as the 50% crop yield level. Maximum potential means 100% of possible yield, therefore that rainfall is sufficient (as are duration and intensity) to fulfill all crop needs and cover all normal water losses.

TABLE 24 - HYDERABAD, INDIA:

Minimum rainfall criteria for five levels of crop production (illustrative - see utilization in Figure 20 and Table 4, Appendix A).

YIELDS SEASON* PRODUCTION POTENTIAL	- - - MINIMUM RAINFALL REQUIREMENTS - - - AMOUNT mm	DURATION days	INTENSITY mm/day
MAXIMUM	960	150	7.5
HIGH NORMAL	640	130	5.3
LOW NORMAL	480	110	3.9
SUBSISTENCE	360	90	3.2
FAILURE	<360	<90	<3.2

* Season each year is from defined onset date to final rain date.

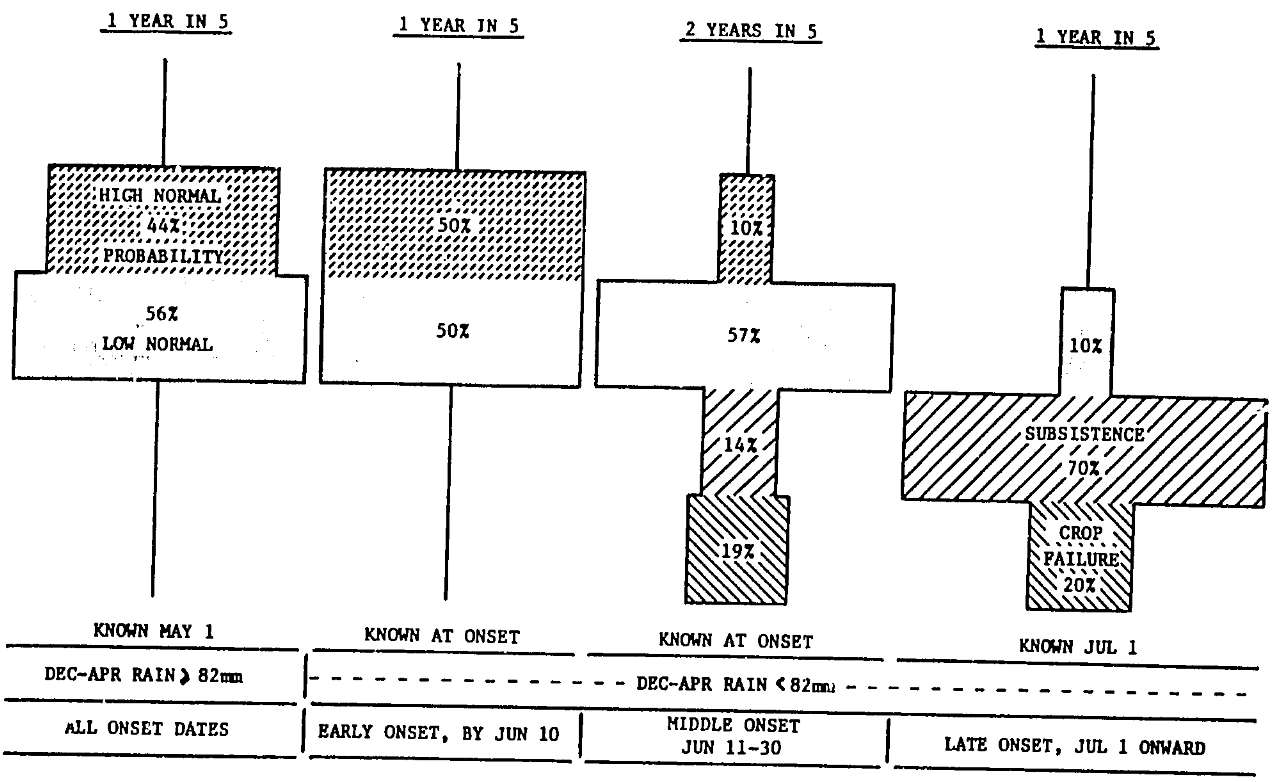
Assuming a linear water production function for the hypothetical standard crop, the above provides all the information needed to quantify the entire function. With maximum potential at 960 mm and 50% potential at 640 mm, zero potential (zero crop yield) will be at 320 mm seasonal rainfall.

Detailed Rainfall Record for Hyderabad

Table 4, Appendix A contains details of all 48 years studied for Hyderabad, listing them in the four groupings

FIGURE 20 -- Hyderabad, India

Probabilities of monsoon crop production levels in seasons categorized prior to the monsoon: on May 1 if winter/spring rains high; at onset if early or mid-period; Jul1 if onset late.



to be predicted, in the chronological order of prediction. The first group of nine years is those with winter/spring rainfall exceeding 81 mm. This group is predictable at the latest on May 1, and earlier if December-April rainfall reaches 82 mm on some earlier date. The three remaining groups are predicted as of the actual occurrence of onset (early or middle onset periods) or on July 1 if onset is late.

The far right hand column of Table 4, Appendix A classifies each year for crop production potential, based on the criteria in Table 24. The concept of limiting factors is applied so that the classification reflects the most limiting of the three monsoon attributes of rainfall amount, duration and intensity. In the table, the limiting attribute(s) each year are shown in parentheses. Finally, the probabilities of occurrence of each of the five crop production potential classifications are calculated for each predicted group of years and displayed in Figure 20. (Note that probabilities of "maximum" are zero, and are not shown in the figure.)

Early Categorization of the Monsoon at Hyderabad

The Hyderabad rainfall predictability and crop production potential probabilities in Figure 20 are of the same type, and essentially equivalent in predictive quality, to the Kusum situation shown in Figure 19. Shown below the drawing are answers to three questions: **a.** did winter/spring rainfall exceed 81 mm or not?, **b.** what period of onset dates pertain, and **c.** when can the prediction be made? This information is provided for all four groupings.

The years in which winter/spring rains exceeded 81 mm at Hyderabad are represented by the drawing on the left side. Above that drawing is the notation "1 year in 5." This refers to the frequency of years meeting these prediction criteria, which in this case was nine years in 48, or approximately one in five. The second group from the left is those with low winter/spring rainfall, but with early onset, i.e., by June 10. This occurred in eight of the 48 years, again approximately one year in five. (Precise figures, if desired, are calculable from the detailed year-by-year information in Table 4, Appendix A).

TABLE 25 - HYDERABAD, INDIA:

Potential yield levels for 105-day grain sorghum, and requirements for monsoon rainfall amount, duration and intensity to attain them. (See Figure 21 and Table 5, Appendix A.)

GRAIN SORGHUM YIELD POTENTIAL			MINIMUM RAINFALL REQUIREMENTS		
Category	%	Kg/ha	AMOUNT mm	DURATION days	INTENSITY mm/day
MAXIMUM	100	5400	600	110*	6.8
HIGH NORMAL	50	2700	330	100	3.8
LOW NORMAL	40	2150	275	90	3.1
SUBSISTENCE	30	1600	220	80	2.5
FAILURE	< 30	< 1600	< 220	< 80	< 2.5

* Duration values embody the assumption that the 10 days following onset are used for planting, leaving 10 days loss in the rainy period during the growing cycle - in this instance, a 100-day rainy period in the 105-day season.

The two groups of years just described, seen on the left side of Figure 20, are the best in terms of potential crop production, and are very similar to each other. The probabilities are all for normal production levels, about evenly split between high normal and low normal. Zero probabilities are shown for maximum production on the high end, but also zero for subsistence level or failure on the low end.

Middle onset years (onset from Jun 11-30) form the largest group, occurring in 21 of the 48 years of record. Crop production potential for such years is shown in Figure 20 to be 2/3 in the normal range (10% high normal, 57% low normal) and 1/3 down in the subsistence (14%) or failure (19%) classifications. More caution is called for in farming these years than those with early onset or high winter/spring rainfall.

The right hand side of Figure 20 shows the probabilities of production in years with late onset, i.e., July 1 onward. This actually occurred in 10 of the 48 years, for a frequency of roughly one in five. Only one of the 10 years reached as high as the "low normal" classification, thus a probability of 10% as seen in the drawing. Of the remaining nine years, seven were at the subsistence level and two were complete failures by these criteria.

Interpreting Crop Production Probabilities

The response farming method is to predict and respond. A rainfall prediction might take the form seen in Figure 20, where, for example, onset might occur on June 20 and you are facing the probabilities shown in the third drawing from the left, in the "Middle Onset" category. There is a 10% chance of high normal production and a 57% chance of low normal, so all in all, normal production is expected in 67% or two of every three such years. But in one of three such years, one expects production to fall to the subsistence level or to fail utterly.

However, Figure 20 represents a "standard" crop, directly geared to median rainfall - a tough standard. It represents a hypothetical crop, but for sake of clarity, a crop with requirements something like those in Table 24 could be a 5-month maize (corn) cultivar.

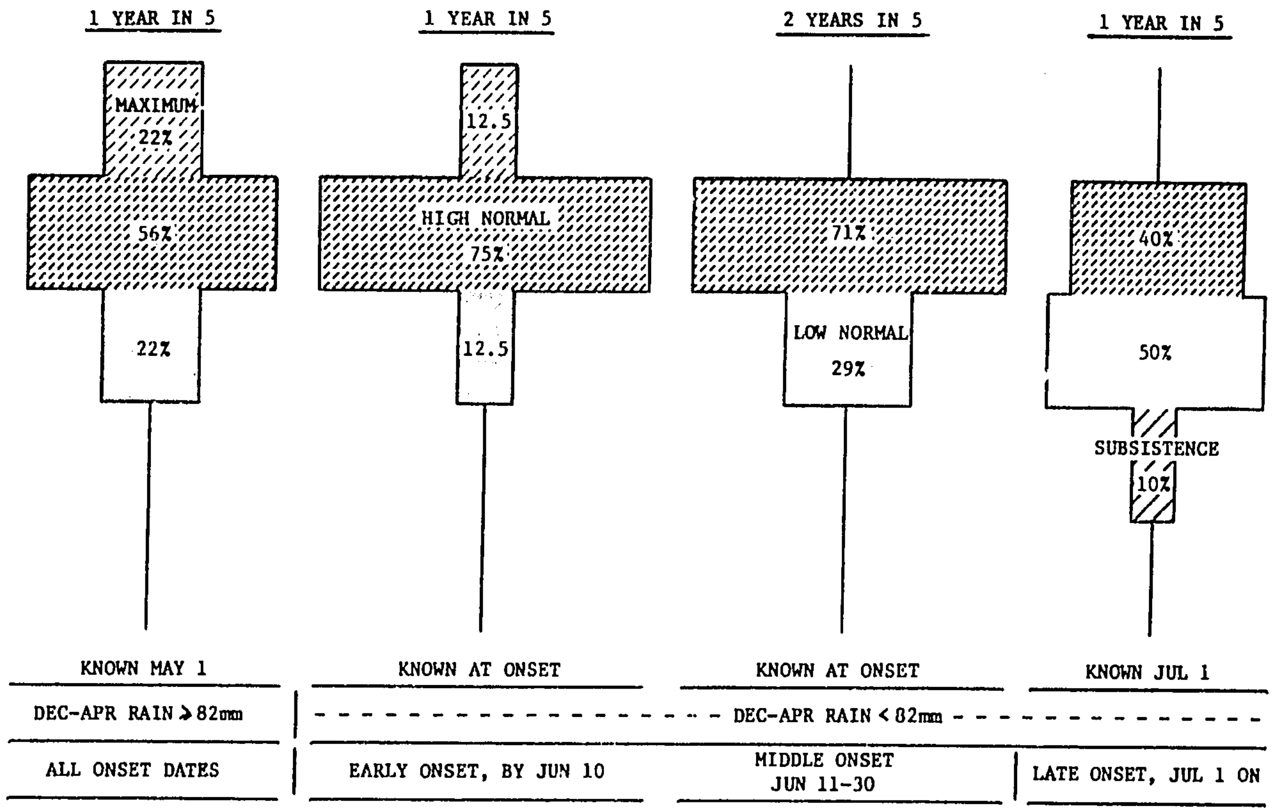
Grain Sorghum Production Potential at Hyderabad

Thus, the most sensible response to the above prediction is probably a change from the most demanding crop (the standard) to a less demanding crop which is equally adapted to the area but which requires less rainfall to produce at its normal level. At Hyderabad grain sorghum is widely grown for reasons much like those suggested. Table 25 shows the lessened water requirements, including shorter duration and less intensity, together with a water production function suggesting actual yield levels attainable if other factors in production are not limiting.

With lessened water requirements, the probabilities of reaching any given production level are increased. Figure 21 shows the probabilities for grain sorghum which

FIGURE 21 -- Hyderabad, India

Probabilities of grain sorghum production levels in seasons categorized prior to the monsoon: on May 1 if winter/spring rains high; at onset if early or mid-period; July 1 if onset late.



for "middle onset" are 71% chance of high normal production and 29% chance of low normal. The chance of water deficiency causing a crop failure or even low subsistence level production is now zero if we can rely on the past 48 years of history to predict the future. The interested reader may see exactly how this analysis is made, or make further analyses if desired, based on the information in Table 5, Appendix A, where the entire rainfall record studied is detailed year-by-year.

CHAPTER 17

Summary Notes on The Technical Section

Information presented in the previous 13 chapters shows new developments over the past seven years in **(1)** ways to analyze rainfall for crop production and **(2)** modes of presentation and interpretation of relevant rainfall season characteristics - season rainfall amount, the duration of the season from onset to the final rain, and the intensity index or average rainfall per day (amount/ duration). The new developments include ways to relate season rainfall characteristics both to potential crop production and to excess water hazards - such as soil erosion and crop waterlogging - and, most importantly, ways to predict them prior to the cropping season.

Examples are presented from 20 locations in 11 countries of Africa, Asia, the Near East and North America -- a wide diversity of climatic and other conditions. The unifying factor is that, at all 20 locations, the date of onset of the rainfall season - as defined for cropping purposes - is a predictor of the rainfall season characteristics listed above. The predictions are most accurate for season duration, intermediate for rainfall amount and least accurate for intensity. Some of the relationships between date of onset and season rainfall characteristics are highly significant in the statistical sense and some are not, but all are of practical significance for providing management guidance to farmers.

SECTION III — RESPONSE FARMING TODAY

CHAPTER 18

The Present State of Readiness of Response Farming

Is the response farming method ready now to provide guidance to low resource farmers in semiarid areas, or does it need further research? This question is often addressed to the writer and the twin answers are emphatically yes and yes!

This is not a frivolous reply - it is totally serious. The method is ready for field application today. It, like all other practices in use in agriculture, will certainly be improved over time through further research. That is why the world supports thousands of agricultural scientists.

Meanwhile, the millions of farmers in India, Jordan and West Africa who traditionally utilize the method, would most probably be upset if they understood how much usable information we could presently give them about their rainfall expectations - but aren't doing so. Rereading the "Small Rainfall Fable" at the start of this book, may help in understanding how the farmers would feel. And the truth is that our present ability to interpret seasonal rainfall expectations is markedly better than the fable suggests. As time goes on, research will make it still better.

We know today how to formulate generalized response farming guidelines to assist farmers in responding to rainfall forecasts in ways which will benefit their operations and enhance production. An example of generalized guides may be seen in Table 3 of Technical Appendix A.

We further know today how to formulate detailed response farming recommendations for specific crops in localized circumstances. Stewart and Hash (1982) provide examples for maize production based on extensive research in semiarid parts of Kenya. Stewart and Faught (1984), based on four seasons of on-farm verification trials at three levels of management, extend the recommendations to beans and to the intercrop of maize and beans. The latter authors reach the following conclusions:

1. **With respect to yield stabilization:** Maize yield failures of one in two seasons under conventional management could be reduced to one in seven seasons with medium level management (includes grain/legume rotations but no commercial fertilizers), and to one in nine seasons with high level management (includes rotations and modest amounts of commercial fertilizers).
2. **With respect to yield enhancement:** Response farming with medium management could boost maize and bean yields respectively to 2.9 and 1.3 times the conventional level, and, with high level management, to 5.7 and 2.2 times as much.

Response farming recommendations can flow from anyone's research, not just that of the writer and colleagues. In fact, much agricultural research is aimed at producing detailed recommendations which will stabilize and enhance production by farm families and improve the quality of their lives. Response farming research does not supplant any other research; rather, it provides a clearer picture to other researchers of the situation they are attempting to improve.

CHAPTER 19

The Nature of Response Farming Field Programs

As earlier noted, a response farming program is an information program. It is a matter of **(1)** developing pertinent information about localized rainfall behavior, and, considering other aspects of the farming system (crops, climate, soils, economics, logistics, etc.), information about optimal responses to rainfall forecasts, and **(2)** before each season, providing farmers with rainfall forecasts and appropriate guides or detailed recommendations to assist in the farm management decision process.

A program of this type could be on any scale. It could serve a single farm, a village, a region, a nation or even an international grouping. It could also be at any level of sophistication or depth, providing information aimed at a single question or numerous questions. It could provide season rainfall forecasts by themselves, leaving appropriate responses entirely to the discretion of the farmers, or forecasts accompanied by guides/recommendations in any degree of detail.

Any of the above requires at the least that rainfall data be analyzed, and, depending on the response information to be provided, that studies be made of the farming situation and agronomic research undertaken as needed. Often, the research need may be satisfied by synthesis and reinterpretation of published research results.

CHAPTER 20

Groups Involved in Response Farming Projects

Basically, three groups of people are required to get a response farming program successfully operational in the field. The principal group is the farming community, already in place. The farmers are performing their functions, and as quickly as they receive improved information on expected rainfall behavior they will modify their actions to take advantage of it - as all people would. Exactly which decisions are affected and the details of the farmers' modifications will depend on a host of individual circumstances and on their personal experiences, traditions and sources of advice.

The second group is the people who advise farmers. These are usually officers of the Agricultural Extension Service (extension agents) - the arm of government officially designated to provide on-going advice to farmers about their operations, including details of all practices. An Agricultural Extension Service exists in virtually every country in the world. Some are very effective in reaching, informing and influencing farmers, and others less so. Other parties such as village elders/leaders, officers of agricultural cooperatives, purveyors of agricultural inputs, women's organizations, etc., may also provide advisory services to farmers. Like the farmers, the advisors are already in place and functioning. They only require new and improved information and training in its interpretation and utilization.

Researchers are the third group. They will train the advisors and provide them with updated and new information as it is developed. Research will be carried on at the global and regional levels, and in the field within those projects having their own research component.

CHAPTER 21

Three Levels of Action Projects

The simplest project calls for just three steps:

1. Rainfall analysis to quantify onset relationships to season parameters.
2. Training extension agents to determine the date of onset at the start of each season, and to understand how expected rainfall amounts, durations and intensity indices relate to dates of onset.
3. Each rainy season, as onset is identified, extension agents inform farmers in the locality of expected rainfall season characteristics.

At the next level, farmers are also provided with generalized response farming guides to give direction to their responses to rainfall forecasts. These are formulated by extension officers and agents in consultation with other sources of expertise. The latter may include experienced farmers and knowledgable agricultural scientists. The generalized guides will be underpinned by information gathered in multidisciplinary surveys of the project area, covering additional weather factors, soil characteristics, major crop and animal enterprises and socio-economic features of the project area. This information, coupled with the rainfall information from the original analysis, will enable formulation of a suitable strategy for coping with the seasonal rainfall variability.

The most comprehensive projects additionally will have a research component to provide farmers with detailed, crop-specific response farming recommendations. Such recommendations will be like those presently formulated by agricultural scientists, but will also include modifications of certain practices when the forecast indicates low or high rainfall amounts or intensities, or an especially long or short season. The research may be simply a synthesis of available published information, or may also involve a considerable field effort within the area of the project.

One of the more effective ways to put a response farming program in motion would be to make it part of an ongoing development/research project, or one in formulation. Such a project would already have the same general goals of assisting the farming community, and would already involve the needed scientific and extension personnel. Additional funding might be required for data gathering, analysis, interpretation, staff training and on-going consultation. However, those costs should be modest compared to normal development/research project costs.

CHAPTER 22

State of the Art, Present Interest and Momentum

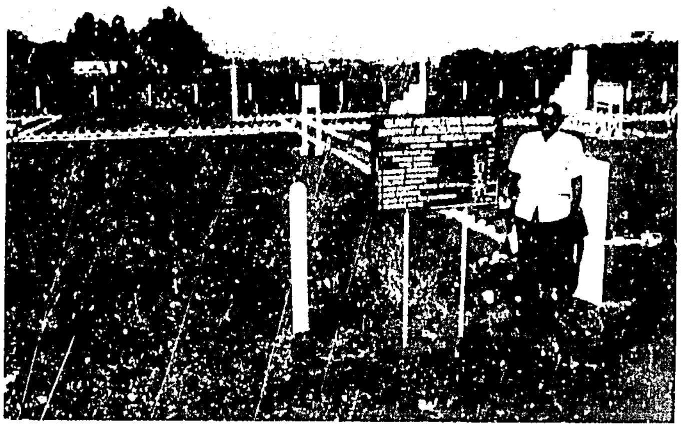
The present state of the art of response farming and the supporting research package is that now, after 20 years, we know what needs to be done and how to do it. Doing it, on a broad scale, is the task from now onward. The Foundation for World Hunger Alleviation through Response Farming (WHARF) constitutes the repository for all of the response farming related information generated since 1966. Since early 1984, WHARF has been the agency entrusted with continuing the research and seeing that the new response farming information and methodology are extended for the benefit of farmers the world over.

Actually, the process is well underway. In research, recent concentration has been on rainfall prediction, on integration of water production function estimates into the forecasts, and on the development of standards which evaluate effects of seasonal rainfall variability on crop production potential. The standards are based either on mean rainfall characteristics or on the water requirements and yield/water characteristics of specific crops of interest. A start has been made on advancing prediction dates based on pre-onset predictors, and on sharpening prediction based on historical periodicities found in onset date relationships with season rainfall characteristics.

CHAPTER 23

Current Research/Development Activities in Five Countries

Geographically, the studies have been extended to 34 locations in 17countries, adequately demonstrating the widespread, if not universal, feasibility of the method. This has resulted in expressions of interest from a number of sources, some of which have resulted in initiation of response farming research and development activities. These are as follows:



Dr. P. Mistry, a leading figure in agrometeorology in India, at the meteorological observatory, Gujarat Agricultural University, Anand, India. March, 1986.

1. **KENYA:** Research on response farming (termed "risk management") was instigated within the Australia/ Kenya Dryland Crop and Forage Project during the first project review of February, 1986. The agencies funding and operating the project are the Australian Centre for International Agricultural Research (ACIAR), the Commonwealth Scientific and Industrial Research Organization (CSIRO) and the Kenya Ministry of Agriculture and Livestock Production.

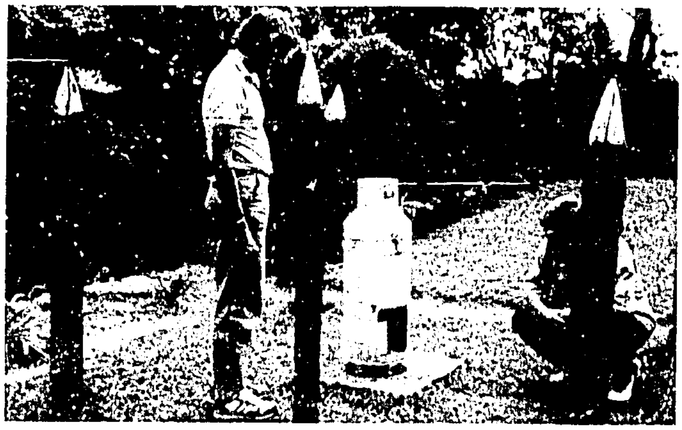
Agricultural extension agent with raingauge during establishment of an "on-farm verification trial" to test the Response Farming methodology. Makutano Market, Machakos District, Kenya. "Short rains" season, November, 1981.

2. **INDIA:** A major expansion and redirection of the All India Coordinated Research Project on Agrometeorology (AICRPAM) became operational in December 1987. The project, titled "Strengthening Agrometeorological Research to Enhance Crop Production," is directed and operated by the Indian Council for Agricultural Research (ICAR). External funding is by the United States Agency for International Development Mission to India (USAID/INDIA). Project expansion will be from 10 already operational locations, to a total of 15, with each serving a different agroenvironmental zone. A principal new objective is to develop a response farming capability throughout India. Coordination of the AICRPAM is from the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad.

3. **NIGER:** Research on response farming (termed "Climate-Responsive Crop Management Tactics") was initiated in 1986 by Dr. M.V.K. Sivakumar, Agroclimatologist at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Center, Niamey. Sivakumar (1987) presents onset versus duration relations found in analyses of long term rainfall records from 58 locations in the Southern Sahelian and Sudanian Climatic Zones of Niger and Burkina Faso.

Dr. M. V. K. Sivakumar, agroclimatologist, displays high producing pearl millet genotype at ICRISAT Sahelian Center, Niamey, Niger. Photo Courtesy of ICRISAT.

4. **USA:** Research on response farming, in collaboration with the author, was begun in early 1987 at Kansas State University, Manhattan, by Dr. E. T. Kanemasu and colleagues. The initial findings are those presented here in the section on West Africa in Fig. 16 and Tables 18 and 19, and Table 1, Appendix A.
5. **SRI LANKA:** Research on response farming within the Land and Water Use Division of the Department of Agriculture, Peradeniya, was initiated in August, 1987, under the guidance of Dr. S. Somasiri, Division Head, and Mrs. R. P. K. Kannagara, Climatological Research Officer. WHARF computer software and training for this activity is sponsored by the USAID funded Diversified Agricultural Research Project (DARP), Royal Botanical Gardens, Peradeniya.



GTZ (German Agency for Technical Cooperation — Federal Republic of Germany) hydrologists note workings of American-made recording rain gauge at Githangiri in the high altitude, high rainfall tea production area of Sri Lanka. September, 1987.

SECTION IV -- RESPONSE FARMING TOMORROW

CHAPTER 24

The Response Farming Research Package

Principal Components of the Research Package

The research package supporting response farming has been painstakingly assembled and streamlined over the past 20 years by the author and valued colleagues, whose names, titles and principal contributions are listed in Appendix B. There are four principal components of the research:

1. **Water production functions** for different crops, showing how rapidly yield declines with decreasing water supply/utilization; how these relations respond to changes in farm practices; and how they may be expressed in transferable forms which provide the basis for estimating crop yields in different rainfall seasons in response farming project areas.
2. **Water balance equations** for different crops, showing how leaf canopy development controls water requirements through the season, and how the pattern of root growth (deepening, spreading, proliferating) determines the maximum amount of water the plant can extract at each growth stage and the rapidity with which it can be extracted when water is limiting. Additionally, how these equations are impacted by changes in farm practices, and how they may be expressed in transferable forms which provide the basis for estimating both crop water requirements and actual crop water use in different rainfall seasons in response farming project areas.
3. **Prediction of season rainfall characteristics,** including rainfall amount, duration and intensity index, based on date of onset. Additionally, advancing, sharpening and widening the geographical scope of predictive capability through research on pre-onset predictors, rainfall periodicity and correlation/interpolation analyses.
4. **Computerized simulation modelling** to estimate water production functions and water balances under different farm management scenarios, in order to optimize farm practice recommendations for responding to different rainfall forecasts in project areas.

Three goals of the program have been to achieve coordination, simplification and transferability.

Research coordination begins with a unified concept of how the findings will be interrelated and the uses they will serve. An obvious need is an agreed system of nomenclature and measurement units throughout. Another feature is consolidation of several studies into a single experiment to minimize confounding factors. Or, two or more related but different experiments may be carried out in the same field over the same growing season. Field operations and measurements are then coordinated in kind, timing, equipment and personnel utilization, and in techniques for carrying them out.

Simplification denotes a constant striving to ascertain which questions, data measurements, farm practices, etc., are meaningfully related to crop water use and yield, and which are not. It aims at minimum data sets, reduction of experimental costs in both time and money, and of requirements for land, equipment and personnel.

The all important goal of transferability is aimed at rapid injection of high quality information into farm development projects. This will cut the need for new research within a project, and enhance the quality of project research which is carried out, by linking it with foregoing experiments and findings - not just ours, but those synthesized from all sources.

What is transferred are relationships between crop water use and yield characteristics, and appropriate environmental and farm management factors. When the transferable relations are coupled with actual measurements of climate, soil and farm practices at project sites, it is possible to estimate how different crops will utilize water and what yields may be expected in different rainfall circumstances, or when the farmer changes his practices to respond to changed rainfall expectations.

There are several important uses for the above estimates. One is during review of the historical rainfall record to determine how well different crops should produce in that rainfall regime. If the crops studied are already grown in the area, the analysis will indicate which should do best under different rainfall conditions - thus, which to emphasize when expected rainfall is high, medium or low. If the crops of interest are not already grown in the project area, the analysis will indicate which ones should be profitable and which would not.

A second use for the estimates is as input for computer models to simulate the effects of changing farm practices. When a season rainfall forecast is made, the computer can immediately pinpoint the changes in farm management which will maximize yields with the expected water supply. This information can then be passed by advisors to farmers in the form of response farming recommendations. It is important to understand that such sophisticated modelling is largely in the future, and is not at all necessary to the success of a response farming project. Research findings presently available in the literature and at experiment stations around the world are entirely adequate for generating basic response farming guides and recommendations. Nevertheless, we may expect continuing improvement from the described types of research and modelling.

A third purpose for estimates of crop water use and yield is for early warning of inadequate food production prospects and for crop yield forecasting programs. The warnings and/or yield forecasts might be at the single farm, community, national or other levels - wherever food security and marketing are of concern. Warnings of impending low production would be based on water balance/production function analyses of actual rainfall through the early part of the growing season, when forecasts of the remaining season rainfall would be improved over those made at onset. Crop yield forecasts would be made about mid-season. At this time the rainfall forecast for the rest of the season would be fairly precise, and the analyses mentioned above would produce a close estimate of expected yield per hectare.

Requirements for Research

Certain environmental requirements as well as experimental equipment and methods have proven ideally suited for this research, in the author's experience. Chief among these are:

1. Deep soil at the experimental site.
2. Low rainfall in the experimental period.
3. Line source design experiments, featuring a continuously variable water supply (Hanks et al. 1974; Stewart et al. 1977).
4. Neutron meter measurements of soil water.
5. Lysimeter experiments.
6. Meteorological observations at the experimental site.
7. Computerized data storage, analysis and modelling.

A deep experimental soil permits total quantification of the particular cultivar's pattern of root growth and maximum soil water extraction when under water stress. Estimates of soil water extraction from either deep or shallow soils in project areas can then easily be made, whereas experimental findings on shallow soils are only transferable to other shallow soil sites.

Low rainfall in the experimental period permits simulation of the entire range of possible rainfall conditions when using the line source design. Higher rainfall reduces the experimental treatment range, thus does not clarify the entire water production function for the study crop(s).

The line source experimental design is one in which water is provided from a single sprinkler line running through the center of a field plot, usually in the same direction as the crop rows. The sprinklers are close spaced (6 m or 20 ft apart) and the heads are selected to provide a triangular water pattern when viewed from the end of the line. That is to say, the greatest water amount is along the sprinkler line, diminishing evenly in both directions away from the line until the rainfed condition is encountered at the edges of the sprinkler pattern.

The line source experimental design is the only one known by the author capable of simulating the entire range of rainfall conditions with a relatively modest input of land, labor, equipment and cost. Usable data production per unit of required input (of any type) is considerably greater than with more conventional designs. Another very important feature of this design for getting your message across clearly to agricultural extensionists, farmers or other interested people is its tremendous visual impact. Its demonstration value is equal to its experimental value. Additionally, the line source design is ideally suited for utilization in developing countries where resources of all types, including trained manpower, may be in short supply.

The versatility and effectiveness of the line source design are exemplified by the author's experience over the nine-year period from 1974 through 1982. A wide range of crops was studied in line source experiments both at UC Davis and in Kenya. By the nature of the design, water amount was a variable in all cases. Interacting variables in different experiments were crop types, cultivars, intercropping versus monocropping, plant populations and nitrogen fertilizer rates. Additional interacting variables were in-season timing of water deficits and effects of salinity in both irrigation water and the soil.

Neutron meters are devices to measure soil water content instantly in the field, with repeated measurements as often as desired at the same locations and soil depths. The amount of water is registered as a percentage of the soil volume. This means the water content of a given depth of soil can be expressed as a depth of water (mm or in) just as we would characterize rainfall or irrigation water. Changes in soil water content are expressed as mm/day, in/day, etc., like water requirements.

Access tubes, for example 2-inch diameter aluminum pipes, are placed in the soil to whatever depth is desired at the start of the crop growing season, at all locations where measurements of soil water are wanted. The instrument has a probe linked by cable to a gauge where results are read. The probe is suspended at different depths in the access tubes while readings are made. When the repeated measurements are combined with information on added water (rainfall for instance) the water balance of the crop can be calculated. However, neutron meters do not account for deep drainage, i.e., percolation of water below the root zone, which invariably takes place in wetter conditions where crop water is adequate or very nearly so - as is the case close to the sprinkler line in a properly conducted line source experiment. Lysimeters, discussed below, are required to complete the water balance and the crop water production function for water-adequate conditions.

Neutron probes are the only widely available type of equipment for measuring volumetric soil water content repeatedly in situ. Gravimetric sampling, or any method requiring transformation of water content from a weight to volume basis, does not produce comparable accuracy. However, three cautions are these:

1. Neutron meters require careful calibration, a laborious task. Errors in calibration can cause serious continuing errors thereafter.
2. Neutron meter readings from moderately wet to wet treatments can be very confusing, even uninterpretable, unless there are readings from drier treatments to provide a baseline.
3. Neutron meters suffer breakdowns from various causes during heavy use, just when they are most needed. It is not wise to begin serious research without a backup instrument.

Lysimeters are soil-filled containers placed in the field at ground level; unless one is very close, they can hardly be seen. They are equipped to drain at the bottom, and for the drainage to be measured. The best are weighing lysimeters mounted on massive but delicate scales, capable of recording even very small changes in the water content of the soil. Crops are planted across the lysimeter as if it were a normal part of the field. Water added to the lysimeter by irrigation or rain, or even dew in some cases, can be precisely measured. So can any removal of water, for example, by drainage, or by surface evaporation coupled with transpiration from the leaves of the crops (the combination is termed evapotranspiration or ET). These measurements permit calculation of the complete water balance.

A principal use of lysimeters is daily determination of crop water use with water adequate to meet crop water requirements. Field studies which assume insignificant losses to deep percolation, or in which water measurements are not sufficiently deep, do not produce the same results.

In rainfed agriculture, crops seldom attain full canopy conditions (Leaf Area Index >3). Yet all published crop coefficients used to estimate crop water requirements are predicated on full canopy conditions. The great importance of adjusting plant populations in accordance with actual rainfall conditions is due to the fact that reduced leaf cover reduces the water requirement, which in turn reduces the stress when water is limiting. Each remaining plant gets more water and more nutrients, thus becomes larger and more able to support a near normal complement of yield (harvest index).

Improved farm recommendations to respond to variable rainfall in future will require more quantitative information on effects of leaf cover on water requirement. Lysimeter experiments can provide the information needed to guide farmers in adjusting plant populations to maximize yields with the available rainfall.

A third important use for lysimeter data is to model bare soil evaporation losses from different soil types in different rainfall regimes (sequences). Improved evaporation models will lead to more realistic definitions of onset of the rainy season for planting different kinds of crops.

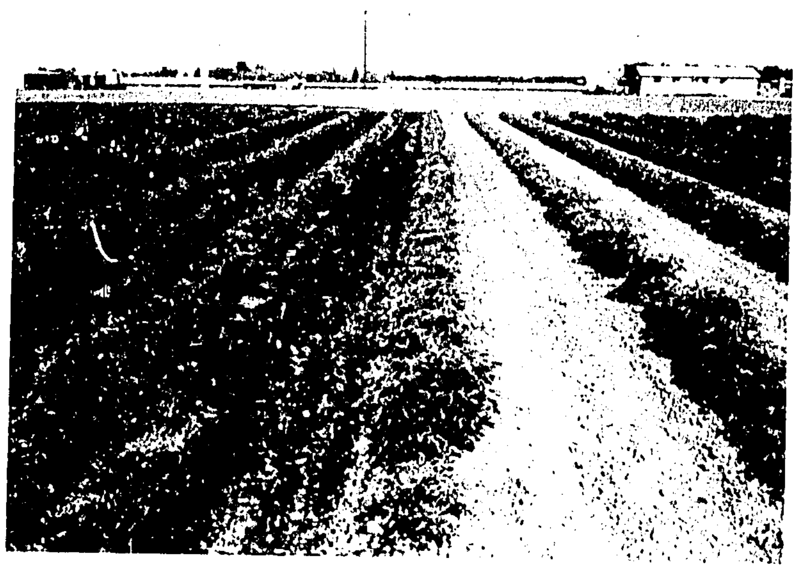
An additional research need is for meteorological measurements to be made at (or in certain cases near) the experimental site - a point stressed also by others, including Virmani et al. (1978). Certainly this includes the critical factors of rainfall and evaporation - the latter because it is negatively correlated with rainfall/cloudiness. Other radiation measurements must also be made at the site while temperature, humidity, etc. are often satisfactorily obtained from the nearest government meteorological station.

Little needs to be explained about the requirement for computerization. The masses of meteorological, soils, crop, economic, experimental and other data required for the modelling tasks ahead can only be accomodated with computers. We live in exciting times for agrometeorological research. It is only now, for the first time in history, that the experimental tools and long data records required have all become available.

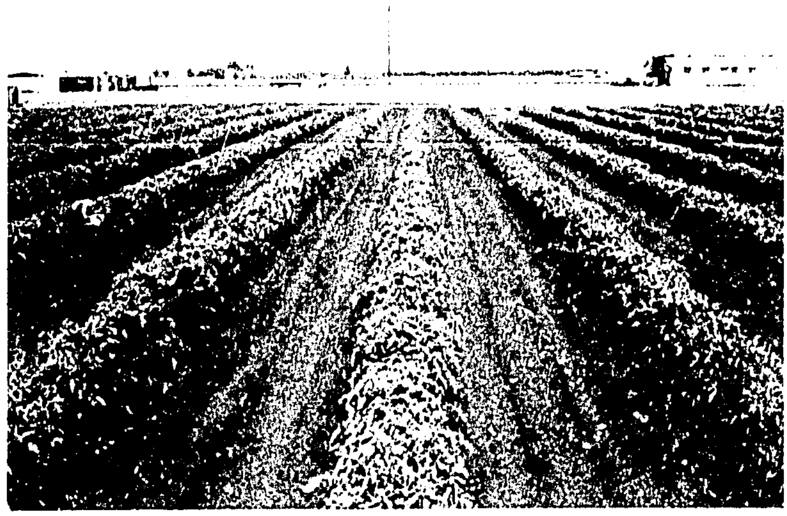
RESPONSE FARMING RESEARCH AT UC DAVIS

Line source and lysimeter field studies of tomato: Determination of water requirements, water balances under different irrigation/stress levels, and water production functions relating yield to actual water use. Generation of transferable relations for estimating all of the above (either for irrigated or rainfed conditions) at project locations in the USA and abroad. UC Davis, 1977.

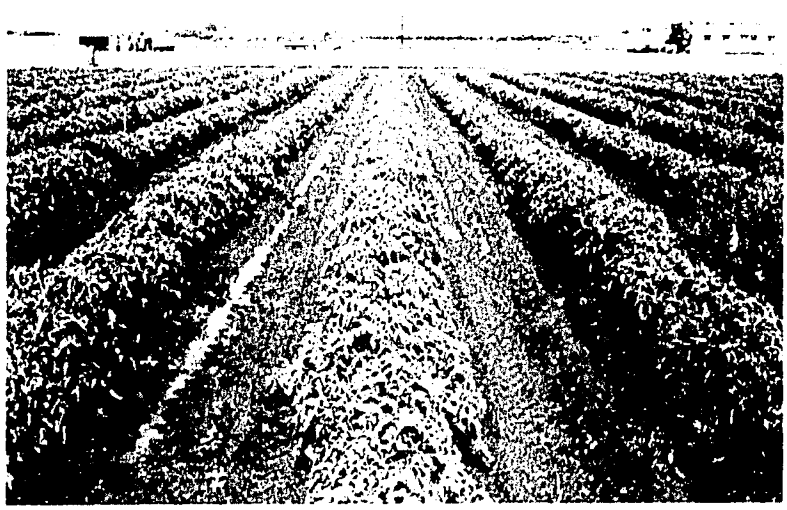
Author in front of line source tomato experiment where 5th weekly irrigation is being applied. Note large plant size and excess wetness at sprinkler line. Adjacent two rows are water application level 11, the wettest treatment. The next three pictures are the same day as this. 1 July 1977.



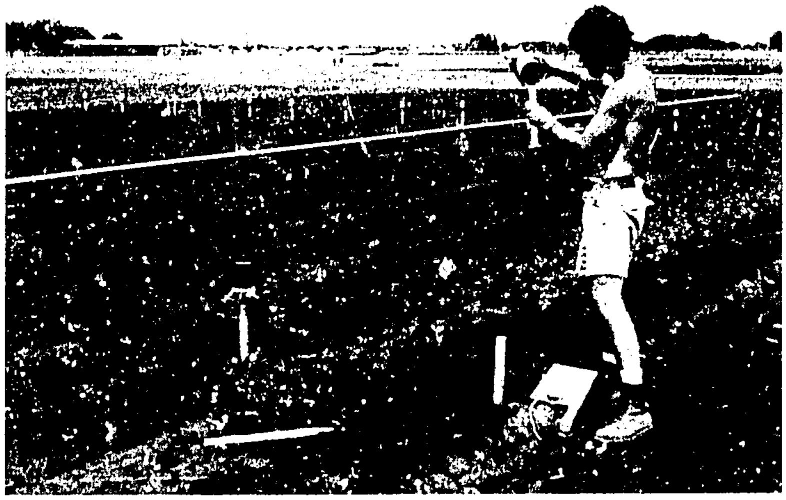
Center row in picture is water application level 1, most distant from the sprinkler line, thus driest, representing rainfed conditions. Note small plant size and white "catch cans" in each row to measure actual irrigation application amount.



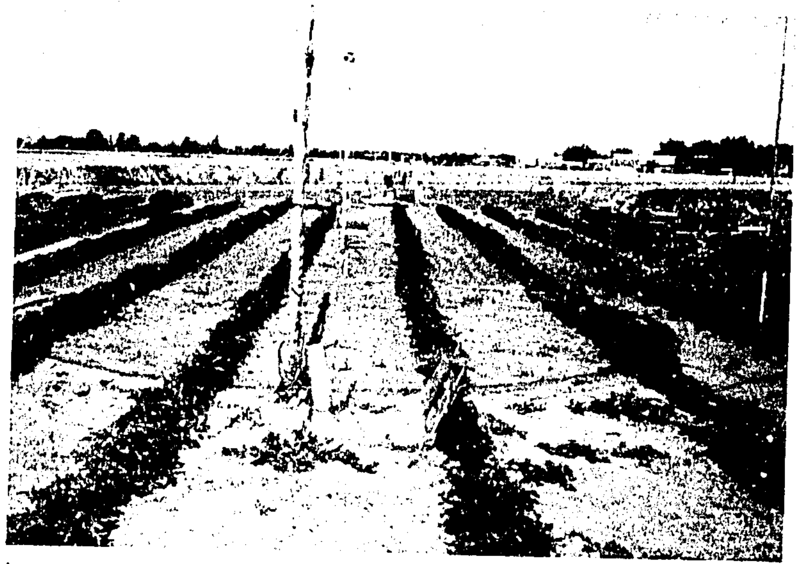
Water level 5 with intermediate irrigation, resulting in medium yield.



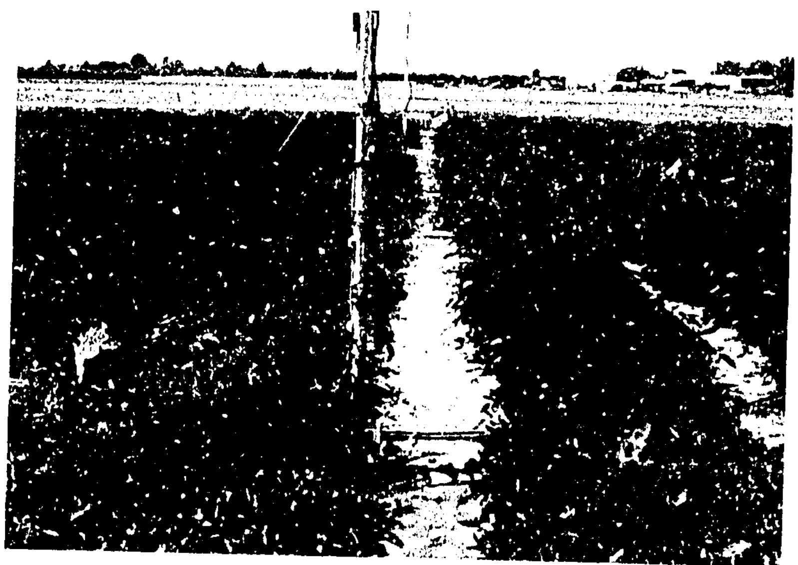
Water level 9, receiving adequate water and producing maximum yield, just two rows from sprinkler line (see left).



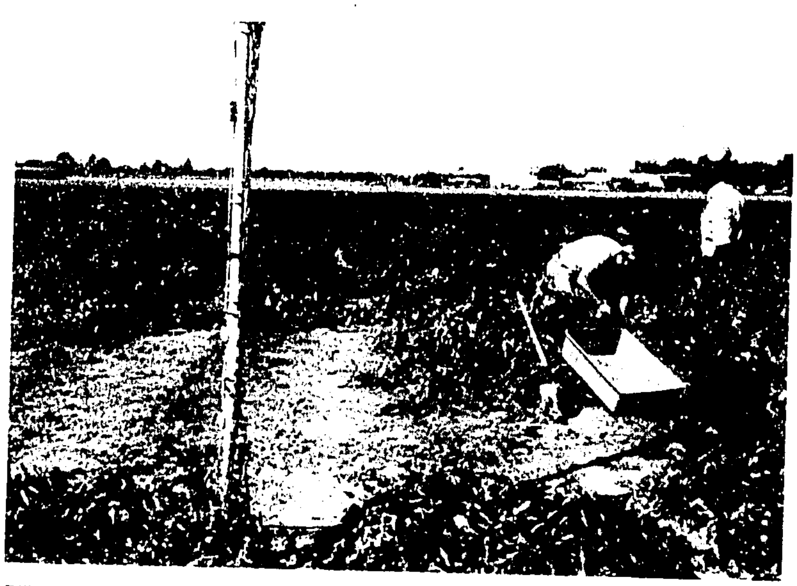
Dick Cuenca, Member, WHARF Professional Advisory Council, measures irrigation amount at water level 6, following 1st irrigation. Catch cans sit atop neutron probe access tubes where soil water content is measured immediately prior to irrigation, in order to calculate water balance at each irrigation level where stress is a factor. 3 June 1977.



Large weighing lysimeter (20 ft. diameter) where daily water use of adequately watered (unstressed) tomatoes is measured, to determine water requirements. 20 June 1977.



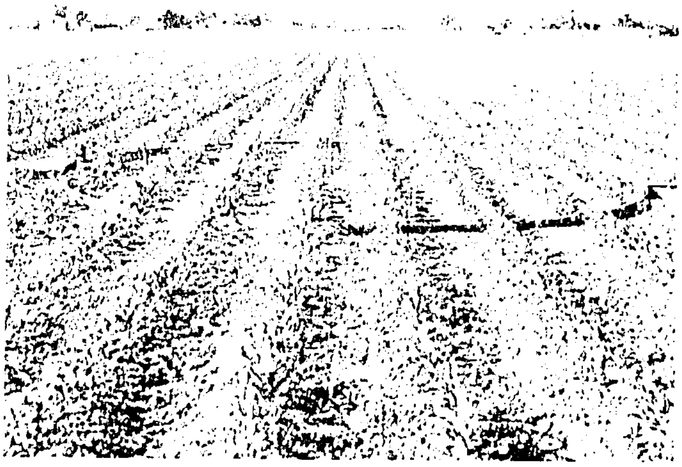
Lysimeter with adequately watered tomatoes in flower. 24 July 1977.



Bill Pruitt, designer of UCD lysimeters and technician (standing), harvest tomatoes from the weighing lysimeter. 8 September 1977.

RESPONSE FARMING RESEARCH IN FOUR WESTERN STATES

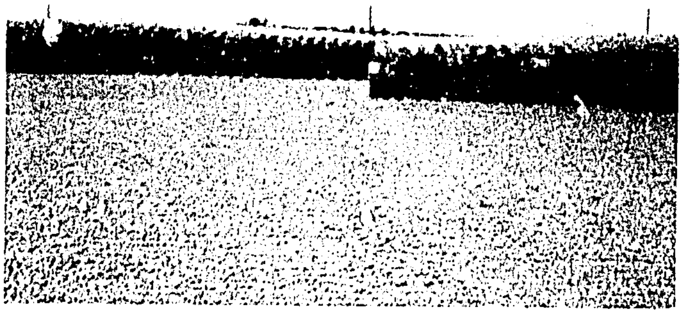
Line source and Lysimeter field studies of corn (maize), in collaborative research with Utah State University (USU), Colorado State University (CSU) and University of Arizona (UA), under the Consortium for International Development (CID). UC Davis, 1974 and 1975.



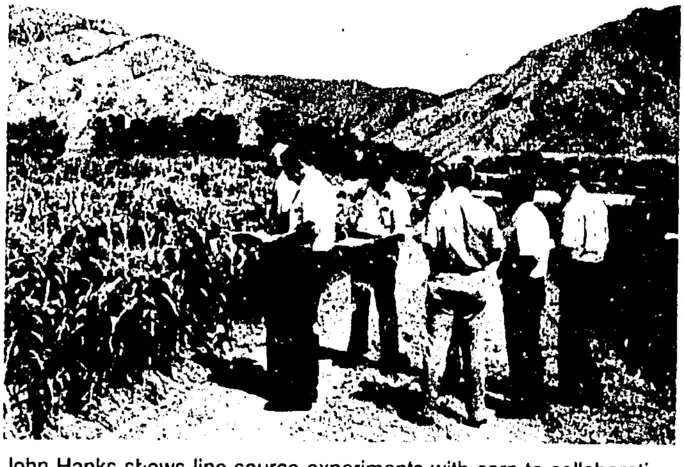
Appearance of corn lysimeter 17 days after planting. 2 June 1974.

Initial irrigation of corn in line source experiment. 14 June 1974.

Paul Martin measures soil water content with neutron probe in line source experiment before 2nd irrigation, assisted by Eduardo Narro, graduate student from Mexico. 21 June 1974.



John Giddens, technician, stands at unirrigated meeting point of two line source experiments. 24 July 1974.

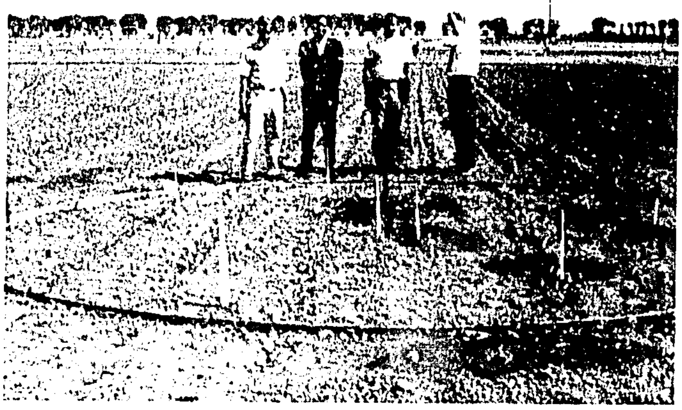


John Hanks shows line source experiments with corn to collaborating researchers at USU. 1 August 1974. Left to right: Ernie Jackson (University of Arizona), Bob Hagan (UCD), John Hanks (USU), Bill Franklin (CSU), Bob Danielson (CSU, presently Member, WHARF Professional Advisory Council), and two visitors.

Line source corn experiment at start of harvest. 15 September 1975.

PREPARING TO TAKE RESPONSE FARMING RESEARCH INTERNATIONAL

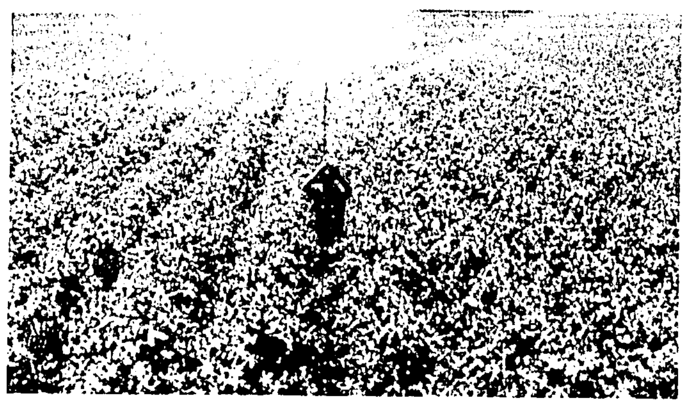
Line source and lysimeter field studies with beans, cotton and corn at UC Davis and UC Westside Field Station, 5-Points, California: Preparation for Kenya.



Bill Pruitt demonstrating use of the large floating lysimeter for determining water requirements of corn, to visiting Indian scientists S. D. Singh and B. S. Malik, and graduate student Ram Misra. 26 May 1971.

Pink beans on the floating lysimeter for determination of water requirements. UC Davis. 10 July 1976.

Bob Hagan (r), WHARF Founding Director, with author, preparing to show line source experiments with kidney beans to farmers on "Bean Day", UC Davis. 17 August 1977.

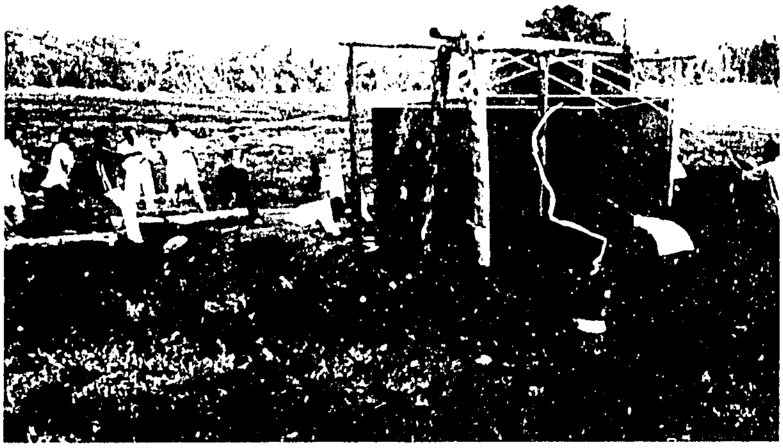


Dick Cuenca adjusts sprinkler head in line source experiment with cotton at Westside Field Station. 4 August 1976.

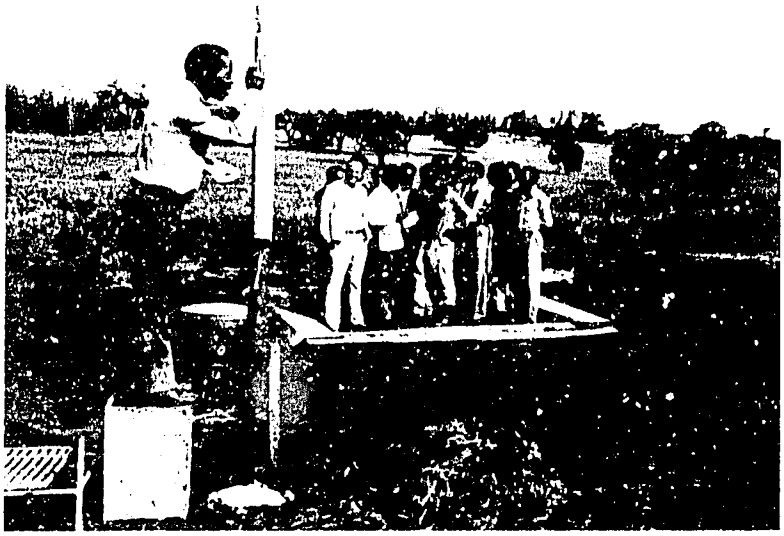
Harvesting cotton in line source experiment at Westside Field Station. 22 October 1976.

Author with Fred J. Wangati (then Deputy Director, East Africa Agriculture and Forestry Research Organization (EAAFRO), later the Kenya Agricultural Research Institute (KARI), in front of line source experiment with corn. UC Davis. 28 July 1975. Dr. Wangati is presently a Member, WHARF Professional Advisory Council.

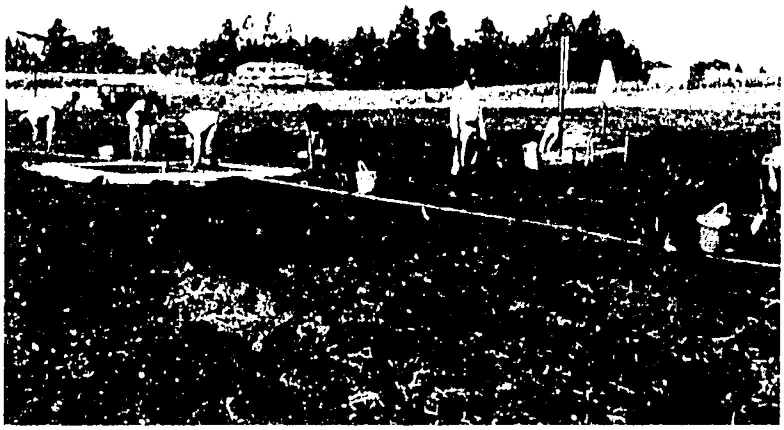
Large lysimeter construction and experimentation at EAAFRO Headquarters (now KARI), Muguga, Kenya.



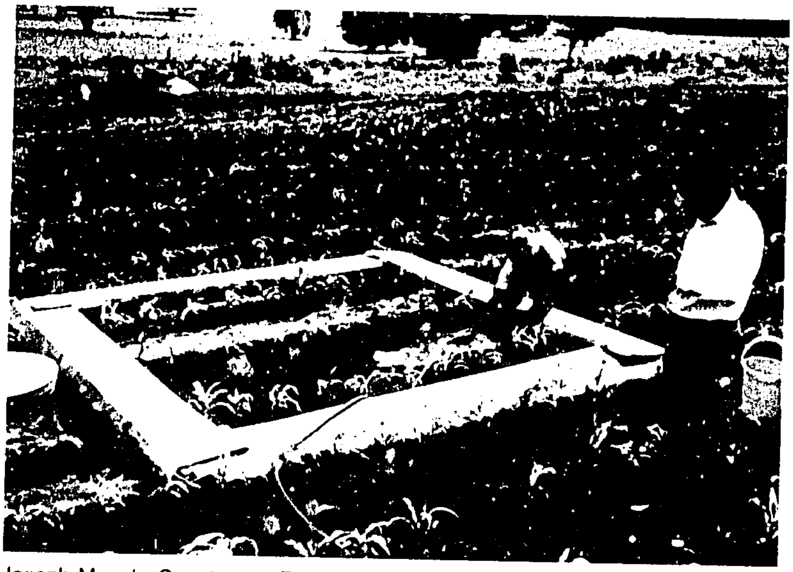
Technicians and workers lower lysimeter tank into prepared pit to rest on hydraulic bolsters, prior to back-filling with soil. 31 January 1977.



Pre-weighed scientists and technicians step onto lysimeter for calibration purposes. 22 May 1978.



The first lysimeter experiment with Katumani Composite B maize is planted at Muguga. 19 Dec 1978.



Joseph Mugah, Counterpart Researcher, (standing) directs initial hand-irrigation of maize on the Muguga lysimeter. 16 January 1979.

Katumani maize on the Muguga lysimeter, seven weeks after planting. 7 February 1979.

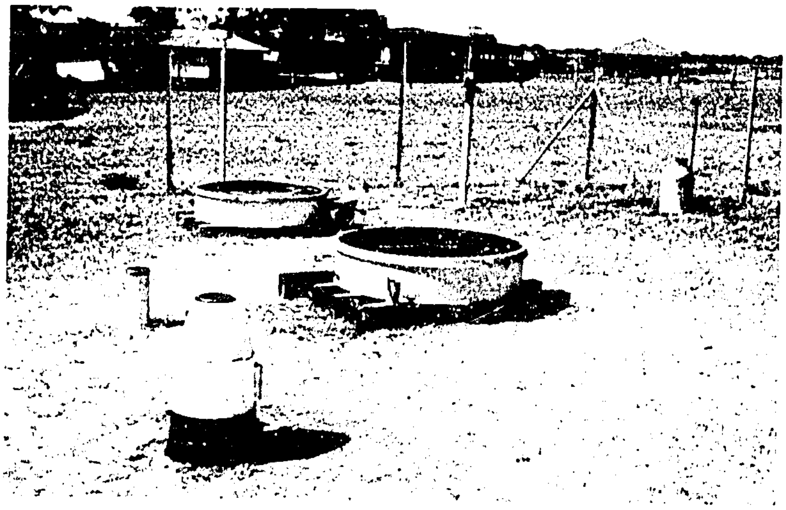
Katumani maize on Muguga lysimeter, nearing maturity. 2 April 1979.

Florence Lenga, Counterpart Researcher, (white coat) cross-calibrates different types of neutron probes for soil water balance studies in line source experiments, Muguga. 11 February 1982.

Agricultural Engineering students from the University of Nairobi observe workings of the Muguga lysimeter. Crop is Mwezi Moja beans. 13 November 1980.

RESPONSE FARMING RESEARCH AT OUTLYING STATIONS IN KENYA

Taking the research to experiment stations in low and variable rainfall areas of Eastern Province, Kenya.



Meteorological compound at the Katumani NDFRS (National Dryland Farming Research Station), Machakos District. Rain gauges and Class A evaporation pans. 10 March 1981.

Fred Wangati measures soil water content prior to irrigation in line source experiment with Katumani Composite B maize in the short rains season at Katumani, NDFRS. 26 January 1978.

Line source experiment with Katumani maize in the short rains season at Katumani, NDFRS. 12 January 1979.

Growth pattern of Katumani maize in line source experiment in the short rains season at Katumani, NDFRS. 9 February 1982.

Elmer McNece, WHARF Founding Director, observes production of intercropped maize and beans in a line source experiment in the short rains season at Katumani, NDFRS. 17 February 1982.

Single rows of many grain sorghum genotypes are planted across (rather than parallel to) the line source in trials to compare resistances to water stress. Between season experiment in collaboration with project agronomist H. Nadar, at Katumani, NDFRS. 17 August 1978.

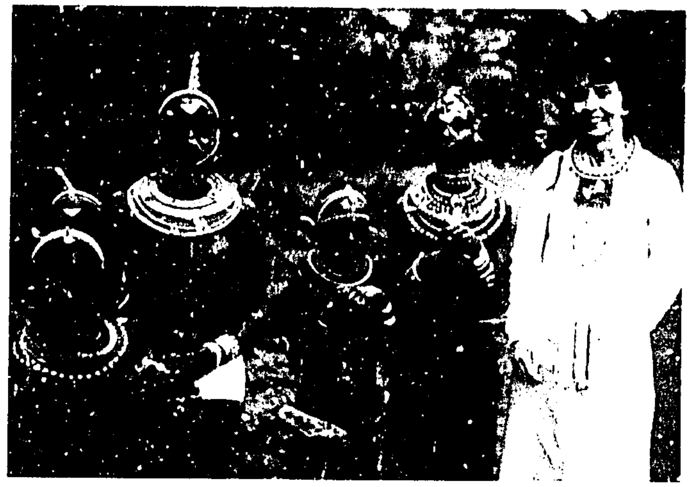
Same experiment with grain sorghum, showing genotype differences as season advances. 28 September 1978.

Multiple crop comparison for production under water stress, using line source technique at Kiboko National Range Research Station. Short rains season. 27 January 1982.

RESPONSE FARMING RESEARCH ON LOW-RESOURCE FARMS IN KENYA

Testing the Response Farming method on farms in Eastern Province Kenya.

Beautiful and dangerous marauders in the countryside.



Masai girls with WHARF Founding Director, Dr. Barbara Webster. 27 June 1981.

A well kept farmstead in Kitui District, Kenya.

The first farm trial. Researcher Joseph Mugah (standing, left) and Akamba woman farmer (right), lead team of technicians in dry-planting Katumani maize just prior to onset of the long rains season. Monna Farm, Mwala, Machakos District. 16 March 1981.

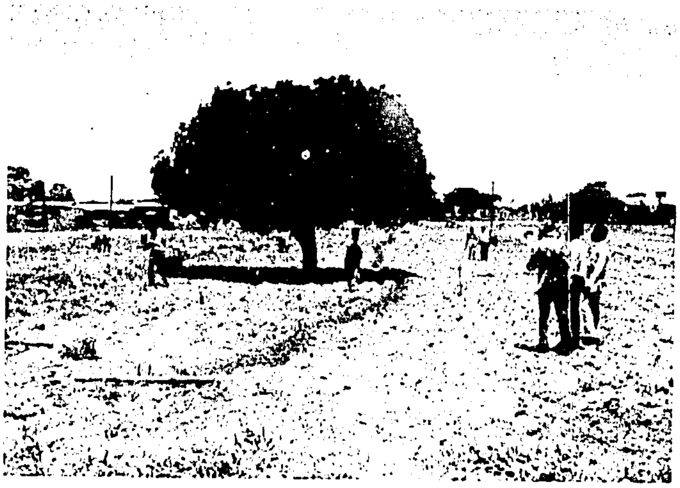
Monna's sons, farmers to be, are pleased with progress of maize in the trial plot six weeks after germination. Monna Farm, Mwala. 29 April 1981.

Elder son happily points to well formed ear of maize in the trial plot. Monna Farm, Mwala. 16 June 1981.

Continuing and expanding farm trials of Response Farming in Kenya (Altogether, 33 trial plots on farms over four growing seasons).

Monna and children thin out maize plants and prepare to weed trial plot, already wilting just three weeks after onset of the driest short rains season in the available rainfall record (27 years). Monna Farm. 2 December 1981.

Boys take pride in rapid recovery of maize in trial plot, just six days after thinning and weeding. Monna Farm. 8 December 1981.



Planting maize and beans (intercropped) in trial plot on Nganga Farm in the very dry short rains season of 1981/82. Makutano Market, Machakos District. 2 November 1981.

Nganga Farm trial plot six weeks after planting. Makutano Market, Machakos District. 15 December 1981.

Elmer McNeece observes maize production in Response Farming trial plot in extremely dry season, following harvest of beans. Nganga Farm, Makutano Market, Machakos District. 17 February 1982.

Technician William Munyao of Katumani Station (NDFRS) stands between unfertilized (front) and fertilized (rear) Katumani maize plants in Response Farming trial plot on Masambia Farm, in the very wet short rains season of 1982/83. Kasebe, Machakos District. 18 January 1983.

CHAPTER 25

Knowledge: The Magic Bullet

A saying with considerable currency today is that there is no "magic bullet" to slay the dragon of recurrent famine and incessant poverty which haunts the semiarid areas of the developing world. But the author takes exception. The magic bullet is improved knowledge - first of seasonal rainfall expectations, and second of how best to modify farm practices in accordance with those expectations.

Is that all? Of course not. We need the genetic advances promised by recent advances in biotechnology. We need available supplies of fertilizers, pesticides, herbicides and other inputs and ready credit so low resource farmers can purchase them. And we need all the additional knowledge which can be brought to bear on the problem by agricultural scientists in every discipline. There are other needs such as improving infrastructure, creating and maintaining markets, changing government policies, etc. etc.

But it appears there is little that can be usefully accomplished toward improving the situation in these areas until we are prepared to deal with seasonal rainfall variability. Response farming is designed to do that, and WHARF has been created to consolidate the available information required, build on it, and see that it is transmitted to the farmers who need it.

CHAPTER 26

A Global Response Farming Center

The groundwork is now completed and the time has come to mount a major effort to provide improved information to poor farmers on seasonal rainfall expectations and how to respond to them. The suggested pathway is to establish a global center for response farming having the following functions:

I. Research

II. Training

III. Coordination of Developing Country Self-Help Projects

IV. Data Collection, Banking and Analysis

V. Information Exchange and Publication

Additional activities at the center, such as policy making, administration, plant maintenance, etc., are self evident and largely self explanatory, so are not elucidated here. But some further detail about activities to be carried out under the five headings listed above may aid understanding of what is proposed.

I. Research

Agrometeorological

- Rainfall Behavior and Prediction
- Crop Water Requirements, Water Balance and Water Production Functions

Multi-Disciplinary

- Synthesis of Relevant Published Findings
- Initiation of New Lines of Research
- Simulation Modelling of Management Impacts on Water Use and Yields
- Development of New, Improved, or Simplified Research and Analytical Techniques
- In Collaboration with Project Scientists, Advisors, etc, Generation of Localized:
  - Strategies for Coping with Seasonal Rainfall Variation
  - Rainfall Prediction Criteria
  - Generalized Response Farming Guides
  - Detailed Crop Specific Response Farming Recommendations

II. Training

Coordinated by Training Officers, Response Farming Center Staff Design and Prepare Training Materials and Carry Out Training Functions

Training of Center Personnel

- Ongoing Training as Appropriate
  - At WHARF Center
  - In Project Countries

Project Related Training

- Scientists & Technicians
  - At the Center, Research Techniques in Agrometeorology and Other Disciplines
  - In Project Countries, Multi-Disciplinary Surveys, Other Startup Research, Workshops and Life of Project Consultation
- Extension Officers and Agents
  - Interpretation and Extension to Farmers of Rainfall Prediction Criteria, Generalized Guides and Detailed Crop Specific Recommendations, Mostly through Workshops in Project Countries
- Other Project Advisors, In Project Countries
  - Cooperatives, Suppliers, Womens Organizations, etc.
  - Rural Teachers (Youth Programs)

III. Project Coordination -- Research and Training Activities

Planning

Start Up Activities

Training/Collaboration Workshops

Life of Project Consultation

Targets and Evaluations

IV. Data Collection, Banking and Analysis -- Computerized

Raw Data

- Climate and Soil
- Crops and Livestock, Managerial
- Social and Economic

Research Findings, All Sources

- Rainfall Behavior and Prediction -- New Analyses and Localized Results or Findings
  - Identification of season onset; onset relations; prediction criteria
  - Historical rainfall periodicities shown by onset relations
  - Pre-onset predictors of season rainfall characteristics
  - Geographic interpolation of rainfall data and prediction criteria
  - Season rainfall probabilities
  - Basic rainfall standards
- Crop Water Requirements, Water Balances and Water Production Functions
  - Transferable relations for estimating the above
  - Localized evaluations of crop production potential and identification of optimal crop types and cultivars, based on historical rainfall analysis
  - Simulation models to optimize current season farm practices, based on pre-season and early season rainfall forecasts
- Multi-Disciplinary Survey Results or Findings

V. Information Exchange and Publication

Data Bank

- Raw Data
- Research Findings
- New Analyses

Library

- Publications
- Visuals

Other Issues

- Publications on Response Farming
- Computer Software for Response Farming Related Analyses
- Videos of Response Farming Field Research & Project Operations
- Scientific Papers
- Newsletters
- Popular Articles
- Media Releases
- Project Materials
  - Training Materials
  - Rainfall Prediction Criteria
  - Generalized Response Farming Guides
  - Detailed Crop Specific Response Farming Recommendations

SECTION V -- APPENDICES

APPENDIX A, TECHNICAL

TABLE 1

Eleven locations in Sub-Saharan Africa, described in Table 18. Regression equations showing how monsoon cropping season rainfall amount and duration relate to the date of onset (see footnote).

STATION	DATA* BASE (YRS)	MEAN ANNUAL RAINFALL (mm)	---------MONSOON CROPPING SEASON---- $R = a_1 + b_1(\text{Onset})$ (a_1)	(b_1)	R^2	$DUR = a_2 + b_2(\text{Onset})$ (a_2)	(b_2)	R^2
PODOR	46	292	1190	-4.31	(.44)	269	-0.98	(.56)
	6	156	- - -	- - -	- - -	- - -	- - -	- - -
ANSONGO	40	334	851	-2.98	(.41)	295	-1.14	(.73)
	ND	(214)**	- - -	-ND-	- - -	- - -	ND	- - -
KAYES	41	749	- - -	- - -	(.10)	275	-0.95	(.52)
	3	546	- - -	- - -	- - -	- - -	- - -	- - -
BOUZA	17	489	1149	-3.89	(.17)	270	-1.00	(.65)
	12	313	1037	-4.14	(.73)	218	-0.80	(.46)
DORI	43	536	1347	-4.76	(.38)	274	-0.98	(.64)
	9	455	1135	-3.99	(.58)	298	-1.12	(.68)
NIORO	33	875	- - -	- - -	(.10)	296	-1.04	(.70)
	ND	(590)**	- - -	ND	- - -	- - -	ND	- -
KOLOKANI	41	848	1550	-4.73	(.28)	289	-1.03	(.85)
	ND	(724)**	- - -	ND	- - -	- - -	ND	- -
NIAMEY	17	603	1382	-4.95	(.47)	269	-0.98	(.83)
	13	504	1693	-7.32	(.52)	334	-1.35	(.64)
KAYA	48	700	- - -	- - -	(.12)	284	-1.01	(.71)
	8	(673)**	- - -	- - -	(.05)	308	-1.18	(.69)
GAYA	36	829	- - -	- - -	(.10)	289	-1.07	(.80)
	13	774	1505	-5.16	(.51)	298	-1.14	(.82)
BOROMO	45	957	- - -	- - -	(.08)	301	-1.14	(.78)
	9	875	1391	-4.24	(.59)	282	-0.95	(.77)

* Upper number is years to 1970, lower number is years from 1971 onward.

** Estimated values -- annual rainfall data unavailable.

Note: In regression equations in headings section, R = rainfall (mm), DUR is duration (days) and Onset is the JULIAN date of onset of the monsoon cropping season. R^2 is the coefficient of variation.

APPENDIX A, TABLE 2 -- Kusum, Nepal

Four categories of monsoon rainfall, based on prior winter/spring rainfall amount and early versus late onset. Monsoon rainfall amount, duration and intensity for each year of record determine crop production potential (see Table 21 for crop production potential criteria).

YEAR	PRE-MONSOON WINTER/SPRING RAIN, mm	MONSOON RAINFALL ONSET date	AMOUNT mm	DURATION days	INTENSITY mm/day	CROP PRODUCTION POTENTIAL
[EARLY ONSET AFTER HEAVY WINTER/SPRING RAINFALL]						
1973	334	5-30	(1154)	129	(9.0)	Low Normal
1971	259	5-16	(2404)*	(160)*	(15.0)**	Maximum
1972	254	6-04	(2203)*	(150)*	(14.7)**	Maximum
1961	235	6-07	(1652)	(130)	(12.7)	High Normal
1959	178	5-31	1942*	144*	(13.5)	High Normal
1968	162	6-03	3032*	(124)	24.4**	High Normal
1970	161	6-03	1204	127	(9.5)	Low Normal
1984	156	5-28	(1158)	141*	(8.2)	Low Normal
[EARLY ONSET AFTER MODERATE WINTER/SPRING RAINFALL]						
1960	97	5-28	2088*	(133)	15.7**	High Normal
1980	85	6-07	1247	(107)	11.7	Low Normal
1964	83	5-22	1293	131	(9.9)	Low Normal
1981	74	5-31	(1027)	(108)	(9.5)	Low Normal
1963	38	6-06	(1117)	121	(9.2)	Low Normal
1983	34	5-16	(1025)	136	(7.5)	Low Normal
[LATE ONSET AFTER MODERATE WINTER/SPRING RAINFALL]						
1957	148	6-22	(1068)	(118)	(9.1)	Low Normal
1962	120	6-11	1405	(108)	13.0	Low Normal
1982	118	6-08	(877)	137	(6.4)	Subsistence
1967	108	6-17	1549	(99)	15.6**	Subsistence
1958	85	6-24	(956)	(102)	(9.4)	Low Normal
1965	69	6-22	(1066)	122	(8.7)	Low Normal
1976	65	6-11	1671	(119)	14.0	Low Normal
1969	56	6-18	1343	(115)	11.7	Low Normal
1978	35	6-11	(775)	111	(7.0)	Subsistence
1974	35	6-30	1076	(81)	13.3	Failure
[LATE ONSET AFTER VERY LOW WINTER/SPRING RAINFALL]						
1966	14	6-15	(1185)	(114)	10.4	Low Normal
1979	10	6-21	(398)	112	(3.6)	Failure
1975	9	6-22	1270	(92)	13.8	Subsistence
1977	0	7-14	(441)	(71)	6.2	Failure

( ) Criteria limiting crop production potential.

* Crop waterlogging danger from high rainfall amount and/or duration.

** Soil erosion danger from high rainfall intensity.

APPENDIX A, TABLE 3

Generalized Response Farming Guides for four monsoon season rainfall categories predicted at Kusum, Nepal (Illustrative)

Land Preparation, Tillage and Soil Selection	Cropping to Assure Family Food Supply	Cropping for Profit
	-- Early Onset Seasons Preceded by Heavy Winter/Spring Rainfall --	
• Clear drainways for possible flooding • Select best drained fields for food crops and high value market crops • Prepare lightly sloping furrows to drain excess water at non-erosive flow rates	• Select desired food crops and cultivars with medium water requirements and maturities • Mixed cropping is recommended • Determine area to be planted based on normal yields and family food/fodder needs • Medium seed and fertilizer rates for normal yields • Other practices for normal yields	• Select high value crops of medium and long maturity • Plant all remaining fields which have good drainage • Use high quality seed and fertilizer at rates enabling above normal yields • Emphasize weed and pest control for high quality produce
	-- Early Onset Seasons Preceded by Intermediate Winter/Spring Rainfall --	
• Clear drainways for possible flooding • Select fields with good internal drainage but high water holding capacity for food crops and high value market crops • Prepare very lightly sloping furrows to drain excess water, but which can be blocked to retain normal rainfall	• Select desired food crops and cultivers with medium water requirements and maturities • Mixed cropping is recommended • Determine planted area based on low normal yields and family food/fodder needs • Seed and fertilizer rates for normal yields • Other practices for normal yields	• Select high value crops of medium and long maturity • Plant all remaining cropland • Seed and fertilize for normal yields • Emphasize weed and pest control for high quality produce

APPENDIX A, TABLE 3 -- continued

Land Preparation, Tillage and Soil Selection	Cropping to Assure Family Food Supply	Cropping for Profit
-- Late Onset Seasons Preceded by Intermediate Winter/Spring Rainfall --		
• Select fields with deepest soils or highest water holding capacity for essential food crops • Prepare contour furrows, tied ridges or small flat basins to retain all rainfall	• Select food crops with short to medium maturities and low-normal water requirements • Mono-cropping recommended. Mixed cropping only with knowledgable control of plant populations • Determine planted area based on subsistence level yields • Seed and fertilizer rates for low normal yields • Control competing weeds, pests	• Select high value crops of short to medium maturity • Plant remaining cropland • Seed and fertilizer for low normal yield levels • Control competing weeds, pests
-- Late Onset Seasons Preceded by Low Winter/Spring Rainfall --		
• Select deepest soils of highest water holding capacity for essential food crops • Prepare contour furrows, tied ridges or small flat basins to retain all rainfall	• Emphasize shortest maturity crops with lowest water requirements • Mono-cropping recommended • Determine planted area based on subsistence yields • Seed and fertilizer rates based on subsistence yields • Rigid control of weeds, pests	• Select short maturity cash crops • Plant all remaining cropland • Seed and fertilizer for low normal yield levels • Rigid control of weeds, pests

APPENDIX A, TABLE 4 -- Hyderabad, India:

Four categories of monsoon rainfall, based on prior winter/spring rainfall amount and whether onset is early, mid-range or late. Monsoon rainfall amount, duration and intensity for each year studied determine hypothetical standard crop production potential (See Table 24 for criteria).

YEAR	PRE-MONSOON WINTER/SPRING RAIN, mm	ONSET date	MONSOON RAINFALL AMOUNT mm	DURATION days	INTENSITY mm/day	CROP PRODUCTION POTENTIAL
[WINTER/SPRING RAINFALL > 81 mm, ALL ONSET DATES]						
1937	258	6-19	(576)	(113)	(5.1)	Low Normal
1963	163	6-06	(758)	(141)	(5.4)	High Normal
1975	158	6-28	1229	(131)	9.4**	High Normal
1962	143	7-11	908	(117)	7.8**	Low Normal
1944	116	6-13	(763)	(143)	(5.3)	High Normal
1957	91	6-28	643	(120)	5.4	Low Normal
1958	91	6-27	780	151*	(5.2)	Low Normal
1948	88	7-23	669	(126)	5.3	Low Normal
1978	82	5-26	1007*	164*	(6.1)	High Normal
[EARLY ONSET, BY JUN 10: WINTER/SPRING RAINFALL < 82 mm]						
1970	46	6-02	1084*	174*	(6.2)	High Normal
1971	8	6-04	(587)	132	(4.4)	Low Normal
1973	24	6-05	848	161*	(5.3)	High Normal
1938	38	6-07	644	(125)	(5.2)	Low Normal
1943	47	6-08	(772)	(136)	(5.7)	High Normal
1947	30	6-08	(866)	(134)	(6.5)	High Normal
1949	11	6-09	(563)	135	(4.2)	Low Normal
1952	26	6-09	(562)	133	(4.2)	Low Normal
[MIDDLE ONSET, JUN 11-30: WINTER/SPRING RAINFALL < 82 mm]						
[illegible]	32	6-12	492	160*	(3.1)	Failure
[illegible]	43	6-12	(733)	(135)	(5.4)	High Normal
[illegible]	7	6-15	467	161*	(2.9)	Failure
1980	35	6-15	(429)	126	(3.4)	Subsistence
1982	41	6-16	647	145	(4.5)	Low Normal
1942	42	6-19	(555)	(115)	(4.8)	Low Normal
1940	21	6-21	552	148	(3.7)	Subsistence
1945	12	6-21	689	(124)	5.6	Low Normal
1953	27	6-21	786	(128)	6.1	Low Normal
1967	59	6-21	769	(101)	7.5**	Subsistence
1955	18	5-22	1067*	(126)	8.5**	Low Normal
1968	47	6-22	(580)	(110)	5.3	Low Normal
1964	47	6-23	(581)	(110)	5.3	Low Normal
1976	29	6-24	652	148	(4.4)	Low Normal
1979	41	6-24	608	156*	(3.9)	Low Normal
1981	59	6-24	817	(129)	6.3	Low Normal
1951	41	6-26	(602)	(126)	(4.8)	Low Normal
1956	0	6-27	(751)	(134)	(5.6)	High Normal
1972	23	6-27	([illegible]36)	128	(2.6)	Failure
1959	15	6-29	683	139	(4.9)	Low Normal
1941	47	6-30	(336)	101	3.3	Failure
[LATE ONSET, JUL 1 ONWARD: WINTER/SPRING RAINFALL < 82 mm]						
1960	34	7-01	(559)	133	(4.2)	Low Normal
1965	6	7-03	614	(81)	7.6**	Failure
1939	53	7-04	450	140	(3.2)	Subsistence
1950	42	7-11	782	(91)	8.6**	Subsistence
1954	37	7-20	689	(96)	7.2	Subsistence
1961	38	7-20	588	(102)	5.8	Subsistence
1966	24	7-23	535	(109)	4.9	Subsistence
1983	10	7-23	783	(98)	8.0**	Subsistence
1969	39	7-25	(441)	123	(3.6)	Subsistence
1974	5	8-09	512	(77)	6.6	Failure

( ) Criteria limiting crop production potential.

* Crop waterlogging danger from high rainfall amount and/or duration.

** Soil erosion danger from high rainfall intensity

APPENDIX A, TABLE 5 -- Hyderabad, India

Four categories of monsoon rainfall, based on prior winter/spring rainfall amount and whether onset is early, mid-range or late. Monsoon rainfall amount, duration and intensity for each year studied determine grain sorghum production potential (See Table 25 for criteria).

YEAR	PRE-MONSOON WINTER/SPRING RAIN, mm	ONSET date	MONSOON RAINFALL AMOUNT mm	DURATION days	INTENSITY mm/day	CROP PRODUCTION POTENTIAL
[WINTER/SPRING RAINFALL > 81 mm, ALL ONSET DATES]						
1937	258	6-19	(557)	(109)	(5.1)	High Normal
1963	163	6-06	(595)	(109)	(5.5)	High Normal
1975	158	6-28	1022**	(106)	9.6**	High Normal
1962	143	7-11	877	110	8.0**	Maximum
1944	116	6-13	619	110	(5.6)	High Normal
1957	91	6-28	595	(98)	6.1	Low Normal
1958	91	6-27	763	110	6.9	Maximum
1948	88	7-23	(517)	(107)	(4.8)	High Normal
1978	82	5-26	769	(95)	8.1**	Low Normal
[EARLY ONSET, BY JUN 10: WINTER/SPRING RAINFALL < 82 mm]						
1970	46	6-02	850	110	7.7**	Maximum
1971	8	6-04	351	102	(3.4)	Low Normal
1973	24	6-05	606	(109)	5.6	High Normal
1938	38	6-07	(587)	(109)	(5.4)	High Normal
1943	47	6-08	656	(109)	(6.0)	High Normal
1947	30	6-08	664	(106)	(6.3)	High Normal
1949	11	6-09	(529)	110	(4.8)	High Normal
1952	26	6-09	(430)	(107)	(4.0)	High Normal
[MIDDLE ONSET, JUN 11-30: WINTER/SPRING RAINFALL < 82 mm]						
1946	32	6-12	396	108	(3.7)	Low Normal
1984	43	6-12	(584)	(109)	(5.4)	High Normal
1977	7	6-15	360	110	(3.3)	Low Normal
1980	35	6-15	(418)	(108)	(3.9)	High Normal
1982	41	6-16	(578)	(106)	(5.5)	High Normal
1942	42	6-19	535	(99)	5.4	Low Normal
1940	21	6-21	(506)	110	(4.[illegible])	High Normal
1945	12	6-21	(582)	(101)	(5.8)	High Normal
1953	27	6-21	(543)	110	(4.9)	High Normal
1967	59	6-21	769	(101)	7.6**	High Normal
1955	18	6-22	984	(108)	9.1**	High Normal
1968	47	6-22	(580)	110	(5.3)	High Normal
1964	47	6-23	(580)	110	(5.3)	High Normal
1976	29	6-24	(591)	(102)	(5.8)	High Normal
1979	41	6-24	(578)	(100)	(5.8)	High Normal
1981	59	6-24	802	(96)	8.4**	Low Normal
1951	41	6-26	(528)	(101)	(5.2)	High Normal
1956	0	6-27	642	(109)	(5.9)	High Normal
1972	23	6-27	(318)	103	(3.1)	Low Normal
1959	15	6-29	670	(102)	(6.6)	High Normal
1941	47	6-30	337	106	(3.2)	Low Normal
[LATE ONSET, JUL 1 ONWARD: WINTER/SPRING RAINFALL < 82 mm]						
1960	34	7-01	519	(96)	5.4	Low Normal
1965	6	7-03	614	(81)	7.6**	Subsistence
1939	53	7-04	355	110	(3.2)	Low Normal
1950	42	7-11	788	(97)	8.1**	Low Normal
1954	37	7-20	689	(97)	7.1	Low Normal
1961	38	7-20	(597)	110	(5.4)	High Normal
1966	24	7-23	(534)	(108)	(4.9)	High Normal
1983	10	7-23	783	(99)	7.9**	Low Normal
1969	39	7-25	(432)	(108)	(4.0)	High Normal
1974	5	8-09	(515)	(107)	(4.8)	High Normal

( ) Criteria limiting crop production potential.

* Crop waterlogging danger from high rainfall amount and/or duration.

** Soil erosion danger from high rainfall intensity

APPENDIX B

COLLEAGUES IN RESPONSE FARMING RELATED RESEARCH

Robert M. Hagan, Professor of Water Science, University of California at Davis (UCD): Administrative leadership, vision and guidance in water production function development - participation in formulation of an internationally adopted methodology for estimating water production functions of crops for planning purposes. APP. D: 1-5, 7-9, 11, 12, 14, 15, 18-21.

William O. Pruitt, Professor of Water Science, UCD: Leadership in lysimetric determination of crop water requirements and crop coefficients, and in formulation of an internationally adopted methodology to estimate crop water requirements for planning purposes. APP. C: 3, 14. APP. D: 4, 7, 9, 11, 12, 14, 15, 18-21.

R. J. Hanks, Professor of Soil Physics, Utah State University (USU): Developer of the "line source" design for field experiments- which greatly reduces land and equipment needs as well as costs, and simplifies determination of crop water production functions and water balance, and effects of interactions of other factors (e.g., fertility, plant population) with the basic water constraint. APP. C: 7. APP. D: 17-19.

R. E. Danielson, E. B. Jackson, W. T. Franklin and J. P. Riley, Professors at Colorado State University (CSU), University of Arizona, CSU and USU respectively: Collaborative research with the above and the foregoing to determine effects of water and salinity on water production functions and water balances of adapted corn hybrids in four different environments in the Western USA. APP. D: 17-19.

R. H. Cuenca, J. Tosso, R. D. Misra, Doctoral Candidates at UCD: Deep involvement in development of water production functions, water balance equations and transferable crop coefficients for corn, grain sorghum, alfalfa, pinto, pink and kidney beans, cotton and tomato. APP. D: 9, 12, 20-22.

P. E. Martin and J. D. Prato, Research Associate, Water Science, and Agronomy Specialist, Cooperative Extension Service, UCD: Deep involvement with all aspects of field crop and lysimeter experiments to determine water production functions, water balance equations and transferable crop coefficients for crops named above. APP. D: 4, 9, 21.

F. J. Wangati, Deputy Director, East Africa Agriculture and Forestry Research Organization, EAAFRO (later Kenya Agricultural Research Institute, KARI), Muguga, Kenya: Administrative leadership, plus planning and guidance of the USDA/USAID/Government of Kenya (KARI) project to develop cropping systems for marginal rainfall areas. APP. D: 24, 25.

J. O. Mugah and F. K. Lenga, Counterpart Researchers and Doctoral Candidates, KARI, Muguga, Kenya: Major involvement in development of water production functions and water balance equations for maize, pinto, mwezi moja and tepary beans, maize/bean intercropping, grain sorghum, pearl and proso millet, sunflower and cotton. Also, impacts of soil fertility and plant populations on the functions and equations developed. APP. D: 22, 27, 28, 32, 33.

D. A. Kashasha, Master of Science Candidate, University of Nairobi: Research within the USDA/USAID/KARI project - expanding "effective rainfall analysis" for season rainfall prediction to nine additional locations surrounding the Katumani site where the initial finding was made that season rainfall amount and duration are related to date of onset. Demonstrated significant relations at all sites, despite considerable differences in elevation, temperature and annual rainfall. APP. C: 12, 19.

A. H. Kaila, Master of Science Candidate, University of Nairobi: Research within the USDA/USAID/KARI project - developing evaporation pan factors to standardize data from pans which differ in color, screening and nature of surrounds. Standardized data are coupled with crop coefficients to estimate crop water requirements for planning purposes. APP. C: 10.

C. T. Hash and W. A. Faught, Agricultural Economists, USAID Manager, Dryland Cropping Systems Research Project (DCSRP), and USDA/OICD Team Leader, DCSRP, Kenya: Provided economic evaluation of benefits expected from use of response farming in Eastern Kenya to produce maize, beans, and the maize/bean intercrop, under three levels of management of soil fertility. Economic analyses are based on production data for several seasons from both experiment station and on-farm verification trials. APP. C: 18, 20.

E. T. Kanemasu, S. van Donk and J. Hwang, Agroclimatologists; respectively, Professor and Graduate Students, Evapotranspiration Laboratory, Kansas State University, Manhattan, Kansas: Provided rainfall data for 11 sites in Niger, Mali, Senegal and Burkina Faso, and collaborated in analyses of the data for the latter three countries. APP. C: 11.

APPENDIX C

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APPENDIX E

GLOSSARY

Bioscience	-	Science applied to life or living organisms.
Biotechnology	-	An array of tools and applications that allow researchers to manipulate the genetic material of plants, microbes and animals.
Crop Coefficient	-	Ratio between study crop evapotranspiration (ET_m) and that of a reference crop (ET_o), both with adequate water and optimum growing conditions. Also, ratio of study crop ET_m to standard pan evaporation (E_p).
Crop Extractable Water	-	Maximum amount of water which can be extracted by a study crop under stressed conditions, from a soil initially at well drained Field Capacity. Expressed either as a depth of water (mm) from the entire root zone or portion thereof or as a fraction or percentage of Field Capacity from a stated depth of soil.
Crop Production Potential	-	Greatest possible crop yield, initially limited only by plant genetic characteristics and energy for photosynthesis when water is adequate, then further limited by water deficiency as the water supply declines. Five categories established are (1) **Maximum,** meaning water adequate, thus 100%, (2) **High Normal,** limited by rainfall amount and/or duration and/or intensity index to the range of 50-100%, (3) **Low Normal,** 40-50%, (4) **Subsistence,** 30-40%, and (5) **Failure,** under 30%.
Crop Water Balance	-	Balance between water into the crop root zone in the growing season (soil water at germination + rainfall to maturity) and water utilized by the crop (ET_a), or lost (runoff, deep percolation) or stored (net gain in soil water).
Crop Water Production Function	-	Relationship between crop production and water. Production and water are defined in each case to fit the circumstances, e.g., grain yield in kg/ha versus actual crop water use (ET_a).
Crop Water Requirement	-	Depth of water which, when utilized by a crop for evapotranspiration, is fully adequate to meet all needs of the crop. Expressed as mm/day average during any given period from one day to the entire season. See ET maximum (ET_m).
Crop Water Utilization	-	Actual depth of water evapotranspired by a crop when water supply is less than adequate during some or all of the period of interest. See ET actual (ET_a).
Crop Yield Forecast	-	A pre-harvest forecast of crop yield in kg/ha, lb/ac, etc. The response farming method incorporates water balance and water production function analyses to provide rough forecasts at onset, improving at mid-season. Forecasts may benefit farmers, buyers, food storage managers, national food planners, etc.
Cultivar	-	A cultivated variety of a crop, here including hybrids, composites, etc, as well as true varieties.
Date of Onset	-	The first date in the new rainfall season when rainfall amount and/or surface soil water content is deemed sufficient to safely launch the crop of interest. The definition will vary with location and type of crop, and requires clarification for each set of analyses.
Detailed Crop Specific Response Farming Recommendations	-	Detailed instructions to farmers on how best to modify a few key practices for growing particular crops of local importance - in response to season rainfall forecasts.
Dry Planting	-	Planting a crop prior to onset of the rains.

Early Warning System	-	Onset or very early season forecasts of impending food shortages, or, if appropriate food gluts, generally aimed at planners responsible for food security, export/import, etc
Evaporative Conditions	-	Atmospheric parameters which govern rates of evaporation, thus crop water requirements (ET_m). The chief factor is sunlight. Temperature, humidity, wind speed and advected energy also play a part.
Evapotranspiration (ET)	-	Water use by a crop in field conditions, combining evaporation from the soil surface with transpiration from the leaf canopy.
ET Actual (ET_a)	-	Actual rate of ET, governed by the same factors as ET_m (below), and additionally by limiting water supply. See crop water utilization.
ET Maximum (ET_m)	-	Maximum rate of ET by a crop with no water supply limitation. Governed by evaporative conditions, crop physiological characteristics and by leaf area index (LAI), the latter depending on plant population - a key management factor. See crop water requirement.
Farm Activities, Management Decisions or Practices	-	Terms used interchangeably referring to those activities the farmer carries out each season which, if modified, would affect either crop water utilization or crop yield or both.
Final Rain Date	-	The last date of rainfall occurrence prior to crop maturity. Precise definition may be modified to suit specific rainfall behavior patterns. Requires clearly stated definition in each analysis.
Generalized Response Farming Guides	-	General instructions to farmers on directions to move when modifying key practices for crop production -- in response to season rainfall forecasts.
Green Revolution	-	Dramatically increased food harvests through introduction in the 1960s of new varieties of wheat and rice to irrigation farmers in Asia and Latin America, along with fertilizers, pesticides and mechanized farm equipment.
Intercropping	-	Growing two or more crops simultaneously in the same field. Generally beneficial in low resource agriculture in terms of overall yield per hectare, but can be disastrous if rainfall too low.
Leaf Area Index	-	A measure of crop leaf canopy cover. Ratio of total leaf (green tissue) area over land area. As a rule of thumb, crop water requirements are usually maximized when LAI is 3.0 or greater.
Lysimeter	-	A device for making precise field measurements of all components of crop water balance, especially crop water requirement or ET_m. A weighing lysimeter is a tank of soil set in the field at ground level on a weighing balance which measures all surface soil water gains or losses, and also provides for measuring all drainage.
Mean	-	Average, as in long term average or mean annual rainfall.
Median	-	The middle value of a distribution of, say, amounts of annual rainfall, with half of all years above that value and half below.
Monocropping	-	Producing a single crop in a field at a given time, as opposed to intercropping.
Photosynthesis	-	The formation of organic compounds from inorganic compounds within green plant cells containing chlorophyll, fueled by energy from light. The process of crop growth and yield.
Plant Population	-	Numbers of plants per hectare or other measure of land area. Controlled by seeding rates and/or plant thinning to reduce population.

Rainfall Behavior - General term referring to ways in which season rainfall amount, duration and intensity index relate to the date of onset or other predictor.

Rainfall Flag - A coined term referring to a scatter diagram relating, say, seasonal rainfall amount to date of onset, with all data points enclosed within a drawn border. When rainfall amount or duration declines with later onset, as is typical, the resulting pattern has the appearance of a flag drooping away from a flagpole - the latter represented by the vertical axis which shows rainfall amount or duration.

Rainfall Prediction Criteria - Quantified rainfall predictors (See below). An example would be a specified date, before which "early onset" would suggest normal farm practices should be followed ("Plan A"), but after which "late onset" would suggest farm practices should be modified ("Plan B").

Rainfall Predictors - Pre-season or early season rainfall occurrences which are found to be related to historical rainfall behavior. For example, the date of onset of the rainy season relates closely to season duration and rather well to season rainfall amount, both of which, on average, decline with later onset. Thus, whenever onset actually occurs, one knows which portions of the historical ranges of season duration and amount might recur this season, and which may be excluded from further consideration. Additionally, one may calculate probabilities of recurrence of different durations and amounts within the (now narrowed) ranges still to be considered.

Rainfall Season Standards Based on Crop-Production Potential - A new approach for ranking recorded rainfall seasons in terms of crop production potential based on three important season characteristics (rainfall amount, duration and intensity index) rather than rainfall amount alone. Five rankings are delineated, termed Maximum, High Normal, Low Normal, Subsistence and Failure. After seasons are ranked, probabilities of production at each of the five levels are calculated. Two types of standards in development are:

1. Relative value standards for each location based on a hypothetical crop which has water requirements and yield responses directly related to long term mean values of the three season rainfall characteristics (See examples in Tables 21 and 24). Crop production potential probabilities are calculated initially for the entire record. These probabilities are used to compare rainfall stability factors and general behavior patterns between different locations. Separate sets of probabilities are then calculated for each predicted group of seasons in order to show graphically the value of prediction, and to underpin Generalized Response Farming Guides for on-farm responses. (See Figures 19 and 20).

2. Absolute value standards based on the water/yield characteristics of selected crops/cultivars of interest at a given project location. For example, grain sorghum at Hyderabad, India (Table 25). Probabilities of attaining the five levels of crop production potential can then be calculated anew for each predicted group of seasons (Figure 21).These will help underpin Detailed Crop Specific Response Farming Recommendations.

Regression Analysis - Statistical analysis of available data, e.g. rainfall records, to examine the degree of linkage or correlation between a measurable variable such as date of onset of the rains, and a variable one wishes to predict, such as season rainfall amount or duration.

Response Farming - A flexible system of farming in which key decisions affecting crop water utilization and crop yield are modified each season in response to pre-season and early season predictions of season rainfall amount, duration, intensity index and other parameters as appropriate. The overall goal is to maximize production/returns per unit of rainfall. In more human terms this means to stabilize crop yields at the low end of the variable rainfall scale, and attain higher yields which will break the poverty syndrome when rains are good.

Response Farming Research Package	-	A coordinated program of research along distinct but interrelated lines, assembled and streamlined over the past two decades, and designed to produce the information requirements of a response farming program. These include rainfall prediction criteria, generalized response farming guides and detailed crop specific response farming recommendations.
Response Farming Strategy	-	An approach for coping with seasonal rainfall variation, with three major components: 1. Risk reduction through agriculturally relevant rainfall analyses, followed by both pre-season and early season predictions of expected rainfall behavior. 2. Flexibility in the farming system permitting modification of decisions and practices to maximize production per unit of rainfall received. 3. Incorporation of farmers' priorities, whether based on social, economic, infrastructural or political factors. As an example, in some areas there is a need to assure the family food supply prior to consideration of cash crops.
Season Rainfall Amount	-	For generalized analyses, the season rainfall amount is the total rainfall from the date of onset until the final rain date, plus extractable water stored in the future root zone on the date of onset. For specified crop types, substitute germination date for date of onset above.
Season Rainfall Characteristics	-	Season rainfall amount, duration and intensity index.
Season Rainfall Duration	-	For generalized analyses, the number of days from date of onset (day zero) to final rain date, including the latter. For specified crop types, from germination date to final rain date.
Season Rainfall Intensity Index	-	The average amount of rainfall per day in the season, or amount/duration.
Season Rainfall Parameters	-	Same as season rainfall characteristics.
Season Rainfall Prediction	-	Pre-season and early season forecasts of expected ranges and probabilities of season rainfall characteristics -- including rainfall amount, duration, intensity index and other parameters as appropriate.
Sidedressing	-	Applying commercial fertilizer, usually a nitrogen source, to a cropped field after the crop is germinated and growing e.g., as to maize at thinning time, perhaps 30 days after germination. Part of response farming strategy when applicable.
Thinning	-	Reducing plant population in a cropped field by purposely removing or destroying some plants. Part of response farming strategy when applicable.
Transferable Relation	-	In response farming research data are developed on crop water use and concurrent yield for the purpose of estimating values of these parameters at project locations without endless repetition of costly experiments. But the environmental conditions, i.e., evaporative and soil conditions, of the experimental site greatly influence the original values determined. Therefore, to become transferable, the original values must be related to the environmental conditions in appropriate ways - such that the same relationships will remain true at project locations. Measurements (or records) of actual environmental factors at the locations, coupled with the transferable relations, will form the basis for new estimates of water use and yield.
Wet Planting	-	Planting a crop after onset of the rains has occurred.

APPENDIX F

Acronyms and Abbreviations

ACIAR	Australian Centre for International Agricultural Research
CID	Consortium for International Development
CRIDA	Central Research Institute for Dryland Agriculture (Hyderabad, India)
CSIRO	Commonwealth Scientific and Industrial Research Organization
EAAFRO	East African Agriculture and Forestry Research Organization
FAO, UN	Food and Agriculture Organization of the United Nations.
ICAR	Indian Council for Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
INRA	The National Institute for Agronomic Research (Morocco).
JD	Jordanian Dinar: 1JD $2.68 (Nov. 1985)
KARI	Kenya Agricultural Research Institute
MIAC	Mid-America International Agricultural Consortium
NDFRS	National Dryland Farming Research Station, Katumani, Kenya.
OICD	Office of International Cooperation & Development (USDA).
UCD	University of California at Davis.
USAID	United States Agency for International Development.
USDA	United States Department of Agriculture.
WHARF	World Hunger Alleviation through Response Farming - A Non-Profit Foundation.

APPENDIX G

Conversions

Metric		English	English/Metric		
1 millimeter (mm)	=	.0394 inches (in)	1 in	=	25.40 mm
1 meter (m)	=	3.281 feet (ft)	1 ft	=	.305 m
1 kilogram (kg)	=	2.205 pounds (lb)	1 lb	=	.454 kg
1 hectare (ha)	=	2.471 acres (ac)	1 ac	=	.405 ha
1 kg/ha	=	.892 lb/ac	1 lb/ac	=	1.121 kg/ha
1 ton (t) =1000 kg	=	2205 lb			
1 t/ha	=	892 lb/ac			

APPENDIX H

FACTS ABOUT WHARF

- WHARF is the acronym for the non-profit foundation World Hunger Alleviation through Response Farming located in Davis, California, USA.

- WHARF was incorporated by the State of California in February, 1984, receiving registration as a scientific, educational and charitable trust. Tax exemption has been granted by the U.S. Internal Revenue Service and the California Franchise Tax Board under Sections 501(c)(3) and 23701d of the Federal and State Taxation Codes, respectively.

- Funding to date is principally through private donations, and contracts with the U.S. Department of Agriculture Office for International Cooperation and Development (USDA/OICD) — on behalf of the Asia/Near East, Africa, and Science and Technology Bureaus of the U.S. Agency for International Development.

- Activities are both in the USA and abroad, including Africa (Kenya Rwanda, Niger, Mali, Burkina Faso, Senegal), Asia (India Pakistan, Nepal, Sri Lanka) and the Mediterranean/Near East region (Portugal, Morocco, Cyprus, Jordan, N. Yemen). These include Response Farming Feasibility Studies, Guidance of Response Farming Research by interested individuals, agencies, institutes, etc., or within self-help development projects, and Design of Response Farming Projects, followed by Life-of-Project consultation.

- Financial support is welcomed from individuals, foundations, corporation, universities, research institutes, governmental agencies in the USA and abroad, and international bodies. Forms of support sought include memberships, donations, grants, cooperative agreements and contracts, as well as gifts of real property, equipment, other items of value, and voluntary assistance.

- The Goal of WHARF is to develop and give the knowledge required to avert starvation, alleviate hunger and enhance the quality of life of peoples everywhere who live today at the whim of highly variable and unpredictable rainfall. The Directors and Professional Advisory Council Members of WHARF cordially invite your participation in this endeavor.

APPENDIX I

WHARF BOARD OF DIRECTORS AND PROFESSIONAL ADVISORY COUNCIL

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