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RESEARCH FOR IRRIGATED AGRICULTURE[1]

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Introduction

On-farm water management problems often are not recognized, but are very common on most irrigated projects. Crop production reduced by disease or insect damage is recognized and describable. Consequently, and understandably, research on disease or pest control is often given a higher priority than research on water management problems. Similarly, research results that produce distinct and obvious benefits under existing farming practices, such as new crop varieties, are easy to transfer as are research techniques necessary to adapt a new variety to a new environment or to change its resistance to local diseases or pests over a few years. Production limited by water management problems is often more difficult to comprehend and describe. Water affects the entire crop-soil-climate system, and water-related problems are not always readily discernable. Problems that seem too complex, or cannot be visualized, generally are not given a high priority by policy makers and funding organizations. A large amount of water management research exists, which, if applied, could increase food production substantially. These research results seem to go unused because we apparently have not developed adequate adaptive research techniques necessary to produce site-specific information, and we have not developed acceptable techniques to apply new technology. This situation is not unique to developing countries but is commonplace even in highly developed countries. Why? There are several key reasons. General solutions to problems will not be applied if the problems are not apparent, and site-specific solutions will not be applied if they are not economical and practical. There must be an incentive to apply a new practice. These are some of the specific major issues addressed in this paper as part of the assignment related to the overall goal, purpose, and objectives of this Symposium.

The ultimate goal of this Symposium is to develop guidelines and recommendations for on-farm water management research which, when implemented, will lead to increased agricultural production and income in less developed countries. The specific purpose of this Symposium is to thoroughly evaluate water management problems in developing countries, available research information, and research completed or underway in a world network so that gaps in research can be identified. We are also to assess the interrelationships of the Colorado and Utah State Universities' water research projects sponsored by AID and to determine whether these projects support each other's objectives and whether their findings are generally applicable in developing countries.

I am also to respond to related discussions on the question of the phases of water management of which we have adequate, and those of which we have deficient, knowledge as viewed from various geographical areas. Since these papers were not available before the Symposium, I will not provide a detailed listing of research needs. I will attempt to describe those characteristics of water management problems and research that are often overlooked in developing and implementing research programs and in applying solutions to water management problems.

Specific objectives to be considered during the Symposium are to find answers to five questions concerning The present status of knowledge; how this knowledge is being applied throughout the developing world and major factors limiting its application; who is doing research related to unsolved problems; the breakthroughs which can be applied generally through the various countries; and how general problems may be approached in an interdisciplinary framework. My discussion will concern irrigated agriculture, but many of the principles apply to rainfed agriculture where food production is normally limited by precipitation.

Before we can intelligently discuss research for irrigated agriculture, we must recognize and describe water management problems, especially their uniqueness which makes additional research necessary. At the risk of repeating some of the statements made by those addressing the first question of our objectives, I will describe some of the more critical problems that I see associated with improving on-farm water management and food production. I will emphasize particularly those aspects of water management which limit the production of food to a greater extent than necessary under the existing circumstances.

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Characteristics of On-farm Water Management Problems

Most on-farm water management problems that limit food production are not unique to developing countries. There is much similarity between the problems in the developing countries and the developed countries where managing the complex crop-soil-climate system requires regulating the water component. Many of these problems begin when those who develop water resources do not consider the entire crop-soil-climate system which includes salt control and drainage, but are concerned only with delivering the water—the easy part of the job. Such developers tend to forget that the real purpose of irrigation is to produce crops.

There are many similarities in the techniques necessary to adapt available research and to apply irrigation technology to enhance food production. The major difference is in the alternative approaches available to improve water management. Farmers in the developed countries, for example, may invest in large capital improvements to attain a greater degree of water control that will improve or simplify the management of irrigation water. Farmers in developing countries must use alternative practices such as greater labor input to achieve better management. The principal similarity between the two circumstances is that managing irrigation water implies, first of all, an understanding of the available water status and the mechanisms controlling the loss of water from the soil root zone. Drainage and salinity control requirements are similar in the two types of countries but the options for control may be more restrictive in developing areas. Also, drainage and salinity control generally require control of areas used by many farmers.

Recognizing and delineating water management problems

The *foremost* water management problem is recognizing and delineating any water problem that is directly responsible for limited food production, such as the mismanagement of water, or the reluctance to implement better water management practices. A crop seriously stressed because of a severe shortage of soil water and a crop ruined by flooding are examples of obvious water problems. In most situations, however, numerous instances exist where excess water, or lack of water, and water-related factors significantly reduce crop yields, but are not recognized. Such scientists conducting research in other aspects of irrigated agriculture often do not recognize the adverse effects of poor water management. Obviously, policy makers and the administrators of agriculture programs in both the developed and developing countries will not be as aware of these more subtle water management problems that limit agricultural production unless these problems are carefully delineated and the effects documented. The natural result is to direct their limited financial and technical agricultural research resources towards studies that may in themselves advance scientific knowledge, but may not contribute to the solution of real problems limiting food production.

The *second* major problem that must be recognized at an early stage is that improved irrigation water management requires a continual application of new technology regardless of the capability of the irrigation system except, perhaps, for fully automated systems. Fully automated systems, however, usually require large capital outlays and an extremely high level of on-site technical skills to keep the systems operating. Improving on-farm water management is not like changing crop varieties, which may require a decision only once during a 5-year period or at most annually. Similarly, decisions concerning application of fertilizer are made only once or twice a year. In contrast, improvements of on-farm water management require the application of available irrigation science and technology on a daily or weekly basis, with the exception of improvements such as major land leveling or a change in the irrigation system which may occur only once in a 5- to 10-year period. A communication linkage is needed between those who control water supplies and delivery and the water user to keep the delivery system responsive to the needs.

To understand the necessity of continual application of science and technology to improve crop production, we must recognize the role that water plays in the complex crop-soil-climate system. Slatyer (1967), indicates that water is essential for the structural integrity of biological molecules, cells, tissues, and of the organisms as a whole. Water plays a vital role in the transport of mineral nutrients and the translocation of materials in solution throughout the plant body. He also indicates that in all actively growing plants there is a liquid phase continuity from the water in the soil through the plant to the liquid-gas interface at the evaporation sites in the leaves. The root system provides an extensive absorbing surface across which pass virtually all of the water and mineral nutrients utilized by plants. When the vital roles that water plays are recognized, it is not too difficult to comprehend the importance of water management. The operator of an irrigated farm must control the level of available soil water—a reservoir he cannot see and of which he cannot regulate the rate of outflow, but one whose level directly affects plant water stress and plant growth. In addition, since leaching is the only practical mechanism for controlling the salt concentration and the toxic levels of certain elements in the root zone, he must apply sufficient excess water for this purpose. Salt and sodium control in irrigated agriculture is probably the second and the oldest problem in irrigated agriculture. Applying water for salt control is especially critical where water supplies are limited, but it is also important when supplies are plentiful because excess application may cause drainage problems and leach valuable nitrogen from the root zone.

The crop-soil-climate system is difficult to manage effectively. How often have we assumed that the farmer, who may have the least understanding of the various mechanisms that control the system, will automatically achieve full benefits of water if we merely deliver some water to his land?

Common on-farm irrigation water management problems

On-farm water management requires daily or weekly decisions regardless of the irrigation system involved. The opportunities for mismanagement may be less with systems that are not flexible in their operation. For example, problems of excess water application are not nearly as common with sprinkler irrigation systems because the rate at which water can be applied is low and limited by the system. As a result, many hours of operation are required to apply a normal irrigation. With this method of irrigation, it is much easier to prescribe and control the amounts of water applied but the timing is still subject to wide variations. In contrast, surface systems may allow little opportunity to control water applied because there may be no adjustable structures, water measurement devices, and lined channels. Under these conditions there are much greater opportunities and much more frequent occurrences of mismanagement.

Regardless of the system involved, on-farm water management still has a significant effect on food production from irrigated land. One important factor that is not often recognized is that irrigation scientists and technologists do *not* make the daily or weekly on-farm irrigation decisions though this is often implied by the scientific and technical agricultural communities. The decisions are being made by people with limited background and training, people who have not had formal training in the management of a complex crop-soil-climate system. In addition the needed decision-making data are generally not available to those who must make these decisions. The kinds of necessary decision-making data are: (1) The estimated available soil water status for each field and crop at all times; (2) the projected irrigation dates by fields that will avoid or minimize the effects of water stress or over irrigation; (3) the amounts of water that should be applied for each crop and field if the irrigator can control the amount applied; and (4) some knowledge about the adverse effects of early, delayed, or terminating irrigations. If a program is developed to improve the on-farm decision process through research and application of research results, it can be used initially to improve the management of existing systems without a significant investment of capital. As farms and irrigation systems are improved, the same program would become more essential to realize the full benefits of the improvements.

Problems of water shortages. The most obvious water management problem is a shortage of irrigation water for crop needs. In many areas the average annual supply of water to the farms may be only one-half to two-thirds of the consumptive use requirement. In general, it is automatically assumed that this shortage is the primary factor limiting crop production. It is not obvious that with poor facilities and management practices these limited water supplies may be used inefficiently. It is not uncommon, for example, to find excess water applications with limited supplies because the available soil moisture has not been depleted sufficiently to hold the minimum amount necessary to cover the area. Why would an irrigation be applied at this time? Water may be available only at preset time intervals and, in many cases, the farmer or farm manager, not knowing the rate at which soil water is depleted by evapotranspiration, is not aware of the quantity of soil water depletion that has taken place. Most surface irrigation systems in developing countries probably require a minimum depth of application of at least 4 to perhaps 6 inches (10 to 15 cm). A shallow-rooted crop may need to be irrigated when only 1 inch (2.5 cm) has been depleted, or irrigation water may be available when only 1 inch has been depleted. This is also a common problem but often unrecognized in the developed countries. Under these conditions scarce water supplies are wasted, valuable nitrogen is leached, and groundwater levels may be raised to water-logging levels. Thus, drainage problems may be created under scarce water supply conditions because of poor irrigation water management.

Another serious problem that is often not recognized is the nonuniform distribution of limited water supplies. Such nonuniform applications result in excessive applications to portions of fields, causing groundwater problems and aggravating the water deficiency in other parts of the field. This situation enhances the accumulation of salts due to the evapotranspiration and lack of leaching in the high places. This is particularly a problem with "level basins," regardless of their size.

Another aspect often not considered in water-short areas is the effective use of the limited precipitation or managing the irrigation water to optimize or maximize the effectiveness of what little precipitation is received. Many of these irrigation water management problems are also common in rainfed areas.

Problems with adequate water supplies. When water supplies are adequate many of the same problems mentioned above, such as irrigating when there is inadequate capacity to hold an irrigation and nonuniform distribution of water, are encountered. With adequate water supplies, it is not uncommon to find irrigations delayed unnecessarily which may result in severe crop stress and decreased crop yield potentials, followed by excessive water applications with their adverse affects. These conditions are common in both the developed and developing countries. Another problem often associated with adequate water supplies is the availability of these supplies for crop water needs. This may be particularly serious where there are no or limited water storage facilities. On the other hand, in many of these areas groundwater supplies can be utilized to supplement surface flows during peak water use periods, and if water quality problems are not severe, pumping may accomplish needed drainage for many decades.

Problems of water quality. The most obvious problem associated with water quality is the accumulation of soluble salts as evaporation from the soil surface and transpiration remove pure water and leave the salts behind. Closely associated with soluble salts is the more troublesome accumulation of sodium. Presumably these problems will be discussed at a later time, but irrigation water management is the only practical method of maintaining a favorable salt concentration in the root zone. This is accomplished by uniformly applying slightly more irrigation water than necessary for evapotranspiration. Irrigation to bring the soil to field capacity before rainy periods will enable or enhance salt leaching by rainfall.

Problems with the main delivery system. There may be many problems with the main water supply-delivery system such as limited storage, seepage, sediment, etc However, some on-farm water management problems are associated with how the system is managed. The farmers may not be able to attain maximum crop production with existing water supplies because the delivery system is rigidly controlled to deliver water on a rotation basis that may not be related to consumptive use and available soil water capacities. Water is often delivered when it becomes available in the system, which means that the irrigation distribution system is first a disposal system for water and second a transportation system to deliver water as needed for crop production. Without storage facilities, significant changes in irrigation scheduling may not be feasible, but generally delivery intervals could be modified to meet crop water requirements rather than optimize the operational efficiency of the system. A canal system is not efficient if it efficiently conveys the wrong quantity of water at a particular time or throughout the season (Henry Olivier, 1972). Often the managers of irrigation systems controlling water delivery do not understand the crop-soil-climate system or the farmers' problems. The water user and agricultural specialist need to have some input to the management of the main system The user also needs to be involved in the operation of tube wells used to supplement canal flows. Also, financial resources for structures needed to improve the management and delivery of water may be limited.

Problems with on-farm delivery systems. Unlined ditches overgrown with trees, brush, and clogged with sediment greatly reduce the quantity of water that can be delivered to the fields as well as hamper the manipulation of water from one field to the next. Lack of capital to improve delivery systems is probably the greatest single factor retarding improvements of on-farm delivery systems. The formation of districts for "self improvement" or delegating to the management of the canal system the responsibility to maintain the delivery system to each main field may improve the management of irrigation water on the farm.

Legal problems affecting water delivery. Legal problems that regulate the quantity, timing, and mode of water delivery essentially independent of crop water needs may be a significant factor in both the developed and developing countries. Changing the legal structure to enable improving on-farm water management will be a slow process, but this should not deter efforts to improve on-farm water management within the constraints of the existing system.

Water management problems caused by soil problems

The more common problems that affect the management of irrigation water are low rates of infiltration caused by either fine-textured soils or the accumulation of sodium, low available water holding capacities on coarse sandy soils, and limited rooting depths which reduce the potential available water holding capacity. Rooting depths may be limited by chemical or mechanical conditions, or by a combination of these conditions. The most common chemical problem related to water management is the accumulation of soluble salts because of evapotranspiration. The accumulation of salts may directly reduce plant growth, and the accumulation of sodium may severely affect both the plant growth and infiltration rates and further complicate on-farm water management.

Available Research and How it is Being Applied

Soil-water-plant relationships

Sufficient knowledge is available to enable prescribing good or improved water management guidelines under most existing water supply and delivery systems for essentially all crops. This includes projecting the optimum irrigation dates, taking into account expected precipitation and the amounts of water that should be applied where water is not limiting. General knowledge also enables us to optimize the application of water where water is known to be the limiting factor. This knowledge includes predicting rates of evapotranspiration by growth stage and the probable levels of soil moisture tension where stress adversely affects growth of various crops. These research results are being applied to individual farms and fields by irrigation management service groups in developed countries. These groups are operated either privately or by irrigation districts and canal companies. Many of these service groups also provide plant nutrition and pest control services (Jensen, 1972, Lord and Jensen, 1973). Availability of these services is limited by a shortage of trained personnel who understand the whole system and recognize the farmers' ability to respond to needed changes.

Irrigation systems and management

There is sufficient general knowledge of irrigation water management to enable a thorough analysis of representative existing systems. Such an analysis would indicate where (1) Modifications or improvements should be made, and if made, (2) where substantial increases in crop production would automatically result, or, (3) where improved water management would become much easier to accomplish. The U.S. Bureau of Reclamation recently completed such a comprehensive study on several areas of the Western United States.

General knowledge is sufficient, concerning the hydraulics of on-farm irrigation systems including overland flow, distribution of water over the field, and distribution within the soil, to enable describing the current operating characteristics of representative systems if site-specific data can be provided. Members of a Western Regional Research Project in the United States are nearing completion of a comprehensive publication on Hydraulics of Surface Irrigation.

The limitation of the available research mentioned above is the technical capability of applying functional relationships to new circumstances. In many cases, it may be easier to obtain site-specific water management guide lines by conducting general irrigation water management experiments with local crops. However, there is no need to conduct these studies to reestablish general principles of scientific irrigation water management, but rather adaptive research is needed to verify and to obtain local calibrations of general fundamental relationships.

Gaps in Research and Research Underway

The greatest gap in on-farm water management research is in the ability to clearly delineate the factors limiting crop production as a result of irrigation water management. In most areas, these factors are unique and require local input parameters to apply the general available research. Brief cursory reviews by "experts" seldom pinpoint the real problems. Similarly, application of complicated multiple correlation computer models that are not based on physical-biological principles seldom pinpoint problems.

Major constraints, for example, to increasing food production may be attributed to the lack of adequate water delivered to the farm or group of farms. However, thorough assessment may reveal that only 15 to 30 percent of the water delivered is actually used by crops. The balance of the water may be lost by seepage from on-farm ditches, by runoff or deep percolation caused by applications that exceed the amount the soil can hold or that are nonuniformly distributed because of soil surface topography, and by the nonbeneficial use of water by nonproductive vegetation such as trees and brush growing along waterways. Local scientists and technicians must thoroughly understand the local system to recognize these deficiencies. Understanding the entire system will require detailed studies which thoroughly evaluate representative existing systems. These cannot be conducted in the laboratories or on computers. They need to be conducted by using field experiments which rely on the general available research in their design, but basically integrate the many functional relationships under local climatological, crop, and soil conditions. Sometimes minor problems such as poor germination may play a major role in determining the potential production capability. This problem may be overlooked in a laboratory analysis but would become obvious in a field experiment. Computer models that simulate daily crop growth, evapotranspiration, root growth soil water extraction, drainage, and leaching may pinpoint some of the problems. Local field experiments are needed, however, to provide input data.

Application of general available research knowledge requires site-specific input parameters which usually are not known. These may include soil water characteristics, crop-soil characteristics such as rooting depth, and various crop-soil-climate interactions. In most cases, it is probably easier to obtain this information from a few well-designed and carefully conducted field experiments than from extensive laboratory studies.

Moseman (1970) indicates that in developing nations "an especially neglected area is research on soils and water management, including the conservation and use of rainfall." Extensive water management research is underway at many field stations within irrigated areas of developed countries. In contrast, the necessary training, opportunity for research experience in field plot techniques, and the practical aspects of conducting irrigation field experiments seem to be lacking in developing countries. It appears that too many research trainees and graduate students from developing countries when sent to developed countries for training are assigned to work on theoretical problems and laboratory experiments requiring complex instruments and controlled environmental chambers. The greatest gap is not in general water management research, but in the adaptive research necessary to apply available water management research in developing countries. Facilities for adaptive research are also lacking. Moseman (1970) indicates that "perhaps the most common deficiency in agronomic research is the lack of precision in field experimentation because of plot lands poorly suited to exact and reproducible trials, with inadequate control of irrigation or moisture management and ineffective weed, disease or pest control."

Implementing a Water Management Research Program

Type of research needed

I have referred to applied and adaptive research in this paper as have many other authors. The following statement by Moseman (1970) adequately describes the various categories of research:

> There is rather general agreement that fundamental or *basic research* is designed to deepen insights and understanding into biological and physical forces, or the economic and social conditions with which we are concerned. *Applied research* is the direction or utilization of such basic and background knowledge to the improvement or change of specific materials or conditions. *Adaptive research* . . . involves adjustments, modifications, or changes, brought about through systematic research or "the methods of science."
>
> In distinguishing between *applied research* and *adaptive research,* the former represents the initial direction or application of fundamental knowledge to a practical end use, while adaptive research is concerned with the further modification or adjustment of that applied result....
>
> We have had considerable experience with *adaptive research* in crop breeding and improvement programs, in suiting crops to new environments, in changing resistance or tolerance to diseases and pests, and in modifying product quality. The cooperative federal-state program of adaptive resarch successfully transferred the benefits of hybrid corn from the midwest to the southern states through the development of the "Dixie Hybrids." Similarly, soybean production has expanded in the United States largely because of the breeding and selection of varieties adapted to the different environments, especially to length of day, from the Mississippi Delta to the North Central states. (Moseman, 1970)

Adaptive water management research generally has not been clearly defined. One specific example would be a 3- to 5-year field experiment involving depletion of soil water to different levels before irrigating. This study would be conducted with the best local crop varieties and cultural practices under controlled conditions. Irrigations would be given at specific degrees of soil water depletion or at specific levels of soil water tension in some portion of the root zone. The levels of depletion for the treatments can be provided from studies already conducted in developed countries. The approximate general results would be predictable from previous studies, but not the exact response of the local crop variety under local soil and climate conditions. Complete supporting data on soil water depletion, amounts of water applied, and climate would be obtained to enable developing practical recommendations for other soils in the same climatic region. One or more types of fertilizers could be superimposed on each of the soil water treatments.

Studies like the one mentioned require enthusiastic, well-trained scientists, preferably at the Ph.D. level, who are dedicated to solving a problem which may require many years to complete. Suitable organizational and technical support is needed. Also, institutions in developing countries must recognize the potential for training their own scientists. This can be done to solve critical food production problems under the leadership of water management scientists who have demonstrated abilities and perhaps have the insight and desire to see that the best practices are applied.

Research direction and leadership

Most scientists are competitive. They want prestige and recognition. In the developing countries, the greatest need is to obtain local background information to enable applying general available research results. But often the scientists in these areas want to conduct basic research because, to the local scientific community and nontechnical administrators, basic research appears more attractive than applying available research results. Another significant factor in many areas is the attitude toward conducting field experiments under uncontrolled environmental conditions. These experiments require practical know-how and have a greater risk of failure in one season because of unforeseeable events. Fear of failure in adaptive research may play a significant role in the resistance of scientists to become involved in such studies. Actually, conducting productive applied or adaptive research under normal environmental conditions requires a broad range in technical capability and practical know-how. Often more skill is needed than that required to conduct simple experiments under controlled conditions in a laboratory. On the other hand, with experience, scientists and field technicians can show very productive results from research conducted under field conditions—results that become readily apparent to nontechnical administrators, policy makers, and farmers in the immediate locale.

Most developing countries have limited financial and scientific resources available for research. Much of the scientific effort is often wasted by re-proving the wheel is round instead of applying the wheel to solve problems, re-proving Darcy's law before applying it to solve soil water flow problems, or overlooking basic scientific principles such as the conservation of mass and conservation of energy. Much effort also is wasted in deriving new correlations to show relationships shown many times before. The probable reason for this effort is the lack of qualified guidance in conducting research, and fear of failure if a new concept is considered since previous publications from other areas indicate that repeating an experiment will produce predictable results. This raises the question as to who should do basic research and who should do applied or adaptive research. In general, the more mature the scientist, the more qualified he is to conduct productive applied research, but he also must have technical training comparable to those conducting basic research. In a developing country where on-farm water management research is urgently needed and many of the basic principles are known, the research managers and policy makers should direct about 80 to 90 percent of the research into applied or adaptive areas and only 10 to 20 percent in the basic areas. Those conducting basic research should also have demonstrated a creative ability.

Moseman (1970) suggests the following elements of a research organization:

(1) A strong national center for background research and for conceptual and coordinating leadership for national and regional projects. The former Beltsville Research Center provided this resource in the United States. Similar national headquarters at Chapingo, Mexico; Tibaitata, Columbia; La Molina, Peru; La Platina (Santiago), Chile; and the Indian Agricultural Research Institute near New Delhi furnish similar "national headquarters" services in those countries.

(2) Regional centers for adaptive research and specialized attention to the agricultural requirements of the major cropping regions of the country. In the United States the federal field stations, together with selected state agricultural experiment stations serve as regional headquarters for specific research projects.

(3) Localized research and/or verification and testing stations designed to fit innovations to specific soil and climatic conditions. In the United States this component is represented primarily by the branch stations of state agricultural experiment stations.

> ... The level of competence at the regional stations should be similar or about equal to that of the central headquarters, but with the mix of scientific disciplines determined by the nature and complexity of the problems of the region. The competence at the localized field stations should be of the B.S. degree level of training at the beginning, with upgrading to the M.S. and Ph.D. level in time, as has occurred in the branch experiment stations in many of the states of the U.S. (Moseman, 1970)

In general, I agree with this proposal, but I have also observed that over a period of time replacements for vacancies that occur at the national level may not have the same broad and outstanding traits of the initial staff. Concurrently, as the training of the staff and the quality of facilities and technical services at regional centers improve, the role of the national center may change in time. This must be recognized to sustain a viable research program. There are many factors that contribute to this change. Many productive scientists at regional centers or field stations thoroughly enjoy their work and are reluctant to relinquish direct involvement in research for an assignment with semi-administrative duties that appear less productive and rewarding. These duties may involve preparing broad and long-range project proposals, budget statements, technical reports, etc. Living conditions and schools may be as good or better at regional centers. On the other hand, some more qualified scientists may prefer to avoid assuming additional responsibilities associated with accepting a new challenge for fear of failure, or may prefer the more comfortable routine of their present assignment. The net effect, if not recognized and corrected, may be a lack of communication with regional and field staffs resulting in an unrealistic appraisal of high priority research needs. The problem may become more serious when scientists at the national center begin to believe that only the national staff is qualified to conduct background research, and only the national staff has the ability to determine the direction of research programs. In practice, competent scientists that work day to day with current problems of food production often are aware of critical deficiencies in research and often are as qualified as scientists at the national center to conduct some of the needed background research. New ideas are scarce and should be solicited from all scientists.

Of prime importance is the technical direction and support provided to qualified scientists conducting research on all related aspects of water management that will lead to increased food production. The specific example of adaptive water management research would also be applicable to related aspects of irrigation water management. For example, knowledge about the hydraulics of surface irrigation is well known, but local intake rates, soil surface roughness parameters, etc., are not known. These data, obtained under local conditions, are needed to apply hydraulic principles. Closely related to water management research is the management of nitrogen which because of its solubility is subject to leaching. General research knowledge is adequate to enable local scientists to prescribe general nitrogen requirements and predict specific requirements. But local data needed for these predictions such as the mineralization capacity of soils are often not available.

Research direction also has the responsibility of avoiding the inefficient use of limited scientific resources for research by preventing too much of the research effort to go into nonproductive, or less productive activities such as constructing research equipment when it can be purchased and put to use.

General and Site-specific Research

A few examples of needed water management research or applied technology that can be generalized are given as follows:

1. Expected consumptive use (evapotranspiration) curves beginning with major food crops. The curves would show expected daily ET by growth stage under typical climatic regions and would serve as a guide to both the water user and manager of the irrigation distribution system.

2. General experimental guides to calibrate or adapt general crop-soil-climate interations, including probable levels of allowable soil water depletion, tentative crop growth-soil water stress relationships, and tentative levels of plant nutrients essential to sustain the productivity of new high-yielding varieties.

3. Experimental guides for calibrating or verifying ET-salt control-production relationships.

4. Experimental guides to evaluate and clearly show the limitations of existing irrigation systems and water management practices. The results of these studies would show the need to develop alternative methods of managing the crops and existing water delivery systems to meet crop water needs.

5. Experimental guides to provide continuous and effective water management services to each farm and farm operator. This also would require trained personnel working directly with the farmer.

6. Experimental guides to demonstrate the benefits of better water management and determine what incentives will result in the application of better water management practices.

7. Low cost, easy-to-maintain systems to control the quantity of water delivered to individual fields.

The results from site-specific experiments conducted by well-trained scientists following these general guides will lead to practices that can be applied economically to each irrigated field to increase and sustain the production of food.

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