Paper 9

Technological Innovations in Irrigated Agriculture

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THE PROBLEM

IN MANY RECENT publications it has been stated that global population is expected to increase from about 5 billion today to at least 8 billion by 2025, with most of this increase being in the developing world. Agricultural production in the world will have to expand by at least 2 percent per annum to keep pace with population growth and related growth in income and changes in food habits. However, in many parts of the world, there is little land available for lateral expansion of agriculture and increases in output will have to come from improved productivity. According to Le Moigne and Subramaniam (1990) there are indications that as much as 80 percent of the required increase in food grain production over the next few decades must come from yield increase. Irrigation could play an important role in achieving and stabilizing such a yield increase. In fact, most of the required increase in food output is expected from the irrigation sector. But one has to recognize that competition from industrial and urban uses is rapidly limiting agricultural water supplies in many parts of the world, especially in the developing world. Furthermore, energy resources are finite and past experience has shown that irrigated agriculture can lead to land degradation through waterlogging and salinity, depletion of groundwater and surface water quality, fertilizer components and pesticides in return flows, saline water intrusion into groundwater, fertility depletion, increase in weeds and pests in irrigated areas, and/or serious public health problems through an increased incidence of water-borne diseases (Feyen and Badji 1992; Keller 1992).

Despite the abovementioned constraints it seems impossible to feed the increasing number of people in the developing world without irrigated agriculture. As a consequence, there is a need for action on many fronts in order to improve the performance of irrigated agriculture. In agriculture as a whole and in irrigated agriculture especially, pricing and other policies need to provide incentives for production. There must be cost-effective access to agricultural inputs and markets. Besides the improvement of the general conditions for an increase in agricultural production, it is more or less agreed these days that the expected improvement in yield from irrigated areas of around 3 percent per annum can only be achieved by administrative and technological innovations and, where relevant, adaptations. This paper will focus only on technological innovations in irrigated agriculture.

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IRRIGATION TECHNOLOGY—STATE OF THE ART

Although many of the irrigation works built hundreds and even thousands of years ago are still evident throughout the world, and some are still in use, major changes to the water supply system and the traditional methods of surface irrigation took place only during the second half of this century. Most of the innovation has been in water lifting and in pressurized systems, where plastics, solid-state and computer controls have allowed significant advances. Only very recently has technological progress been achieved with respect to the water supply part of irrigation systems, especially in the development and physical improvements of flow control systems. A short overview is given below.

Technological Developments of Water Delivery Systems

The function of an irrigation water conveyance system is, according to Burt and Plusquellec (1990), to provide water in a timely and reliable manner so that water may be efficiently used for crop production. Furthermore, they state that the selection and management of water delivery systems affect agronomic and social aspects of projects. The control strategy must be compatible with the flexibility of the ultimate water supply, and the social, political, geographical and economic conditions under which it will be used.

According to Horst (1990) the crucial components of the irrigation system—the operational parts—are all structures for regulating, dividing and measuring the flows of water to the various parts of the project. Their type and characteristics largely determine the operability and subsequently, the manageability of the system. There is a great variety of structures available from simple overflow structures to automatically controlled systems. During the last decades, advances have been made mainly in terms of automation, and today systems are often based on automatic and remote control, computer models, advanced communication systems, micro processors, etc. Worldwide, the technology for microprocessor and computerized control of irrigation is much more sophisticated than its application. According to Horst (1990) the a priori choice of modernization by automation as a panacea for all irrigation problems should be considered questionable. It could even aggravate the managerial problem. Furthermore, this solution merely supports the never-ending struggle for farmer participation.

In many surface irrigation projects of the developed countries there has been a shift from small canals to pipelines for conveying irrigation water at secondary and tertiary levels. Pilot projects in Sri Lanka and Pakistan have shown that low pressure semiclosed and closed pipeline systems could solve many of the problems at the farm water level in developing countries by supplying water on demand (Merriam 1992).

Technological Developments of Farm Irrigation Systems

Water Lifting

For centuries, water lifting by mechanical means has been practiced around the world in irrigated agriculture. One of the most ancient, being the Archimedean Screw, is still in use on small farms in Upper Egypt. But there, as anywhere else around the world, farmers prefer to use motor-driven pumps to irrigate their fields, because motor pumps give farmers a greater spectrum of possibilities and more flexibility in irrigation.

The development of motor pumps has come a long way, but through improved manufacturing techniques, engineering principles, and new materials the performance of pumps has been dramatically improved while reducing the energy requirements due to increased efficiencies. Pumps are being produced in a great variety with a wide range of performance characteristics. There should be no problem for an irrigation farmer to find a pump and a motor, well adapted to the particular conditions of operation on his farm in order to obtain high efficiencies.

The centrifugal pump design has grown to become quite common in use for irrigation. It is very simple, durable, and relatively easily repaired and does a very nice job of pumping water within its design range of limited pumping head and flow.

Pumps are driven by internal combustion engines or by electric motors. Farmers prefer electric motors because of the ease of operation, low maintenance costs, dependability and the relatively long life. Frequent power interruptions and other uncertainties in power supply are major disadvantages associated with electric motors, especially in developing countries.

The cost of pumping irrigation water is governed to a large extent by the cost of energy. Since wind is a free energy source, its use to drive irrigation pumps has generated increased attention in recent years. In most cases, the use of windmills in pumping irrigation water has so far not shown to be economically feasible. This also applies to solar pumps.

Land Preparation and Water Recovery Technologies

Despite the tremendous increase of the area irrigated by pressurized irrigation systems, surface irrigation methods are still leading worldwide. They are expected to retain their popularity in the foreseeable future because of their:

- exclusive suitability in rice irrigation;
- low investment and energy requirements; and
- suitability to irrigate heavy soils like vertisols.

With the growing realization that comparatively high efficiencies can be achieved with surface systems, some significant advances can hopefully be expected in the near future. Developments during recent years include the following:

Land Grading

The introduction of heavy earth-moving machinery in irrigation land leveling and especially the introduction of laser-controlled leveling are probably the most significant advances in surface irrigation in the last 30 years. Fields can now be leveled to a near-perfect plane, allowing rapid application and removal of surface water. Moreover, leveled fields can be 'touched up' readily in succeeding seasons, after heavy fills have settled. The fitting of a plane or a mathematical curve to a land surface is most expediently done by computer calculation.

Tail Water Recirculation

Especially surface-irrigated fields frequently lose 10 to 30 percent and even more of the applied water as tail-water runoff, not to mention significant volumes of storm-water runoff. By the incorporation of the tail-water return system, comprising mainly of a channel or pipe to carry water from the lower end of the field back to the head of the system, the collected water can be used and the efficiency of the irrigation system increased.

On-Farm Storage

In Australia, according to Barrett (1985), the construction of large on-farm reservoirs has accelerated rapidly during the last two decades. Although most storages incorporate the tail-water return system, their prime purpose is for harvesting unregulated stream flows. The subsequent use of this water in producing various irrigated crops can be worthwhile, particularly if used in conjunction with allocated regulated flow. In addition, the storage provides the advantages of timeliness of application—especially for those irrigators with long lag times following water order—and the availability of a "buffer supply" for those occasions when ordered or allocated water does not arrive at all or is late. If water delivered is not required due to subsequent rainfall, it can be pumped to storage to avoid loss from allocation.

On-Farm Water Application Systems

Turnouts and Water Application Devices

The ancient and still prevalent method of releasing water from a delivery channel on to the field is to either allow water to overtop the channel banks or make a cut in the earthen embankment of the channel. These techniques allow the least control of the water. The result may be erosion of the embankment and complete loss of water control and because of this an uneven distribution of water from the delivery channel cannot be avoided. There is quite a large variety of turnouts available to overcome this constraint.

Remotely controlled devices have been developed for use with gravity irrigation systems. These devices include sliding, falling or rotating gates for controlling water levels in open channels, controls for pipe turnouts from channels, fixed overflow sills with appropriate water-level controls as well as devices for control of water level or individual openings in low pressure gated pipelines. Several valve configurations have been developed which require little or no external power to control flows from either underground or surface delivery pipes.

Siphons are increasingly and most successfully used in most advanced irrigation areas using surface irrigation, especially furrow irrigation. Here is a trend especially on larger farms towards the use of larger diameter siphons, up to 685 mm, or through-the-bank pipes (spills) of about 300 mm diameter, serving multiple furrows simultaneously (Barrett 1985).

During the last decades, several automated water application systems have been developed, cablegation being an example. Cablegation is an automated surface irrigation system in which a pipe is laid along the head of a furrowed field, with orifices drilled near the top of the pipe opposite each furrow. A moveable plug in the pipe blocks the flow of water, causing water to be emitted from a number of holes nearest the plug. The orifice nearest the plug delivers the maximum discharge, successively decreasing upstream. The initial furrow stream is therefore large, providing rapid advance. The furrow stream size continually diminishes with time as the cable plug advances along the pipeline. The plug is pushed downstream by the water pressure, with its speed governed by a braking device to which the plug is connected via a cable and reel. In general, the cablegation and other automated water application systems provide more uniform water application than is normally achieved with surface irrigation systems. The runoff is reasonably low and more readily useable because of its continuous nature. They are also intended to reduce the labor requirement and ease the work of the irrigation farmer.

Irrigation Methods

Level Basin Irrigation. Compared to other irrigation methods, relatively little progress has been achieved during the last decades, but still some interesting developments have taken place (Barett 1985; Huebener and Wolff 1990). Because of the developments in land leveling it became possible to apply level basin irrigation to larger fields or basins. Level basin irrigation is a method of applying water uniformly to a field by surface methods. It is used for crops planted on beds, furrows, corrugations or on the flat. Water is applied so that it will cover the basin relatively quickly. Dykes around the field keep the water within the basin so that all of the water infiltrates. Thus the water remains in all parts of the basin for about the same duration with only minor differences occurring because of the advance time required for the water to cover the basin completely. In low intake rate soils, predetermined depths of irrigation water can be applied precisely, resulting in high irrigation efficiencies. The method is limited to areas of low intensity or infrequent rainfall, due to surface drainage problems.

Surge Flow Irrigation. Under surge flow irrigation, water is diverted onto one set for 10 to 60 minutes; then diverted onto an adjacent set for a similar time period; and then again diverted back onto the initial set, etc. This technique results in the water advancing to the end of the field in roughly the same time as if the flow had run continuously, but with a substantial decrease in the volume of water needed. The method is most successfully used on silt loam soils resulting in a reduced variability between furrows and a higher distribution uniformity and all together leading to marked improvements in water application efficiency. The method may be of less benefit on cracking clay soils.

Sprinkler Irrigation. Sprinkler irrigation began early this century in the USA and Germany and was slowly introduced in other countries. Up to the 1960s, mostly portable handmove systems, stationary or to a lesser extent side-roll wheel move systems were in use. Traveling irrigators have become popular in many parts of the world from the mid-1960s. Although their use came under question following the rapid rise in energy prices during the 1970s and because of the problems in respect of the uniformity of application under windy conditions, the area irrigated by traveling irrigators has remarkably increased during the last three decades (Wolff 1988: Huebener 1988).

Probably the most significant development in sprinkler irrigation has come with the center pivot system. Early prototypes were developed in the 1940s, but it was not until the late 1960s and the 1970s that the most rapid expansion occurred, principally in the USA. The rise in energy prices in the 1970s forced a conversion from impact sprinklers to low pressure spray nozzles. Instantaneous application rates rose accordingly, causing problems especially on heavy soils. This problem has been overcome by fixing transverse spray booms under the lateral, again enlarging the wetted patterns. The center pivot provides high application uniformities and high efficiencies.

The limitations on farming and land utilization imposed by the circular patterns of center pivots have led to the development of side-move or linear-move systems. In addition to irrigating rectangular fields, linear-move systems can operate at lower pressures due to a constant rate of application along the lateral, compared to an increasing rate with a center pivot lateral. Water application and energy problems associated with center pivot and linear-move systems have led to a comparatively new concept in irrigation systems design, known as a low energy-precision application (LEPA) system. Rather than spraying into the air at moderate to high pressures, water is distributed directly to the furrow at very low pressure through drop tubes and orifice controlled emitters. This occurs as the system moves continuously through the field in a linear fashion. The system is used in conjunction with micro-basin land preparation which also optimizes the utilization of rainfall by minimizing runoff.

Sprinkler irrigation can also be used to protect tree crops from frost damage by coating the plant with ice. Since a stationary overhead sprinkler system is required covering the whole orchard to be protected, the costs of such protection measures are very high.

Drip Irrigation. Although the development of drip/trickle irrigation started shortly after World War II for irrigating crops in glasshouses, the use of this irrigation method in open fields began only in the 1960s. Under drip irrigation, plants are watered by means of low pressure pipelines (laterals) fitted with emitters, placed along the plant rows. A fixed system is generally used, and irrigation can be carried out frequently to maintain a minimum moisture stress and optimum growth. Labor requirements are low and the system lends itself readily to automation and the application of fertilizers and other chemicals through the system. The irrigation efficiency is high, since losses by evaporation are almost eliminated and percolation losses are low. Because of costs, drip installations are more or less restricted to wide-spaced crops, mainly orchards.

During the last three decades, the drip irrigation technology has been improved tremendously and other localized irrigation methods, like micro-jet and mini-sprinkler irrigation have been developed (Wolff 1987).

Drainage

Inadequate drainage followed by land degradation is a major problem associated with irrigation around the world, especially in arid and semiarid areas. In the last three decades, tremendous developments in the field of drainage technology have been achieved. Major developments in drainage technology include the use of durable, low cost plastics as replacement materials for clay and concrete drain pipes. Corrugation of the plastic pipe walls for increased strength/weight ratios, the use of flexible pipe to transfer live and dead loads to the encasing envelope of soil or other backfill material, longer lengths of drains, high speed trenchers and plows, and the standard use of laser grade controls have drastically changed drainage technology during the past decades. Computer programs also have been developed to solve complex and complete drainage system problems.

ADAPTABILITY OF MODERN IRRIGATION TECHNOLOGY TO DEVELOPING COUNTRIES

The Systems Context

The thrust of irrigation development in the industrial countries is on techniques that systematize management decisions, reduce labor inputs, and provide more precise and timely water applications. The socioeconomic factors driving irrigation technology development are the desire to reduce labor, management and resource input expenses and the need to increase agricultural output (Keller 1990). It has been shown above on an exemplary basis that new irrigation application hardware and software have been and still are evolving for managing, conveying and applying water to achieve these goals.

The question whether it makes sense to transfer those advanced irrigation technologies, which have been developed in a specific system context, to developing countries has been discussed most controversially on many occasions in the past and will most probably be so in the foreseeable future. A general answer to this question seems not possible since the conditions under which irrigated agriculture is performed in developing countries vary so widely and so does the feasibility of such a technology transfer. Therefore, each case has to be analyzed individually. One has to consider that technological innovations will only contribute to the development of the farming sector, and to the irrigation sector, especially if they can be integrated into the pertinent political, socioeconomic, cultural and ecological system context. An understanding of these systems is essential to identify problems on the technical, socioeconomic and scientific level and solve them through managerial and technological innovations and, where relevant, adaptations. Innovations which have not been deduced within a system context will probably not be transferable or will not bear the anticipated results.

In this respect, the system is the network formed through the interdependency of natural, technological and social factors. Agricultural production, especially in irrigated agriculture, takes place in a system context at international and national levels, at the level of the rural regions, at the irrigation project level, at the farm level and at the household level, the latter being of the greatest importance to start out from.

Technological innovations are translated into practice on the farms. Their practical application depends on the structure and function of the household and farming system, for example the family structure, availability of resources and individual function patterns. An analysis of economic and social systems in rural or irrigation areas provides knowledge of the total carrying capacity and of the capacity to absorb technologies in agriculture, especially in irrigation itself as well as in its upstream and downstream sectors. The national system, with its agro-policy, its agricultural constitution, service institutions, etc., strongly influences the willingness to accept innovation, but technology transfer cannot be induced solely by agreements and provision at the macroeconomic level.

Advantages and Constraints

Major advantages of modern over traditional irrigation systems in developing countries are, according to Keller (1990), potentially higher on-farm irrigation efficiencies and more precise control over water application. Coupled together, these can greatly increase crop productivity per unit of both land and water. Furthermore, this can be achieved with limited labor and drudgery and very little user expertise and skill. Precision irrigation requires money and management (of time and labor) with the latter playing the major role in traditional irrigation systems. For modern systems involving pressurization or precision leveling, money is traded for management and labor.

Despite the big advantages, modern irrigation technologies have their disadvantages, especially in third world countries. They usually require energy for mechanical pumping and special support systems to provide repair parts and mechanical services. These in turn require a continual and reliable source of fuel and maintenance. The more automated the technology, the more complex the required support structure for fuel, spares, repairs, etc.

Farmers who use modern irrigation technologies may not need much specific training to manage and operate them. However, they still must understand and adapt to the new principle involved and be aware of and follow through on the maintenance requirements. Furthermore, the technicians providing support services for complex irrigation machinery or components need special skills. This requires special training. In addition, the fuel, repair and maintenance required to operate modern systems cost money. Thus, the farmer must be involved in a cash economy or be continuously provided with fuel and mechanical services at public expense (Keller 1990).

According to Keller (1990) the principal dilemma in using modern irrigation technologies in developing countries is twofold. There is an apparent incompatibility with the management skills and a general lack of the necessary commercialization associated with diversified agriculture on small landholdings. The challenge is how to take advantage of the economics and benefits of modern irrigation delivery and application systems while preserving the vitality and human-initiative associated with privately operated small-scale farming enterprises.

By reviewing the field experience with modern irrigation technologies in developing countries the following three major lessons must be stated (Keller 1990):

1. Success often requires more attention than traditional farmers tend to give to the technical details required for equipment operation and maintenance;
2. For the successful uptake of modern irrigation there must be significant physical and agricultural advantages for using it, good market conditions, and considerable financial incentives for the users; and
3. Modern irrigation is not a panacea but it can play an important role in specific niches of irrigation development worldwide. The challenge is first to know when it is best

to use modern irrigation systems, then to select the ones with optimal fits and formulate the necessary institutional environment and supporting structures for successful operation when and where they are appropriate.

WHERE IS IRRIGATION TECHNOLOGY HEADING FOR IN DEVELOPING COUNTRIES?

James R. Moseley, the US Assistant Secretary of Agriculture for Natural Resources and Environment in the USA addressing a meeting of agricultural scientists in 1991 opened his speech with the following story. "Oliver Wendell Holmes, the distinguished U.S. Supreme Court jurist was once riding on a train and couldn't find his ticket. The conductor told him not to worry, he could send it when he found it. Holmes looked at the conductor with some irritation and said, 'The problem is not where my ticket is. The problem is where am I going?' " It seems to us that irrigation, especially irrigation technology in developing countries, finds itself in the same situation. Where is irrigation, especially irrigation technology in the developing world going to? Where should it go?

There are no quick answers available to the abovementioned questions. We do not have them either. But we have a hypothesis which we would like to put forward and discuss with you during this meeting.

Experts who predict world population trends tell us that the world's population is expected to reach over 6 billion by the year 2000 and over 8 billion by 2025. Most of the increase is expected to take place in developing countries; and what is even more dramatic is the fact that two-thirds of the total population growth is expected to occur in the cities. Big cities, particularly those with more than 2 million inhabitants, are growing ten times as fast in developing countries as in the industrial nations. Only more recently it has been recognized that the main cause of urban growth is not rural migration. Rather, it is the natural growth of existing urban populations. In rural areas of the developing world, a relative decrease of the agricultural population and an increase of the nonagricultural population can be noticed.

In our opinion the abovementioned trends will result in the following:

1. In the developing world, a relatively slow-growing agricultural population has to feed more and more people, especially people in and around urban areas. Therefore, the output of the agricultural labor force has to be increased by the introduction of appropriate technologies, including irrigation technologies which save labor and ease the workload of irrigation. Under no circumstances should irrigated agriculture be looked upon as having a capacity to absorb all the unemployed masses of people for which the national system is unable to provide enough industrial employment! The opposite will be the case.

2. Market-oriented production in agriculture will increase more and more, forcing the farmers to a more cost- and profit-oriented management. The need to reduce labor, management and resource input expenses and to increase the agricultural output will result in a drive to develop and use more sophisticated production technologies.

3. The necessary increase in food production will come, or has to come from land which is already under production.

4. The increase in food production will be achieved through

   a) an increase of inputs; and/or

b) a change from products of low energy output per unit area (grain) to products of high energy output per unit area (tubercrops).

Most countries will follow a) as long as possible.

5. In many countries, the increase of food production through an increase in inputs, will fairly soon reach a point where any further increase is going to be determined by the availability of water to the plants, so that irrigation will become a necessity if production is to increase. Water may become even more important than fertilizers.

6. Water as a production means will become increasingly scarce and expensive, making high on-farm irrigation efficiencies and precise control of water applications indispensable.

7. Because of the environmental problems associated with intensive agricultural land use one has to expect that traditional agricultural production practices including irrigation are being continuously questioned. An increase in the regulation of how to farm may be expected. Irrigation is not expected to be abandoned if sustainable land use is assured, which in most cases is only possible by applying advanced irrigation technologies.

8. With rising income expectations and standards of living, an increased agricultural yield level becomes necessary. This is why in the course of development, land which has been regarded up to this point, as fairly fertile, will become marginal land and the previous marginal land will go out of production. Agriculture and especially irrigated agriculture will concentrate more and more on highly productive land only. More food will be produced on an even smaller area. To obtain this more sophisticated production, technologies are necessary in developing countries.

From the assumptions mentioned above, it is concluded that more sophisticated irrigation technologies will have to be introduced into irrigated agriculture in developing countries in the years to come despite the problems of logistics. Since we cannot expect all the land being irrigated today to stay in production in the future, technological innovations will mainly affect irrigated agriculture on its most productive lands. Any investments on the more marginal lands will not be feasible.

So, irrigation in developing countries will, in our opinion, be heading towards the application of more sophisticated labor and land substituting irrigation technologies. This will not necessarily mean computerization and automation.

The trend to more sophisticated irrigation technologies may not be always clearly noticeable. Emphasis on irrigation technology is not static and is shifting as time goes by. This is because of the changing needs and desires of the society of the population. For example, during periods of surplus farm products, emphasis is on production efficiency; whereas, during periods of farm product deficits, emphasis is on increasing crop yields. During energy crises, emphasis is on energy efficiency, while environmental concerns result in placing emphasis on quality of soil, water and air. Because of this shifting emphasis one can notice ups and downs and changing directions in the technological developments in agriculture and especially in irrigated agriculture. Nevertheless, we are convinced that in the long run more and more sophisticated irrigation technologies have to and will be introduced into irrigated agriculture.

SUMMARY AND CONCLUSIONS

To innovate irrigated agriculture in developing countries towards sustainability is a serious concern of numerous research and development efforts. The approach has been so far twofold by distinction between managerial and technological concepts, with the former receiving lately more attention than the latter. In other parts of the world, irrigation technology advanced considerably during the past decades. After progress in water lifting and pressurized field application systems, i.e., optimized pump and well design, laser leveling, surge flow, localized irrigation, center pivot design, etc., very recently, notable improvements in water delivery systems have been achieved, i.e., automatized canal regulation, low pressure semiclosed or closed pipe delivery systems, delivery on demand, etc.

Now it seems to be the time to adapt these modern irrigation technologies to developing countries. Actually these processes have already started in several developing countries, for example the introduction of center pivot systems to Egypt, Burkina Faso, etc. Adaption really means a thorough process of transfer and modification to site-specific conditions, and for some cases the often misused definition of an "appropriate technology" must be revised. Action has to be taken in this respect at the farm level with all necessary considerations of the system context. Since agricultural production is based on the same rules of economics as industrial production, i.e., input optimization and profit maximization, it would be most contradictory to vote for labor-intensive irrigation in the long run, especially under conditions of low-food-price policies as in developing countries.

Sustainability in irrigated agriculture calls for a holistic approach with new, but precise initiatives and concepts combining technological and managerial measures.

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