Economic Considerations in Choosing Irrigation Systems

Hellmuth Bergmann*

INTRODUCTION — PROJECT APPROACH

The concept "irrigation system", within the context of the economic considerations expounded in this paper, should be taken to mean the final on-field water use system, e.g., surface irrigation, sprinkler irrigation, drip irrigation, etc. The economic advantages and disadvantages can be evaluated only in the context of the total irrigation project, comprising water storage, water transport and water distribution up to the fields because, if well conceived, the final water use (irrigation) system has an impact on all up-stream installations.

Economically, it is wrong to consider the advantages and disadvantages of the irrigation system alone without taking into account its influence on total water consumption, total investment costs for storage and transport, distribution, and operation and maintenance costs.

IRRIGATION SYSTEMS CONSIDERED — DEFINITIONS

For the sake of brevity and clarity, this paper does not attempt to consider every type of irrigation system. It has been thought preferable to confine our evaluation to the most important ones, which are in order of technical sophistication:
— surface-furrow irrigation;
— transport and distribution by earthen canals only;
— transport and distribution by lined canals or canalettes.

In all cases accurate land leveling and grading are necessary. It is supposed that the distribution system is a rational one, i.e., that canals follow the optimal contour lines and not the boundaries of properties. This is, of course, only the case if one is dealing with a completely new project or if, as in Greece, thorough land consolidation[1] is to be carried out.

* Chief Technical Adviser, European Investment Bank, L-2950 Luxembourg.

Sprinkler irrigation

For sprinkler irrigation, water is transported by a buried pipe system to the fields. On-field distribution is effected either
— by a mobile network;
— by a fixed installation (buried pipes—solid set).

In both cases, it is necessary to distinguish between water distribution on a fixed schedule or on free demand. The latter means that every farmer is at liberty to irrigate whenever he likes. The calculation of secondary and tertiary networks must be based on the probability formula for water distribution, elaborated by René Clement, and the most probable daily utilization rate fixed in advance. In this context, it should be borne in mind that it is absolutely unrealistic to believe that farmers use the system for a uniform 14 or 18 h/day. According to our experience, the effective time varies between 8 and 13 h/day.

Drip irrigation

Drip irrigation comprises many kinds of localized irrigation, including drippers, microjets, etc. It is not the purpose of this paper to go into details, such as the need for more or less sophisticated filtration and the advantages of different types of dripper or jet.

FACTORS TO BE CONSIDERED

The irrigation methods mentioned above have an important influence on the total design, operation and production of the system as a whole. It is therefore useful to analyze in relation to each irrigation system the following factors:
— water consumption;
— investment costs;
— social factors;
— operation and maintenance costs;
— time element;
— land use and yields;
— ecological factors.

Method used

The economic value of the above factors depends so much on local circumstances that is is impossible to present exact cost figures for the different items and systems. Economic evaluation depends on local circumstances in terms of availability of water, which can be scarce or abundant, on the cost of labor, cement and other construction materials, prices for agricultural input and output, as well as relief, soil, climate, etc.

Assuming other factors to be equal, it is possible to establish orders of magnitude for each item in order to illustrate the most advantageous and the most disadvantageous irrigation system. All other systems can be ranked in between these two extremes with ordinal numbers. However, it must be borne in mind that the ordinal numbers have no absolute value and do not indicate a cardinal difference between one or the other system (Table). Identical numbers have no significant difference, 1 indicating the most economical system with regard to the item under consideration. The method used here is therefore designed to compare systems, without undertaking any economic evaluation of the total project, and to calculate project profitability[2].

ECONOMIC, SOCIAL AND ECOLOGICAL EVALUATION OF DIFFERENT SYSTEMS

Water consumption

The most important feature is probably water consumption. A distinction should be made between the requisite total volume per ha and per year, the effective discharge in liter/s/ha during the peak demand period, and water productivity, i.e., water consumption per t of produce.

Drip irrigation has the lowest water consumption per ha as a result of its low losses during transport and on the field and because of the low evaporation rate. Surface irrigation systems with earthen canals have the highest water consumption per ha due to high losses during water transport and in the field.

If the effective discharge per liter/s/ha, is considered, then the order is not exactly the same. Again drip irrigation is the best; surface irrigation with earthen canals needs the highest effective discharge because of its low water efficiency. Sprinkler systems on free demand, either mobile or fixed, need a higher discharge rate than the same systems operated on a tight schedule. The effective use of the system is in practice limited to 10—14 h/day, which means that the effective discharge will be about twice as much as for systems on schedule where the sprinkler system can be used during a full 24 h day. If left to decide for themselves, farmers usually prefer to irrigate after breakfast and before lunch, etc.

Sprinkler systems with a mobile network have higher losses and a shorter effective time of utilization than systems where the final distribution network is fixed. Water losses with a mobile network increase because of imprecisely moved laterals, and the time to transport the mobile network from one place to the other shortens the effective irrigation time.

Water productivity is of the same order of magnitude as the total volume

Table. Economic, social and ecological advantages and disadvantages of different irrigation systems

Items to be considered	Surface-furrow irrigation by: earthen canals	Surface-furrow irrigation by: lined canals/canalettes or low pressure buried pipes	Sprinkler irrigation with mobile network for on-field distribution: on schedule	Sprinkler irrigation with mobile network for on-field distribution: on free demand	Sprinkler irrigation with fixed network for on-field distribution: on free demand	Sprinkler irrigation with fixed network for on-field distribution: on schedule, automated	Drip irrigation microjet automated
a. Water consumption							
1. Total volume per ha/year	7	6	4	5	3	2	1
2. Effective discharge liter/s/ha	7	6	3	5	4	2	1
3. Water consumption per t of produce	7	6	4	5	3	2	1
b. Investment costs per hectare							
1. Main reservoir	7	6	4	5	3	2	1
2. Water transport, main canals, etc.	6	5	3	4	4	2	1
3. Pumping stations; discharge/pressure	5/1	4/1	2/3	3/3	3/3	2/3	1/2
4. Distribution network (sec. + tert.)	1	2—3	3	5	5	4	4
5. Leveling/on-field distribution works	2	2	1	1	3	3	4
6. Total investment costs	4	3	1	4	5	2	1
c. Social factors							
1. Quantity of labor needed	6	4	5	5	2	1	3
2. Physical effort of workers	3	3	4	4	1	1	2
3. Techn. education of staff/workers/farmers	2	1	3	3	4	5	6
4. Irrigation at night	4	4	3	2	2	1	1
d. Operation/maintenance costs							
1. Energy consumption, if any	2	1	4	5	5	4	3
2. Maintenance: distribution network	4	3	1	1	1	2	2
3. Maintenance: leveling, field distribution	6	5	3	3	1	2	4
e. Time element							
1. Construction time	5	6	1	2	3	3	4
2. Adaptation time	3	3	3	4	2	1	1
3. Lifetime (technical)	1	2	4	4	3	3	5
f. Land use							
1. Flexibility after installation	2	2	1	1	3	3	4
2. Suitable for cereals	no	no	yes	yes	0	0	no
3. Suitable for maize	yes	yes	yes	yes	0	0	0
4. Suitable for forage, pasture	no**	no**	yes	yes	yes	yes	no
5. Suitable for potatoes, sugar beet, cotton	yes	yes	yes	yes	0	0	0
6. Suitable for vegetables	yes	yes	yes	yes	yes	yes	yes
7. Suitable for fruit trees	yes	yes	yes	yes	yes	yes	yes
8. Yield per ha	5	4	3	3	3	2	1
g. Ecological factors							
1. Risk of salination, drainage needs	4	3	2	2	2	2	1
2. Risk of erosion	4	4	2	3	3	2	1

* The numbers in each column are ordinals and give the rank, not the magnitude of the different irrigation systems for each item, 1 being the most economic (lowest cost or highest gross product). Identical numbers mean that there is no significant difference between systems from this particular point of view. "0" means "possible" under certain conditions.

** Irrigable by border/strip irrigation or flooding.

consumed, but cardinal differences will be much more important depending upon the length of the time between water applications. With surface irrigation, water is used once or twice a month, with sprinklers once or twice a week, and with drippers the soil can be irrigated every day.

However, it should be borne in mind that for most crops the water production curve is not linear but concave which means, for example, that with 70% of the optimal amount of water one can produce 95% of the maximal obtainable yield. This is often the case both for total water demand for each season as a whole and for peak demand during the critical week or month.

Therefore, peak demand, on which the maximal discharge for the total project and system is based, should be calculated with reference to precisely checked water production functions for each crop, i.e., not simply with reference to formulae based on evapotranspiration.

If the water production function is as mentioned above, it is self-evident that with the same amount of water one can produce either 100% on a given surface or 136% on 143% of the surface. If water and not land is the limiting factor, it may well pay to equip a larger surface with a network rather than to aim for the highest yield per ha.

The peak discharge (liter/s/ha) determines the capacity of all the installations (transport, compensation reservoirs, distribution) and therefore their cost and dimension should be calculated carefully and without any safety margins. Overload a bridge and it will collapse but the same does not apply to irrigation systems or the plant serving them. They easily adapt to a lower than optimal water supply.

Investment costs per hectare

The total water consumption has a direct impact on the size of reservoirs, pumping stations, etc. Obviously, the reservoir will be far bigger per ha for surface irrigation systems with earthen canals and can be far smaller for drip irrigation. Next, comes the sprinkler irrigation system with a fixed network which operates on schedule and is fully automated and designed to adapt irrigation exactly to crop/plant needs. As a closed system, this makes for relatively low water losses. On the other hand, with free demand, water losses can be higher, particularly if the distribution network is mobile. This factor can be compensated by the fact that with free demand system farmers often use less than the recommended amount of water, but may then have a lower yield or may not irrigate the total irrigable surface. The same considerations hold more or less true for the main water transport system.

As far as the pumping stations are concerned, a distinction should be made between discharge and pressure. Discharge (flow) will necessarily be at its highest in the case of surface systems with earthen canals, should be at its lowest in the case of drip irrigation and should be somewhat higher for on-schedule systems, but much higher, of course, for the free demand systems with relatively shorter irrigation periods per day.

Surface systems call for very low pressure as, next in line, does drip irrigation if little filtration is necessary, whereas sprinkler irrigation systems call for the highest pressure, particularly if irrigation machines or rain-guns are used. But if heavy filtration (3 steps) is needed, drip irrigation may require as much pressure as medium-sized sprinklers, whereas recently low-pressure irrigation machines have been developed combining the merits of self-propelled systems with those of localized irrigation systems.

The distribution network to the fields is, of course, not very expensive for earthen canals (built by the farmers). Lined canals or canalettes are more expensive, and nowadays sometimes very expensive. The costliest distribution systems are those needed for sprinkler systems on free demand because of the high effective discharge resulting from:
— the short time taken to irrigate, less than that taken to transfer the mobile network;
— the fact that the system should allow for the most probable peak demand.

Fixed automated networks operating on a tight schedule definitely call for less capital investment than free demand systems[3]. According to our experience, savings on the distribution network more than pay for the higher cost of the permanently installed field networks, drip irrigation included!

With regard to on-field works and systems (including land leveling for furrow irrigation), investment costs for mobile networks are the lowest. Drip irrigation seems to be more expensive than fixed sprinkler irrigation networks. With modern earth-moving equipment, land leveling costs are normally lower than is the case for all other field distribution systems, except for mobile networks.

In summary, it seems probable that (a) sprinkler irrigation with a mobile network for field distribution operated on schedule and (b) drip irrigation have the lowest total investment costs, whereas sprinkler irrigation on free demand with a fixed irrigation network for on-field use has the highest investment costs. In other words, it does not necessarily follow that the most sophisticated irrigation systems are also the most expensive ones, if you take into account all possible investment cost savings through low water consumption and low pressure.

Social factors

Four different points should be considered:
— quantity of labor needed in terms of man/days/ha;

— physical effort during the operation of the network;
— need for a high degree of technical education for staff, workers and farmers;
– irrigation at night.

Obviously, surface irrigation with earthen canals calls for the most manpower, but needs less skill to operate and maintain the system. The physical effort required for the irrigation itself is not very great ,but the annual cleaning of canals is arduous work. Furrow irrigation with lined canals needs even less skill because these are easier to maintain than earthen canals. Contrary to some opinions, sprinkler irrigation systems, where mobile laterals have to be moved by hand twice or three times a day, call for a high man/day ratio per ha, and the physical effort is far greater than that needed to open and close the furrows of a surface irrigation system, particularly if the water can flow through siphons directly from the canalette into the furrow. This explains why semi-fixed systems (pipe-hose, tow-line, etc.) have been developed, although, for the sake of brevity and simplicity, these are not considered here.

The lowest demand in terms of man/day and physical effort is made by the sprinkler irrigation system where the field distribution network is permanently installed and the total system automated. Drip irrigation needs a higher labor input because the control of drippers and the cleaning of filters are more labor-intensive, but self-cleaning filters and drippers are now on the market and sophisticated electronic remote control systems greatly reduce the necessary labor input.

On the other hand, drip irrigation, particularly if fully automated, calls for very highly trained staff, maintenance workers and farmers. This is almost equally true of permanently installed automated sprinkler systems.

The least sophisticated system is surface irrigation with lined canals or canalettes. The technical quality of maintenance staff and farmers is of key importance: sometimes modern irrigation systems with automatic pressure regulated pumping stations (Venturi system) do not function because the country in question has too few electrical or electronic engineers to operate and maintain the pumping stations. Furthermore, the farmers do not understand how the system works and what rules they have to respect. The system finally opted for must therefore be compatible with locally available engineering and farming skills. A heavy input of training is desirable but becomes absolutely essential for staff, operators and farmers if distribution and field systems are to be automated. Training should be repeated and supplemented by an efficient advisory service.

Operation and maintenance costs

Operation and maintenance costs depend upon investment costs, the

technology adopted and staff and manpower requirements. Three factors should be taken into consideration:
— energy consumption, if any;
— operation and maintenance of the distribution network;
— maintenance of the on-field works and leveling.

Energy costs will be the lowest for surface irrigation systems with lined canals, the highest for sprinkler irrigation systems operating on free demand and almost uneconomic for rain-guns.

Maintenance of the distribution network is simple and not very expensive for sprinkler irrigation systems, although more expensive when these are automatically operated. Surface irrigation systems call for a rather high degree of distribution network maintenance, particularly if water is distributed in earthen canals. In this context, the maintenance of the drainage canals, which are prerequisites for all surface irrigation systems, should not be neglected.

Keeping the slope of the fields exactly right for furrow irrigation is extremely demanding. Only by using special plows and undertaking regular regrading can the leveled surface be maintained. Otherwise, water distribution on the field will be uneven and the yield about 20% lower. Fixed sprinkler irrigation systems have low maintenance costs, whereas the mobile network is very often subject to damage. Drip irrigation involves high maintenance costs and expensive spare parts (filters, drippers, etc.). Furthermore, the plastic tubes have a comparatively short life and are often attacked by mice and rats.

Time element

In all economic calculations, the time element is of great importance. A distinction should be made between:
— construction time;
— time needed after construction to arrive at normal utilization of the irrigation system (adaptation time);
— lifetime of the project.

With modern equipment (trenchless pipe-laying machines, etc.) it should not take long to install underground pressurized networks. Surface irrigation systems take the most time to construct because of the prefabrication of canalettes and the more complicated type of civil works.

As far as the time taken to make full use of the new system is concerned, this is probably the shortest with fixed, installed on-field systems, provided that the installations (solid-set, drip) are constructed simultaneously and, where possible, by the same contractor as for the distribution network. The on-demand systems need more decision-making input from the farmers and therefore take more time to develop. Surface irrigation systems occupy a medium position.

However, it should be noted that only under very favorable circumstances are public irrigation systems put to use quickly. Individual farmers normally need time to learn how to irrigate, how to cultivate new crops, sometimes how to conserve fodder for livestock breeding. Where tree crops are to be irrigated, the plantation time extends over several years, for technical and financial reasons. The financial input by farmers in terms of investment capital and added working capital is high when switching over from dry cultivation to irrigation and has to be phased over 5—15 years, depending upon land use, the type of irrigation system and the need for new buildings.

The period during which projects and systems should depreciate (the technico-economic life-span) is generally overestimated. Most public authorities base their calculations on a lifetime of 50 years for the networks and often a 100 years for reservoirs. But some of these are already filled with silt after 25 years and the surface irrigation systems (earthen canals and also canalettes or lined canals) constructed during the fifties and at the beginning of the sixties are now in need of "rehabilitation", i.e., complete replacement by an underground pressurized pipe network.

The sprinkler on-demand systems of the seventies are now complemented by fixed on-field networks, drip irrigation and automation.

Drip irrigation and remote electronic control systems, in particular, have short depreciation periods. Technically, earthen canal systems could be maintained endlessly, but depreciation is also an economic problem and long before the effects of corrosion, etc. become evident, it is technical progress that renders all systems economically obsolete.

Land use

It is not always clear which crops will be irrigated. The flexibility of the system is then of very great importance. The most flexible system is sprinkler irrigation with a mobile network which can be used for practically any crop, trees included. All that needs to be decided is whether sprinklers should be low or high. Surface irrigation systems, which allow for irrigation of almost all crops, are also very flexible. Sprinkler irrigation systems with a fixed, installed, on-field distribution network are most suitable for lucerne and pasture, vegetables and fruit trees, but can also be used for cereals, maize and industrial crops, with the disadvantage, however, that the sprinklers hinder the use of large machinery, in particular for land preparation and harvesting. As far as labor is concerned, when the time comes for mechanized harvesting the sprinklers can, of course, be removed provided that pipes are buried.

Drip irrigation is probably the least flexible system and should be used mainly for high value crops (vegetables or fruit trees). Drip has been adapted to sugarcane and cotton in some countries. It can also be adopted for maize and industrial crops, but this requires annual installation of the field distribution network which, of course, more or less hinders hoeing, etc. This disadvantage is largely compensated by the high yields which can be achieved by drip irrigation, particularly if water productivity is taken into consideration. Fully automated, fixed, installed sprinkler irrigation should provide almost similar yields per ha, but with a higher water consumption. The lowest yields are obtained with surface irrigation because of the irregular availability of water and the stress put on the crops/plants.

Drip and sprinkler systems can both be used for fertilization and crop protection (chemigation), but drip irrigation is technically more advanced and results in higher productivity from fertilizers.

Ecological factors

Ecological factors should also be taken into consideration. Salinity and erosion are two major concomitant risks of different irrigation systems. These can easily lead to salination and alkalinization of soils if the drainage system is not adequately constructed and maintained and if farmers do not pay attention to leach-accumulated salts. Drip irrigation has the great advantage of not creating any erosion problems and of allowing the use of water with a comparatively high salt content, because soil humidity can be maintained at a suitable level. However, in this case, natural and/or artificial leaching by other irrigation systems during the off-season will be necessary. Sprinkler irrigation systems can be installed and operated in such a way that erosion and salination will not be a problem. They nevertheless offer more risks than drip irrigation, but again, drainage must be adequate. Rain-guns are particularly risky as far as erosion and soil structure are concerned.

CONCLUSION

It is impossible to state in an apodictic manner which irrigation system is the best. Individual decisions must take all the abovementioned factors into consideration, any one of which may limit the number of suitable systems.

The Table can be used to evaluate the economic, social and ecological factors applicable to the different systems cited. Obviously, this paper has not covered every available system or the numerous intermediate technical solutions designed to adapt systems to local conditions.

Two further points are noteworthy: first, all economic calculations should be based on the total project in terms of the impact on the population as a whole and the farmer himself. The results may vary considerably because of subsidies, taxes, levies, inflation or artificially fixed exchange rates. Second, the economic profitability of irrigation projects, commonly expressed as the

Internal Rate of Return (IRR), is sensitive to all the abovementioned factors. Some of these, such as the technical education and qualification of staff and farmers, salination, erosion, availability of water or land use, may eliminate one or another system right from the start. Still others influence profitability to varying degrees. Contrary to what is generally thought, total investment costs have a relatively minor influence. Overall operating and maintenance costs are far more important; for both factors, we can say that a 10% increase will decrease the IRR at the same rate, i.e., from 10% to 9% (in real terms).

Completely neglected by the public authorities but of far greater importance is the time element. Doubling the investment period or the adaptation time may remove all or any element of profit from the project, i.e., the investment capital will have been wasted.

The most important factor is the gross product obtained, i.e., yield x price, with agricultural output depending on the efficiency and productivity of the system, and producer prices determined by quality and the market situation.

Any steps to shorten construction and adaptation times both increase the quantity produced (higher yields and/or larger surface irrigated) and improve their quality. Therefore, a good advisory service, ready availability of credit for every farmer and an efficient marketing system are economically more than justified.

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