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TECHNICAL INTERVENTIONS TO IMPROVE WATER USE EFFICIENCY IN IRRIGATED AGRICULTURE

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SUMMARY - The increasing scarcity of water in the dry areas of the Mediterranean is now a well recognized problem. High rate of population growth and economical development require continuous diversion of agricultural water to higher priority sectors. The need to produce more food with less water poses enormous challenges to transfer existing supplies, encourage more efficient water use and promote natural resources conservation. On-farm water use efficient-techniques if coupled with improved irrigation management options, better crop selection, appropriate culture practices and timely socio-economic interventions would help achieving this objective. In arid and semiarid countries of the region, water is a more limiting factor to production than land; hence, maximizing water productivity should have higher priority over maximizing yield in the strategies of water management. This implies that planning water and land use should be based on the comparative advantages of the dry areas, but, within the framework of maximizing the return from the limited available water resources. Achieving the greatest water productivity needed to resolve water shortage problems will not happen automatically. There is great need to find appropriate ways and proper tools for water saving and to achieve greater efficiency and equity in the irrigation system. Equally, procedures and practices for the assessment of the performance of irrigation must be improved with better management systems for water conveyance, allocation and distribution. Such issues, beside others, will be addressed in this paper, with major emphasis on the technical interventions that could be adopted in order to increase water productivity through water saving and the improvement of the rates in water use efficiency in irrigated agriculture.

Key words: water use efficiency, irrigation.

INTRODUCTION

The availability of freshwater is, today, one of the great issues facing the human kind, and in some ways the greatest, because problems associated with its availability affect the lives of millions of peoples, particularly those in the developing countries. In the Southern and Eastern countries of the Mediterranean, the agriculture sector is, by far, the largest water user. On a consumptive-use basis, 80 to 90% of all the available water resources are consumed by the agriculture sector. However, average losses in the irrigation projects suggest that only about 45% of the delivered or extracted water for irrigation actually reaches the crops. Very often, the conveyance losses of conduits (unlined canals or leak pipes) are much too large, a 30% losses of the available water is common in the irrigation systems.

Another cause of inefficient water use is the emphasis on meeting the demand by constructing new supply facilities rather than improving the inefficiencies of the existing ones. Furthermore, for most countries of the Mediterranean, on-farm irrigation practices deliver significantly more water per unit area that what is required, leading to such low irrigation efficiencies.

Up to now, water conservation and efficient use of water have not been given the attention they deserve. As agriculture is, by far, the largest water user, efficient irrigation management will undoubtedly be a major conservation option in the future. An increase in water use efficiency in the agriculture sector will serve a double purpose: it will free sufficient amounts of water for alternative industrial uses, while at the same time, it is quite possible to take away a certain amount without scarifying food production. In deed, it is possible to produce “more out of less”, but, this requires finding out the appropriate ways to achieve greater efficiency and equity in the irrigation systems.

Several issues were recommended as proper tools for the improvement of irrigation efficiencies; among those issues: lining canals, improvement of irrigation structure, modernization of irrigation systems, … etc. However, as irrigation efficiencies are basically ratios of volumes in the water balance of an irrigation system, concentrating mainly on the relationships between the components of the water balance of the irrigation system and the factors that might influence these relationships, it is not always realistic to expect increased efficiencies.

There are other factors related to irrigation efficiencies such as management of the crops, socio-economic and legal environment of the irrigation systems, capacity building in the irrigation sector and quality of the water. These factors, together with the ones related to the components of water balance, should be fully considered in all the programs and projects dealing with water use and efficiency improvement in the irrigation sector.

Indeed, efficient use of irrigation water "more crop per drop" and improving the productivity of water in agriculture through an appropriate water management is not an easy process. Significant challenges still remain in the areas of technological, managerial and policy innovation and adaptation, human resources development, information transfer and social environment considerations. Our success and/or failure is a matter of our capability in finding sustainable solutions to the challenges we are facing.

WATER USE EFFICIENCY IN IRRIGATION

Efficiency in the use of water for irrigation consists of various components and takes into account losses during storage, conveyance and application to irrigation plots. Identifying the various components and knowing what improvements can be made is essential to making the most effective use of this vital but scarce source in Mediterranean agricultural areas.

Generally speaking, efficient water use is defined as the ratio between the actual volume of water used for a specific purpose and the volume extracted or derived from a supply source for that same purpose.

Functionally expressed, we have: $Ef = \frac{Vu}{Ve}$

where: Ef - Efficiency, dimensionless
Vu - Volume utilized, m^3
Ve - Volume extracted from the supply source, m^3.

In this case, water use efficiency refers exclusively to irrigation. In accordance with the definition proposed by the International Irrigation and Drainage Committee (quoted by Burmau et al., 1981) efficiency in the use of water for irrigation has several different components (Table 1).

It is not redundant to insist on the fact that one can properly judge the hydraulic performance of irrigation only when both its efficiency and its effectiveness are assessed.

The product of the three types of efficiency (Table 1) is the total efficiency of water use of irrigation Ei. Functionally expressed, we have:

$$Ei = Es\ Ec\ Eu$$

The term of irrigation efficiency, which is different from efficiency of water use in irrigation, is also used. According to Israelsen (1963), such efficiency is expressed as:

$$Ea = \frac{Vt}{Up}$$

where Vr is the volume of usable water stored in the exploration zone of the plants' root, Vp is the volume received by the plot and Ea is the irrigation efficiency. Also if we consider the volume of runoff loss and E and the seepage loss as D then this efficiency can also be expressed as follows:

$$Ea = \frac{Up - E - D}{Up}$$

Irrigation efficiency has several different components (Table 2). Losses in the distribution system are due to leakage and evaporation; losses during application to the field are due to wind, evaporation and runoff, and losses from the soil are due to excess water, applied beyond what the crop uses.

Table 1 - Components of efficiency of water use in irrigation

1. Storage efficiency Es.
$Es = \frac{Vd}{Ve}$ – Ratio between
The volume diverted for irrigation (Vd) and the volume entering a storage reservoir (Ve) for the same purpose.
2. Conveyance efficiency Ec
$Ec = \frac{Vp}{Vd}$ – Ratio between
The volume of water delivered to irrigation plots (Vp) and the volume diverted from the supply source (Vd).
3. Irrigation efficiency Eu.
$Eu = \frac{Vu\ (*)}{Vp}$ – Ratio between
The volume used by plants throughout evapotranspiration process, Vu, and the volume that reaches the irrigation plot, Vp.

* (Vu) is equal to the volume of evapotranspiration by plants minus the volume of effective rainfall.

Table 2 - Irrigation efficiency factors

1 - Conveyance efficiency - ratio of water delivered to water diverted from source.
2 - Application efficiency - ratio of water reaching the soil to water diverted.
3 - Water use efficiency - ratio water available for the crop to water applied to soil.

IRRIGATION EFFECTIVENESS

As defined above, irrigation efficiency is an indicator of how much water is being lost in the process of irrigation and nothing more. It is a usual and misleading habit to take irrigation efficiency as an indicator of the overall hydraulic performance of a system. There is a tendency to think that as long as efficiency is high, the system is performing well overall. However, one can easily get very high efficiencies if he under-irrigates over the entire field, in which case there is in fact a bad performance.

Effectiveness is another criterion of performance in that it indicates the degree of achievement of the desired irrigation objective, consisting of replenishing the root zone after depletion by root extraction.

In general terms, effectiveness is usually defined as the ratio of output achieved to the target or desired output. It is thus a measure of the degree of achievement of a fixed desired objective. In the case of irrigation, effectiveness can thus be defined as:

$$Ef\ (\%) = \frac{Amount\ of\ water\ stored\ in\ the\ root\ zone}{Soil\ moisture\ deficit\ before\ irrigation} \times 100$$

Ef is a parameter which may vary from 0 to 100% and is actually an indicator of the degree of under-irrigation since it falls below 100% in such a case. Walker and Skogerboe (1987) referred to this same criterion as water requirement efficiency and in other instances it is termed storage efficiency.

Another criterion which has also been used for judging the extent of under-irrigation and which is area-based rather than volume-based is the percentage of area adequately irrigated (Pa) which can be defined as:

$$Pa\ (\%) = \frac{Area\ with\ root\ zone\ replenished}{Total\ irrigated\ area} \times 100$$

The drawback of this criterion is that while it indicates the spatial extent of under-irrigation, it does not give any indication on the severeness of under-irrigation. One can thus theoretically have a root zone that has been replenished to a level of 95% over the entire field, in which case Ef will be 95% while Pa will be 0% since no point on the field would have had the root zone entirely replenished. Effectiveness is thus a better indicator of the fulfillment of the irrigation objective than is the % of area adequately irrigated.

GENERAL DISCUSSION AND CONCLUSIONS

The way to water saving and whenever possible to its re-use, is still open. From the purely technical point of view, important water savings are possible, if one thinks that under realistic conditions water efficiency can vary depending on the cases, the modes as well as equipment, for instance from 75% to 25% about, one understands that moving from the former to the latter value means to triple the irrigable surface at equal water use efficiency, with technologies and methods available today, agriculture could cut its water demand by 10 to 15 percent.

If one considers not only crop requirements and the pedological environment but also the fact that quite often the water saving techniques are labor-capital-energy-multiple-factors consuming techniques, on one hand, and the new concerns about environment and some social problems particularly related to the frequently low school levels of farmers, on the other hand, one understands indicate that the solution through water saving is not simple but a complex one.

To achieve a sound use of water for irrigation with higher efficiency and better water saving requires, on one hand:

- deeper scientific and technical knowledge which is still far from being perfect although using models which are hoped to be clearer and more and more widespread (Ait Kadi,1992);
- a more systematic and permanent monitoring of supplying unbased data at reasonable cost, on the other hand;
- a closer participation and collaboration of the whole technical environment and the involvement of the farmers in the implementation of the program for some tariffing criteria, or in the improvement of the modes of use of water (Abu Zeid, 1990-1992). A great equilibrium is necessary in evaluating the needs of the different user's groups and more flexibility and reconversion have to be ensured. As for the technical aspects again, it should be noticed that, however, irrigation is a tool used to maximize the general objectives of the whole agricultural management.

These are complex objectives, with a strong although not unique economic component, quite different depending on the type of enterprise and scenarios, changing over time and space. It is then very superficial and misleading to think of optimizing the use of water resource by maximizing only irrigation water efficiency (in terms of money) as such, this could be a utopian ideal of a given hypothetical owner of irrigation water only.

In practice some remarks are made: the first one is that the scenario where food demand is greater (countries with a high population rate) and the natural rainfall regime is more limiting (arid and semi-arid areas), the objectives of irrigation approach more the one of maximum water use efficiency; it is less so and more related to income, in the case of more developed countries.

The second is that the irrigation efficiency is the result of all interactions with other production factors and this may need adequate investments also in other factors (for instance, fertilizers, new varieties, modern machinery, etc...).

The third remark concerns the need to have a team of well specialized technicians available for irrigation, and then also the need to ensure training and update knowledge of these cadres.

It is a great effort and not only a technical scientific one. Cultural and social progress of the agricultural world should be promoted as much as possible.

Operation and maintenance (O&M) is one of the most underestimated aspects of irrigation projects in developing countries. As a result, the efficiency of the project continues to decline, and during a crisis situation, generally the problem faced is more complex to resolve technically and more funds have to be extended than had the maintenance works been carried out on regular basis. Another issue worth noting is the fact that poor though O&M is for irrigation, it is generally even worse in drainage.

The impending crisis of land and water scarcity by the turn of the century particularly in the arid and the semi-arid region of the Mediterranean countries implies that research should be oriented to cope with such alarming situation and to increase the productivity of available land and water resources in a sustainable manner. In this regard, the following teams of research are suggested:

1) - Modern Irrigation methods made appropriate to the least developing technological context: irrigation techniques have to be adapted and made appropriate to self-sustained technological improvements, taking into account economic, technical, maintenance and cultural aspects. Adaptive research is needed to modify the hardware of modern methods to permit local construction and engineering use of local and low cost materials and skills. The process will also help in enabling users to master the technologies and facilitate easier maintenance. Similarly the software modern methods would also need adaptation to accommodate cases where data are inadequate or unreliable.

Another topic which should be carefully considered is the regulation of land networks; its sequence regulation of water deliveries not only has the direct advantage of rising the crop yield but also contributes to control waterlogging and salinity, beside other advantages such as the reduction of seepage losses and sedimentation, control of disease vectors and the reduction of weed growth.

The introduction of pressurized irrigation systems as a tool for a better water saving and a better economy in fertilizer use and less pollution of ground water, is among the points that should receive the attention of researchers. Research is required to adapt such methods to specific soil, topographic ecological and social conditions in order to ensure cost-effectiveness and sustainability. A part of the research should be devoted to the rehabilitation and modernization of large systems, with the objectives of greater decentralized operations, improved water conservation, and reliable and equitable water delivery to self-managed groups. Systems now in operation will have to meet the challenges of water scarcity and hence of conservation; moreover, rapid changes in all aspects of the economy and in agriculture, call for systems that offer flexibility in crop production.

2 - Decision support at various levels: the potential decision support system (DSS) as planning, policy-information and operational tools at a national, regional and farmer level is becoming evident. At national and regional level, the combined use of models, remote sensing and geographical information system can help predict the effects of different policy scenarios and allow better management of existing land and water resources. At the farmer's level, DSS can help to improve crop production and irrigation efficiency.

Existing models should be further developed, improved and tested in different situations; also new models are required.

At the local level, research should focus on the operational use of models. Research is needed with respect to parameter estimation for different crops and soils and model calibration and verification in combination with field tests. Models should be adapted to the users by making them user-friendly (generation of input data, understandable output, etc.). Furthermore, attention should be given to the introduction of water quality aspects especially salinization into the soil-vegetation-atmosphere (SVAT) model.

3 - Sustainable use of marginal quality water: there is increasing awareness of the need to augment water supply and improve water quality through the use of the treated sewage and drainage water.

For a sustainable use of drainage and brackish water for irrigation, research work is needed on the physical parameters governing the flow of water and salt in the irrigated soil profile with an estimation of the risk of salinization through modeling and testing improved methodologies to reduce salinity through drainage. Research should be also directed towards the establishment of new strategies including different crop rotations based on proper soil, water and crop management that favor the reuse of drainage and brackish water in irrigation without deterioration either in crop production or soil productivity. Adaptive research programs should be planned on the recycling of used water which could lead to a great deal of progress, but which is still limited by the lack of research in this field. The approach appears to be promising and will enable the impact of scarcity to be minimized in times to come. A part of the program should include the waste water technologies and methodologies to achieve the most appropriate ones to be used in irrigation to produce an effluent which meets the recommended microbiological and chemical quality guidelines, both at low cost and with minimum operational and maintenance requirements.

An important aspect of the use of marginal quality water for plant production is the possibility of ground water contamination with undesiderable pollutants. Further basic and applied research is needed to preserve and/or to improve the quality of ground water from serious contamination. Lack of knowledge about long-term effects of treated waste water has to be searched; this will greatly encourage and facilitate its use in irrigation on a wider scale.

4 - Performance assessment, monitoring and evaluation of irrigation and drainage systems: one main reason for poorer economic performance of irrigation projects is deficiency in project planning and management. The result is a restricted budget for operation and maintenance, crucial the integrity and sustainability of an irrigation system. Research is needed to formulate a methodology for the collection, storage and processing of administrative, technical and environmental data required for an effective and efficient management of soil and water resources. The conveyance of information from evaluators to planners and designers creates a positive feedback mechanism leading to a better design which is another important area of research.

5 - Water optimization: crop water requirements and irrigation scheduling; efficient irrigation: in order to optimize water application by irrigation to different crops under different soil types, irrigation systems and climatic conditions, research should be continued to provide better knowledge of soil-water-plant relationships, reviewing the concept of an optimal water supply. The management of irrigated crops to cope with droughts should receive priorities in research. In addition the link between crop water requirements and irrigation schemes reliability should also be considered.

6 - Environmentally sound practices for sustainable land and water use: new approaches and methods are needed to solve some of the old problems in irrigation. These approaches need to be cost-effective and bearable by farmers in order to be ecologically and economically sustainable. Many fields of knowledge including engineering, biological science, and social science need to be drawn on the development of these approaches and methods.

Research is needed in areas like: control of soil erosion and soil fertility conservation, water conservation practices, economic criteria for irrigation and drainage of heavy saline and/or other problem-affected soils; also alternative crops and cropping systems better suited to problem-affected soils and other ecological constraints; integrated pest management and pest control; and development of irrigation management practices to cope with drought and aridity, including water conservation practices and the reuse of drainage and waste water for irrigation.

7) Socio-economic studies: management and design interaction in relation to community dynamic and local managerial capability: The design of schemes has traditionally been the domain of irrigation engineers whose concern has been to optimize technical efficiency of water use. The projected returns to such schemes are too often unrealized because they rely on an unrealistic precision in water allocation and water use across the design of irrigation area. Efforts need to be made to design schemes whose layout is simpler to be operated and managed by farmers and their communities. The challenge is for engineers to work with local farmers at whatever level of technology is appropriate, and design more manageable schemes to economize, where possible, to compare real social and

economic impact in relation to the money spent as between simpler and more complex designs under similar conditions.

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