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ending Challenge**

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Abstract

Most on-farm water management (OFWM) problems are not new. They have been a threat to agriculture in many countries around the globe in the last few decades. However, these problems have now grown larger and there is increasing public demand for the development and management of land and water to be ecologically sustainable as well as economic. As there is a close interrelationship between land use and water resources, farmers need to be aware of this interrelationship and adjust their OFWM efforts in order to address the issues. In their management efforts, they need to consider both the on-site and the off-site effects.

This paper highlights holistic approaches in water management as being indispensable in the future. Present and future water-utilisation problems can only be solved on the basis of an intersectoral participatory approach to water management conducted at the level of the respective catchment area. In the context of this approach, farmers need to realise that they are part of an integral whole.

The paper also lists a range of present and future challenges facing farmers, extension-ists, researchers, etc. in relation to OFWM efforts. Among the challenges are: the effects of the increasing competition for freshwater resources; the increasing influence of non-agricultural factors on farmers' land use decisions; the fragmentation of the labour process and its effects on farming skills; the information requirements of farmers; the participatory dissemination of information on OFWM; the process of changing permanently the agrarian structure; and the establishment of criteria of good and bad OFWM.

Keywords: On-farm water management, problems of on-farm water management, challenges of modern on-farm water management

Stichworte: Wassermanagement auf Farmebene, Wassermanagementprobleme, Herausforderungen eines modernen Wassermanagements

1 Introduction

Water, or the control of water, affects most crop production activities. Sufficient water must be present in the rootzone for germination, evapotranspiration, nutrient absorption by roots, root growth, and soil microbiological and chemical processes that aid in the

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decomposition of organic matter and the mineralisation of nutrients. These factors are all necessary for sustaining crop growth on a particular field. At the same time, the rootzone must be sufficiently dry to ensure adequate aeration and root growth. The rootzone must also be dry enough to allow field access for performing cultural practice activities such as planting, cultivating, fertilisation, pesticide and herbicide applications, and harvesting. Water movement through the soil is necessary in order to leach excess salts from the rootzone and so enable potential yields to be achieved. Farmers around the world are aware that farm-level land and water management practices are of prime importance for satisfying the needs of field-crop and other agricultural and horticultural ecosystems. Therefore, they endeavour to optimise the water supply of their crops within the limits of their knowledge and the farming operations practised. That is, over time, they have developed some sort of on-farm water management (OFWM) practices. However, farmers may often be unaware that conditions for the operation of farms are changing continuously. This has consequences for farm-level water management as **the** improvement of OFWM is a never-ending process.

This paper attempts to define OFWM, to discuss old and new OFWM problems, and to examine the challenges that farmers, extension personnel and researchers are most likely to face in the future.

2 On-farm water management, definitions and components

Water management can be defined as the planned development, distribution and use of water resources in accordance with predetermined objectives while respecting both the quantity and quality of the water resources. It is the specific control of all human interventions concerning surface and subterranean water. Every planning activity relating to water can be considered as water management in the broadest sense of the term

(INTERNATIONAL COMMISSION ON IRRIGATION AND DRAINAGE (ICID), 2000).

Therefore, OFWM can be defined as the manipulation of water within the borders of an individual farm, a farming plot or field. For example, in canal irrigation systems, OFWM starts at the farm gate and ends at the disposal point of the drainage water to a public watercourse, open drain or sink. OFWM generally seeks to optimise soil-water-plant relationships in order to achieve a yield of desired products. The managers (farmers) usually try to achieve this desired yield by minimising inputs and maximising outputs, so as to optimise profits. In order to accomplish this, water has to be managed skilfully through certain practices covering areas of: soil and water conservation, water application, drainage, soil amelioration, and agronomy. All this has to be done within the context of the socio-economic environment of the community and the farmer's personal situation. There are a range of tools available that enable the manager (farmer) to apply these practices.

When defining OFWM, it becomes clear that the term covers not the water resources, the irrigation facilities, the laws, the farmers' institutions, the procedures and the soil and cropping systems. OFWM is concerned with how these tools and resources are used and made available to provide water for plant growth. Moreover, it encompasses all the water used for that purpose, i.e. precipitation and water applied through irriga

tion. Furthermore, it includes the use of respective practices and tools to improve site conditions and to protect crops and farming property from excessive water (ABU-ZEID, 1979; IZUNO, 1997).

In the past, extensive research work in many countries has shown that, for example, in irrigated agriculture, good OFWM practices require well-levelled fields, appropriately designed on-farm distribution systems, and a good knowledge of when to irrigate and how much water to apply. Irrigated agriculture also requires a reliable source of water, readily available when needed, and in quantities that can be distributed effectively and efficiently over the farmer's field. In addition, soil amelioration measures such as sub-soiling and gypsum application may be necessary, as may a well-functioning drainage system. However, all this will lead to good OFWM only if the system as a whole is well managed, if the managers or farmers take the appropriate management decision at the right time, and if they make sure that the management decisions are indeed transferred into practice correctly and on time. Furthermore, part of the success of good OFWM depends on close communication and interaction among farmers and other water users of the respective catchment area as well as with the service providers and the water supply administration. This is especially the case if the measures taken on-site will be affected by off-site activities or will affect such activities.

3 Old and new problems

In addition to satisfying the needs of field-crop ecosystems, OFWM is of prime importance to soil and water conservation. However, field observations have shown that not all forms of OFWM are appropriate to achieving a sustainable land use while conserving soil and water. For example, differences in erosion due to different management practices of the same soil are often greater than the differences in erosion from different soils under the same management. The same applies to water where differences in water use efficiency due to different management at the same site are greater than the differences in water use efficiency at different sites under the same management. Although inappropriate management practices are an old problem in OFWM, this problem now ranks higher on the agenda as the world is faced with significant population increases, as food security becomes more of an issue and as land and water resources become scarcer.

Traditional farming systems in the tropics and subtropics often included the 'good practices'³ of water and soil conservation. However, in many cases, increased population pressure, the introduction of new cash crops and farming systems, and the mechanisation of farming operations have led to the abandonment of these farming and conservation practices. The shift towards annual crops on steep slopes that were previously under forest, tree crops or permanent pasture has led to increased water and soil losses. Other practices such as ridge constructions, ploughing down slopes and clean weeding have created additional problems in this respect.

³ The authors suggest the use of the term 'good practices' as being more appropriate and correct than 'best practices' as the use of the superlative indicates that the ultimate solution or practice has been found and that there is no need for further improvement. The term 'good practices' is being used increasingly and it has also been adopted by 1PTRID at FAO.

Problems associated with the introduction of irrigation are: waterlogging; salinisation; soil and water contamination; and a lowering of the quality of the water released through natural or artificial drainage. Overirrigation is a common fault that together with seepage from unlined canals causes the groundwater table to rise. This leads to waterlogging and salinisation especially where there is no natural drainage or where the drainage system is inadequate. In addition, yields of crops commonly grown at the site are also reduced if the soil is compacted and soil aeration and water permeability are reduced.

Another old problem is the overuse of groundwater. The new aspect of this problem is that it has become increasingly widespread. Overexploitation leads to lower ground-water levels and increasing costs of supply, and, under certain circumstances also to subsidence, landslips, seawater intrusion, etc. All these problems have been well known to agriculture for some time. They are mostly the result of inappropriate land use decisions and/or the inability to adjust to changing circumstances. They are quite often influenced significantly by non-agricultural factors such as those of a social, economic or political nature. In many cases, political factors are more important than the technical considerations usually discussed in connection with on-farm land and water management issues.

Traditional management practices of the irrigation supply and conveyance systems often contribute to high water losses. On many farms, the low irrigation efficiency is further accentuated by farmers' traditional irrigation methods and practices, inadequate land levelling, lack of a crop-specific water application, insufficient drainage, and poor maintenance of irrigation and drainage infrastructure. Farmers are often unaware of the possibilities of applying water in a more productive way. The potential of horticultural crops with their high land, water and labour productivity is often not adequately recognised, especially by less educated and poorer farmers. Farmers generally lack technical and economic information on improved OFWM methods and techniques and on the related aspects of more productive cropping patterns and crop management. Therefore, proper training and capacity building at all levels of OFWM would be useful.

As mentioned above, these problems have been a threat to agriculture in many countries in past decades. However, these problems have now taken on an added dimension. There is increasing public demand that the development and management of land and water be ecologically sustainable as well as economically viable. As there is a close interrelationship between land use and water resources, farmers have to be aware of this interrelationship and have to adjust their OFWM efforts to address this issue. Hence, both on-site and off-site effects have to be considered in management planning and practices.

By increasing the proportion of rainfall lost due to surface runoff as a result of inappropriate land use, problems of flooding and downstream erosion arise following rain events. As less water percolates down to provide base flow for streams, the dry season flow may be lowered and even reduced to zero. Lowering of the water table can lead to the loss of well water. Decreased soil-moisture supplies result in progressively poorer vegetation. Removal of the fertile topsoil by erosion will reduce crop yields. Deposition of coarse

sand, gravel and stones removed from steep slopes onto low-lying areas decreases the agricultural potential of the soils. Sediment deposition in channels and reservoirs resulting from upstream erosion is causing major problems. Suspended sediment represents a deterioration in water quality. Fine clay particles require expensive treatment by chemical flocculation and filtration. The contamination of water resources by agriculture with harmful substances has become a widespread problem and one of increasing concern for the non-agricultural public.

Another new feature is the fact that the agriculture sector is coming under pressure to make more efficient use of water. It has been and still is criticised for being the greatest water user while having the lowest water use efficiency and lowest output per unit of water used of all sectors. In particular, irrigated agriculture, the greatest water user of all, has been accused of being responsible for inefficient water use and land degradation. In the past, agricultural research and practices dealt solely with the subject of water for the purpose of optimising water management in order to satisfy the water needs of the crop. It is only in recent times that the effects of agricultural activities on water resources have been studied in the context of intersectoral water management and have consequently become a matter of public concern. In areas of water scarcity, the competition between different sectors of water users (i.e. between agriculture, municipalities, trade, industry, nature conservation, etc.) is attracting increasing public attention. It is also clear that future agricultural practice and research will no longer be geared exclusively to the task of optimising the water supply of crops. Rather, there is a need to curb agricultural water consumption for the benefit of other sectors, for example, by reallocating water originally designated for crop production to supplying drinking-water and domestic water to the population. The challenge is clear: OFWM has to contribute to an increase in overall water use efficiency.

Finally, it is necessary to realise that the water issues of quantity and quality are not related solely to agricultural production. They are increasingly related to urbanisation and industrialisation. The migration of water from agriculture to urban and industrial uses is underway and increasing, driven by the fact that "water flows uphill towards money". Aggregate supply economics suggest that cities will gain in the long run because of the higher prices for water that urban users are more likely to pay.

4 Holistic approaches will be indispensable in the future

To date, assessments of water use efficiency have not taken account of the fate of the so-called unproductive losses, e.g. the irrigation water that seeps into the groundwater and/or flows off above ground via the drainage system. Efficiency calculations have ignored the possibility that such flows may be used by downstream water users and hence greatly improve the overall efficiency of a system. On the other hand, too little consideration has also been given to the fact that water pollution can seriously impair water use efficiency for the catchment area as a whole because polluted water will only be of limited use to downstream users.

Strictly speaking, losses in water are only unproductive if the water has irretrievably left the catchment area in either liquid or gaseous form or if it has become unfit for use.

Thus, water that runs off a farming plot or a farm area above ground or seeps into an aquifer need not necessarily be lost in the physical sense provided it can be recovered within the catchment area and reused. Therefore, in assessing water savings, it is necessary to make a distinction between 'real' and 'theoretical' savings or improvements in efficiency (SECKLER, 1996). For example, a farmer who succeeds in reducing seepage to groundwater and/or surface runoff to the drainage canal by means of water saving techniques may not necessarily be improving the water use efficiency of the catchment area as a whole, especially if the seepage water and surface runoff were previously used by downstream water users. From the overall viewpoint of water management, this example shows that there is little sense in referring water use efficiency to an arbitrarily defined irrigation area or irrigation perimeter. Instead, one should always take account of what is happening in the water catchment area as a whole. This becomes more important as water grows scarcer and as competition for the available water resource increases. Water users defending their interests within a catchment area need to realise that the present and future problems of water utilisation can only be solved on the basis of an intersectoral form of water management conducted at the level of the catchment area. Moreover, farmers need to be aware that they constitute a part of an integral whole.

In addition to quantitative losses, qualitative losses also need to be addressed and taken into consideration when looking at water losses and efficiencies of systems on various levels. Presuming that water would be passing through a system theoretically with no or only a minor decrease in quality, it is strictly speaking not lost as it may be picked up by the downstream user without any restriction concerning the quality.

As the *quantitative* water use efficiency (E_{qn}) is too narrow to provide a good judgement and estimate of the farm, system or river-basin water use efficiency, the authors suggest that the additional concept of the *qualitative* water use efficiency (E_{qj}) be introduced. This concept could be used in conjunction with the quantitative water use efficiency. This means that even if an irrigation system had a very high *quantitative* water use efficiency, as nearly all the water is being applied carefully and through modern management and irrigation practices, it may well result in a very low *qualitative* water use efficiency as all the drainage water released downstream (e.g. to maintain the leaching requirements) would be very saline or of very poor quality. With the availability of good-quality water for irrigation and for environmental needs and flows decreasing, the disposal of low-quality drainage or surplus water is becoming a critical issue. It is becoming increasingly unacceptable to dilute better quality water through low-quality drainage water. In some areas, measures have been taken to prevent natural streams from becoming the cloak of irrigated agriculture. As in the Murrumbidgee Irrigation Area in Australia, drainage water of lower quality has to be treated on-site and not disposed of to natural streams. This may be done through evaporation basins, which allow the saline drainage water to evaporate or enable it to be more viable economically while producing crops through the use of Sequential Biological Concentration systems (SBC) based on Filtration and Irrigated cropping for Land Treatment and Effluent Reuse system (FILTER), e.g. those being developed at the CSIRO in Griffith (CSIRO LAND AND WATER, 1998, 2000a,b).

5 Challenges

Within the next few decades, agriculture will face a number of important challenges. On the one hand, it is necessary to increase food and fibre production in order to guarantee food and clothing for the increasing world population. This contribution is urgently needed to help combat poverty while fostering economic development. On the other hand, agriculture will face increasing competition for decreasing water resources. The situation is exacerbated by the dwindling financial resources and increasing costs for the rehabilitation of existing irrigation and drainage systems and the setting up of new ones. Moreover, agriculture needs to meet these challenges in a political and social environment that, in many countries, is highly critical of agriculture in general and of irrigated agriculture in particular. Agriculture needs to be more sparing in its use of water resources, minimise its impact on the environment and exercise continual self-restraint by means of eco-auditing (MURRAY DARLING BASIN COMMISSION *et al.*, 2001).

Until now, it has been farmers who have decided what happens on agricultural land. They make rational decisions according to their own circumstances. Their decisions are influenced by: physical factors, such as soil and climate; the socio-economic features of the community; and their own personal situation. Technical advice and the assistance available may be another influencing factor. As natural resources grow scarcer, the general public sees the environment as being increasingly endangered. Hence, farmers will face the challenge of land use decisions being influenced increasingly by non-agricultural factors with pressures coming from social, economic and political quarters.

Farmers cannot ignore the fact that agricultural activities produce a significant proportion of all pollutants entering streams, lakes, estuaries and groundwater. This is especially the case in Europe, North America and Australia, but it is also increasingly true in developing countries. Farmers need to admit that, in order to solve the water pollution problem, agricultural non-point source (NPS) pollution has to be controlled. They have to be aware that the solutions to controlling runoff will require an integrated effort by landowners, government and organisations responsible for protecting and restoring soil and water. OSMOND *et al.* (1995) see the first step in reducing agricultural NPS pollution as being one of focusing on the primary water-quality problem within the watershed; the water-quality use impairment must be identified and the type and source of the pollutant(s) defined. Once the problem has been defined clearly and documented, the critical area, i.e. the area that contributes the majority of the pollutant to the water resource, can be identified. Land treatment, that is the installation or utilisation of good management practices (GMPs)⁴ or better GMP systems, should then be implemented on these critical areas. Good and effective OFWM adjusted to the individual circumstances is an essential part of the GMP systems. For example, in some cases it might be important for farm runoff to be kept on the farm area where there is a risk of nutrient or pesticide contamination. This will require special OFWM efforts.

⁴ GMPs (see footnote 3 above), often referred to as best management practices (BMPs), are practical, affordable techniques used to prevent or reduce sediment, crop nutrient or pesticide entry into surface or groundwater. GMPs conserve soil and water resources without sacrificing crop or livestock productivity

In many cases, the potential for achieving benefits from improved OFWM is substantial. Water savings, yield increases, higher productivity and higher farmer incomes are achievable. Many experiments have demonstrated a positive effect of the yields for farmers. However, in many cases, questions concerning the ability and willingness of farmers to adopt the improved practices remain. In this context, the lack of financial and economic impact assessments of various interventions and the effects of improvement measures on productivity, incomes and water use efficiency remains a major shortcoming, also for policy and strategy formulation (WOLFF and STEIN, 1999).

Water as a means for production will become increasingly scarce and expensive, making high on-farm water use efficiencies and precise water management indispensable. Furthermore, farmers may be forced to devote more attention to the sustainability of natural resources on their land and within their catchment area. This may require and prompt changes in OFWM practices. In this respect, the challenge for farmers will be to manage the water on their farms professionally in the most sustainable and profitable way. This will require detailed planning and a clear definition of the goals and the means for achieving them within the constraints given. A sound understanding of the environment and a clear commitment to sustainable OFWM practices are essential. In order to achieve all the above, it will be necessary to implement good information management and flows. In this way, it will be possible to supply the necessary information and data on which decisions should be based.

For accomplishing GMPs in OFWM, the management structure of the individual farm is quite important. This is especially the case where the labour process is becoming fragmented in the course of development. For example, in Egypt, the head of a rural household is primarily a manager, linked to other households through exchanges and the hiring of labour, rental of machinery and land, and other relationships. One of the tasks of the head of the household is to manage the labour input in agriculture. The head of the household is also usually the only household member who follows the crop through the crop cycle. The other household members and the hired labour do most of the physical work and often lack comprehensive knowledge of crop and water management. The separation of management and farm labour causes a concentration of knowledge in the person of the manager. Hence, a de-skilling of the farm labour takes place, a fact which needs to be considered when developing and implementing strategies for the introduction of advanced OFWM practices.

With generally rising income expectations and standards of living, increased agricultural yields become necessary to satisfy the higher income demand. This is why, in the course of development, land which has been regarded as fairly fertile up to this point will become marginal land, and the previously marginal land will go out of production as it may no longer guarantee the necessary yield and income levels. Agriculture and especially irrigated agriculture will concentrate increasingly on highly productive land only. More food will be produced on an even smaller area. Achieving this requires more sophisticated management of the production technologies in general, and more advanced OFWM in particular.

The implementation of a more advanced form of OFWM constitutes a major challenge for the extension service. The conventional approach of the existing extension service has often proved not to be very successful in changing farmer behaviour. This has mainly been because extension workers often have little awareness about farmers' actual needs and problems, or about the practical value of their messages with regard to the farmers' social and financial conditions. In addition, they often lack experience. New and more participatory ways for the dissemination of information in the field of OFWM seem to be needed urgently. A participatory group extension approach is currently being introduced in Egypt's extension system. It is based on the principle of learning and doing together. It seems to be the only alternative problem-solving concept conceivable for introducing a sustainable, advanced form of OFWM. Generally, it is necessary to conduct extensive education programmes in order to update continuously the knowledge base of the extension service staff and to encourage farmers to adopt good OFWM practices.

The introduction of an advanced form of OFWM also poses many challenges for the agricultural research community. For example, as not all forms of OFWM are good, there is a strong interest in establishing criteria of what constitutes good and bad OFWM. In this sense, OFWM investigations/research/projects cannot be primarily descriptive, although detailed descriptions of the management processes may be important. Instead, OFWM investigations/research/projects have to be predictive. However, the interest lies not only in predicting what a given management will do in a certain circumstance, but more fundamentally in predicting what would occur if certain activities were adopted. The outcomes of these predictions need to be evaluated and an attempt made to rank management activities in terms of better or worse and to discern the best if possible.

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