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ECONOMIC AND TECHNICAL ASSESSMENT OF ON-FARM WATER USE EFFICIENCY:

THREE CASE STUDIES FROM WATER-SCARCE COUNTRIES

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Preface

This study which was undertaken by ESCWA in cooperation with ICARDA, addresses on-farm water use efficiency's assessment from the economical and technical points of view.

The dry areas of West Asia and North Africa face severe and growing challenges to the rapidly growing demand for water resources. New sources of water are increasingly expensive to exploit, limiting the potential for expansion of new water supplies. Water used for irrigation, a prime source of agricultural growth, will likely have to be diverted to meet the need of urban areas and industry. Water logging, salinization, groundwater mining, and water pollution are putting increasing pressure on land and water quality. Given that irrigation accounts for 80-90 per cent of all the water consumed in the region, improving on-farm water use efficiency can contribute directly to increased supply of water for agriculture and other uses. Improving the efficiency of irrigation is achieved by better matching application of water to crop needs in terms of both timing and quantity. Most of the evidence available in the region on water use efficiency is mainly based on experimental trials for monocrop systems. Thus, it does not precisely reflect the complex production decisions at the farm level under different environmental, technological, and economic conditions. Information on on-farm water use efficiency is limited or is not available at all. The main objective of this study is to assess the on-farm water use efficiency under farm conditions. For the purpose of this study, water use efficiency is defined as the ratio of the required amount of water used to the amount of water used by the plant. A methodology for the assessment of on-farm water use efficiency is presented within the framework of multicrop production system. The fixed allocatable input models, variable input model and satisfying are identified. These models are then estimated and tested in three case studies based on farm surveys data collected in three sites, the Ghors in Jordan, Nubaria in Egypt and Beni-Sweif in Egypt. The first chapter of the study addresses the issue in general; the second chapter then explains the concepts of water use efficiency. The third chapter addresses the methodology development for on-farm water use efficiency. In chapter four the three models of water use are presented. Chapters five, six and seven deal respectively with the Jordanian case study and the Egyptian case studies.

This study was prepared by Dr. Kamel Shdeed, Consultant; Dr. Theib Oweiss from ICARDA; Dr. Mohamed Gabr from ESCWA as a joint ESCWA/ICARDA activity. Filed data from the two sites was collected by teams from the National Center for Agricultural Research and Technology Transfer in Jordan and the Agriculture Economics Research Institute in Egypt. We sincerely appreciate and thank the work done by these two institutions.

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EXECUTIVE SUMMARY

West Asia and North Africa (WANA) countries and the world face severe and growing challenges as to maintaining water quality and meeting the rapidly growing demand for water resources. New sources of water are increasingly expensive to exploit, limiting the potential for expansion of new water supplies. Water used for irrigation, the most important use of water in the region, will likely have to be diverted to meet the needs of urban areas and industry but must remain a prime source of agricultural growth. Water logging, salinization, groundwater mining, and water pollution are putting increasing pressure on land and water quality. In all countries water is available to users at no cost or at a heavily subsidized price. Thus, neither water users nor water managers have incentives to conserve water, and water is overused and wasted instead of being treated as a scarce resource.

The demand for water continues to grow in these areas with the fast population growth and improved standards of living. Presently, over 75 per cent of the available water in the dry areas of WANA is used for agriculture. However, competition for water among various sectors deperives agriculture of substantial amounts every year. Meanwhile, most of the hydrological systems in the dry areas are already stretched to the limit, yet more food production is required every year. Such an objective may not be attained without substantially increasing the efficiency with which available water resources are used. To maintain, even the current levels of agricultural production and environmental protection needs, greater efforts should be made to enhance the efficiency of water procurement and utilization. Increasing water productivity in dry areas becomes a vital issue where more food should be produced out of less water. This theme poses enormous challenges to allocate existing supplies, encourage more efficient water use and promote conservation of natural resources.

One of the most extensively used terms to evaluate the performance of an irrigation system is "water efficiency". In general terms, water efficiency is defined as the ratio between the amount of water that is used for an intended purpose and the total amount of water input within a spatial domain of interest. In this context, the amount of water applied to a domain of interest but not used for the intended purpose is a "loss" from that domain. Clearly, to increase the efficiency of a domain of iterest, it is important to identify losses and minimize them. Depending on the intended purpose and the domain of interest, many "efficiency" concepts are involved, such as crop water use efficiency, water-application efficiency, and others.

Maximizing farmers profit may not necessarily result in maximum WUE just the same as maximizing WUE may not give maximum profit. When the cost of irrigation is low, farmers do not have much incentive in term of profit to try to maximize WUE; they tend to apply full crop water needs to achieve near- maximum yield. However, when the cost of water is high, or access to water is limited, maximum yield does not provide maximum profit. The relationship between wheat grain yield and total WUE under SI systems shows a non-linear increase in WUE with an increase in yield peaking at around 8 t/ha. However, the increase in WUE slows down after 50 per cent of this yield is reached. The proper management under these circumstances should take into consideration: the interests of the farmer together with the long-term sustainability of the resource, and the value of water at the national and farmer levels.

The water –use efficiency was evaluated in terms of crop output and value per unit of water. Protective irrigation system was found to perform better in terms of social efficiency and the perennial system in situational efficiency. The yield rates of rice, for example, in the system were higher than under the perennial systems, though the water requirement was lower. The average water- use efficiency of rice in physical and monetary terms was 2.48 kg/ha –mm and 2.65 Rs/ha-mm under the protective system of irrigation. All other crops had higher water- use efficiency. In the perennial system, the water- use efficiency of rice was lower, but the crop was widely grown during the rainy season because of the agroclimate.

Efficient use of irrigation systems is studied for three types of systems including trickle, solid-set sprinkler, and furrow irrigation system. It was found that irrigation efficiency of the sprinkler system was on the average about 22 per cent more that that of the furrow system and about 21 per cent less than that of the trickle system. Overall efficiency of the trickle system, however, was on the average about 28 per cent and 45 per cent more than those of the sprinkler and furrow systems, respectively.

Nine indicators are developed related to the irrigation and irrigated agricultural system. The main output considered is crop production, while the major inputs are water, land and finance. These indicators are output per cropped area ($/ha), output per unit command ($/ha), output per unit irrigation supply ($/m^3), output per unit water consumed ($/m^3), relative water supply, relative irrigation supply, water delivery capacity (%), gross return to investment (%) and financial self-sufficiency.

Three alternative models of multicrop input allocation are proposed for this study. These include the fixed allocatable input model, the variable input model, and the satisficing model. In the short run, an input is considered to be a variable input in the long run it may actually be fixed and allocatable. Irrigation with ground water is an example, where it is modeled as a variable input in the long run. This is based on the assumption that groundwater is subject to market forces with groundwater pumping cost as a water ' price'. Yet constraints on the number of wells pump capacity, and water distribution infrastructure may make groundwater a fixed, allocatable input in the short run. Irrigation with surface water may pose similar short-run constraints, as well as long-run institutional constraints. Hired labor and farm machinery may also be variable in the long run, but fixed and allocatable in the short run.

The three alternative models of short- run input used thus, can be directly estimated econometrically with the crop-level water data. The availability of crop-level microdata on water use effectively makes the data "non-deficient" in terms of information on water allocation in a multicrop system. In this study, the variable input model and the fixed, allocatable model are derived based on the profit maximization assumption using duality theory. Whereas, the satisficing model is a simple model of bounded rationality, these three models of multicrop water allocation will be compared using two techniques of model selection i.e., model specification tests and prediction accuracy measures. The basic unit for the study will be the individual farm and the study will consider the whole cropping system as the target. The water use efficiency will be assessed for all crops planted at a given season and for all seasons over the year. Different farms will be selected to cover the major conditions in the region. These include:

(a) Water sources: surface water, ground water and rainfall;
(b) Cropping systems: field crops, orchards, vegetables and mixed systems;
(c) Water management: rainfed, supplemental irrigation, full irrigation and mixed systems;
(d) Farm size and type: small, medium, and large.

Different sets of information and data need to be collected from farm survey and secondary sources. These include farm-level data (e.g., size of the farm, total amount of water available to the farm and socio-economic characteristics of the producers), crop-level data (e.g., amount of water applied to each crop and area devoted to the crop), price variables, weather information and soil quality data.

To collect required data for methodology testing and validation, a questionnaire has been developed and pre-tested. The questionnaire covers various farm-level and crop-specific informations including socioeconomic characteristics of producers, size of holdings. Sources of household income, soil characteristics, cropping pattern, water availability and cost. In addition, detailed information on input use and allocation, type of land tenure, output levels, input and output prices, amount of water applied, irrigation technology, and annual water budget are included for each crop. Similarly, groundwater quality and wells characterization as well as water management practices used in the farm are included in the questionnaire and will be collected from the farm survey.

The sample farms in the Ghors area of Jordan comprised 70 producers, distributed among 23 villages. The villages are clustered into two districts (North Ghors and Deir Alla Ghors) with most of the producers located in the North Ghors district (63 per cent). The rest of the producers, 37 per cent are located in the Deir Alla Ghors.

Most of the sample farms (63 per cent) are located in a rainfall zone of 350-500 mm, with an average rainfall of 425 mm. Whereas, 37 per cent are in a rainfall zone of 150-300 mm, with an average annual rainfall of 225 mm. The producers' experience in irrigation ranged from 1 to 47 years, with an average of 17 years. The majority of the farmers (89 per cent) are full-time operators, and only 11 per cent are part-time producers. Farming is the main source of income, with 83 per cent of the producers completely dependent on farm income (which accounts for 100 per cent of the household income). The rest of the farmers (17 per cent) are only partially dependent on farm income (which accounts for 20 to 90 per cent of the household income). Crop production accounts for 100 per cent of the farm income, as reported by 97 of the producers interviewed.

The calculated levels of required water are compared with the actual amount of water used. If the amount of rainfall is not included in the calculation of actual water used, the estimated WUE demonstrates perfect efficiency of water use in the production of all crops. In fact potatoes, peppers, lettuce and onions require more water than actual water applied to produce the achieved yield levels by sample farms. Above-average yields and a very efficient use of irrigation can explain these estimates of very high ratios of WUE for all crops. This explanation is particularly applicable to Jordan where water is very scarce resource and its use is well managed administratively and at the farm level using a high efficient technology of drip irrigation. If the amount of rainfall is taken into consideration in the calculation of WUE, the efficiency of irrigation water will drop sharply, implying that producers over-irrigate their crops. The percentage of over-irrigation ranged from a minimum of 23 per cent in the production of citrus crops to a maximum of 70 per cent in the production of wheat. Citrus and eggplant productions are relatively more efficient with a WUE of 0.77 per cent and 0.66 per cent, respectively. Farmers of potatoes, cauliflower, melons, wheat, lettuce, beans and onions are less efficient as they exceed water requirements by more than 50 per cent. Producers of tomatoes, peppers and cucumbers achieved medium level of water use efficiency as they exceed water requirements by less than 50 per cent.

In the Nubaria area of Egypt, the sample farms comprise 50 producers distributed equally among three villages. The producers experience in irrigation ranges from 1 to 41 years, with an average of 17.4 years. Surface water is the main source of irrigation for all farmers in the survey. Main produced crops are wheat, faba beans and bersem for winter cropping, whereas, summer cropping includes water melons, tomatoes, green pepper, squash and corn. The soil type is predominantly medium (94 per cent of the sample farms). Most farms (66 per cent) are of deep soil, and the remaining 37 per cent are of medium and shallow soils. Meanwhile, 56 per cent of the farmers reported that soil salinity is low, whereas, 30 per cent and 14 per cent of the farms are of medium and heavy salinity, respectively. Most farmers (80 per cent) are full-time operators, whereas, 20 per cent are part time farmers. Farming is the main source of household income. Farm income accounts for 84 per cent of the total income, while off-farm income contributes to 16 per cent of the household income. Crop production is the main source of farm income (81 per cent), whereas livestock production accounts for 19 per cent of farm income.

The calculated levels of required water are compared with the actual amount of water used. On-farm WUE is the highest for bersem (0.76), green peppers (0.74) and corn (0.74), indicating that actual water use exceeds water requirements by about 24-26 per cent. The lowest WUE of 0.47 for squash suggests that producers over–irrigate this crop by a large amount compared to its requirements. Squash producers exceed water requirements of the crop by 53 per cent. Therefore, any improvement in the water-use efficiency of this crop will save a large amount of scarce water that can be used to expand the farm's irrigated area or for other crops. Either below- average yields or inefficient use of irrigation water can explain these low-ratio estimates of on-farm water use efficiency for squash and faba beans.

Farmers in the Nubaria area of Egypt over- irrigate all winter and summer crops by a large amount of water in excess of their requirements. Farmers over-irrigate their crops by 24 per cent to 53 per cent, depending on crop under consideration, compared to the required amount of water to produce the achieved yield levels. These figures suggest that a big technology gap exists between the required irrigation practices for wheat, faba beans, bersem, water melons, tomatoes, green peppers, squash and corn, and the actual water application in the study area. This result has important policy implications in that improving WUE for these crops can contribute to the over all WUE in the study area. In this study, the overall WUE for winter cropping is 0.65 and for summer cropping is 0.61, suggesting a high potential for water saving once WUE is improved.

In the Beni-Sweif area of Egypt, the sample farms comprise 50 producers. The producer's experience in irrigation ranges from 1 to 53 years, with an average of 33 years. Surface water is the main source of irrigation for all farmers in the survey. Main produced crops are wheat and bersem for winter cropping.

Whereas, summer cropping includes cotton, sunflower, tomatoes and corn. The soil type is mainly medium (66 per cent of the sample farms). The other 30 per cent of sample farms, are of heavy soil. Most farms (78 per cent) are of deep soil, and the remaining 22 per cent are of medium soils. Meanwhile, 90 per cent of the farmers reported that soil salinity is low. Whereas, only 10 per cent of the farms are of medium salinity.

The calculated levels of required water are presented in table 22 and compared with the actual amount of water used. On-farm WUE is the highest for cotton (0.75), bersem and corn (0.72, each), indicating that actual water use exceeds water requirements by about 25 to 28 per cent. The lowest WUE of 0.56 for tomatoes suggests that producers over-irrigate this crop by 44 per cent compared to its requirements. Therefore, any improvement in the water-use efficiency of this crop will save a large amount of scarce water that can be used to expand the farm's irrigated area or for other crops. Likewise, farmers of wheat and sunflower exceed crops' water requirements by 35 per cent. Either below-average yields or inefficient use of irrigation water can explain these low ratios of on-farm WUE for tomatoes, wheat and sunflower.

I. INTRODUCTION

West Asia and North Africa (WANA) countries and the world face severe and growing challenges as to maintaining water quality and meeting the rapidly growing demand for water resources. New sources of water are increasingly expensive to exploit, limiting the potential for expansion of new water supplies. Water used for irrigation, the most important use of water in the region, will likely have to be diverted to meet the needs of urban areas and industry but must remain a prime source of agricultural growth. Water logging, salinization, groundwater mining, and water pollution are putting increasing pressure on land and water quality. In all countries water is available to users at no cost or at a heavily subsidized price. Thus, neither water users nor water managers have incentives to conserve water, and water is overused and wasted instead of being treated as a scarce resource.

Rationalization of water supplies has been accompanied by rapid growth in demand for water. Between 1950 and 1990, water used increased by more than 100 per cent in North and Latin America, by more than 300 per cent in Africa, and by almost 500 per cent in Europe. In 1990, Asia accounted for 60 per cent of world water withdrawals, North America for 17 per cent, Europe for 13 per cent, Africa for 6 per cent, and Latin America for 4 per cent. Global demand for water has grown rapidly, at 2.4 per cent per year since 1970.

The dry areas of WANA are characterized by low rainfall with limited renewable water resources. The share of the dry areas of the world's available fresh water is very small. Renewable water resources in WANA is about 1250 m^3 per capita, compared to about 7420 m^3 for the world, 15000 for Europe, 20000 m^3 for North Africa and 230000 m^3 for Latin America (World Resources Institute, 1999). In many WANA countries, available water will barely meet basic human needs in this century (The World Bank, 1994).

The demand for water continues to grow in these areas with the fast population growth and improved standards of living. Presently, over 75 per cent of the available water in the dry areas of WANA is used for agriculture. However, competition for water among various sectors deprives agriculture of substantial amounts every year. Meanwhile, most of the hydrological systems in the dry areas are already stretched to the limit, yet more food production is required every year. Such an objective may not be attained without substantially increasing the efficiency with which available water resources are used (Tribe, 1994). To maintain, even the current levels of agricultural production and environmental protection needs, greater efforts should be made to enhance the efficiency of water procurement and utilization. Increasing water productivity in dry areas becomes a vital issue where more food should be produced out of less water (Oweis, 2001). This theme poses enormous challenges to allocate existing supplies, encourage more efficient water use and promote conservation of natural resources.

High water savings can be achieved through promoting water use efficient techniques, adopting efficient on-farm water management, selecting proper cropping patterns and cultural practices and developing more efficient crop varieties.

Technologies for improving yield, stabilizing production and providing conditions suitable for using higher technology are important, not only for improved yields but also, for better water productivity. Yields and water productivity are substantially improved with the application of supplemental irrigation in the rainfed areas, the adoption of water harvesting in the steppe areas and the use of improved irrigation systems in irrigated areas.

The rainfed areas play an important role in the production of food in many countries of the region and the world. They cover more than 80 per cent of the land area used for cropping throughout the world and produce some 60 per cent of the total production. In general rainfall amounts in the WANA region are lower than seasonal crop water requirements; morever rainfall distribution is rarely in a pattern that satisfies the crop needs for water. Periods of severe moisture stress are very common and in most of the locations that coincide with the stages of growth that are most sensitive to moisture stress. Soil moisture shortages at some stages cause very low yields. Average wheat grain yields in WANA range between 0.6 to 1.5 ton/ha, depending on the amount and distribution of seasonal precipitation.

It was found, however, that yields and water productivity are greatly enhanced by conjunctive use of rainfall and limited irrigation water. Research results from ICARDA as well as harvest from farmers showed that substantial increase in crop yields were obtained in response to the application of relatively small amounts of supplemental irrigation. Applying 212, 150 and 75 mm of additional water to rainfed crops increased wheat yields in northern Syria by 350, 140 and 30 per cent over that of crops receiving annual rainfall of 234, 316 and 540 mm, respectively. In addition to yield increases, supplemental irrigation also stabilized wheat production from year to the other. The coefficient of variation was reduced from 100 per cent to 20 per cent in rainfed fields that adopted supplemental irrigation (Oweis, 2001).

Crops breeding and selection for improved water use efficiency, and the use of genotypes best adopted to specific conditions can improve soil water use and increase water productivity. An important approach to increase the efficiency of water use is to change both management practices and cultivar concurrently. The proper varieties need first to manifest a strong response to limited water applications, which means that they should have a relatively high yield potential. At the same time, they should maintain some degree of drought resistance, and hence express a good plasticity.

In conventional irrigation, water is applied to maximize crop yield (maximizing production per unit of land). This is the case when water is not limiting, rather land is the limiting factor. In the dry areas, land is not, any more, the most limiting factor to production, rather water is increasingly becoming the limiting factor. It is, therefore, logical to conclude that since water is a more limiting factor, then the objective should be to maximize the return per unit of water not per unit of land. This should yield higher overall production, since the saved water can be used to irrigate new land with higher production. ICARDA long-term research in Syria has shown that applying only 50 per cent of full supplemental irrigation requirements (over that of rainfall) would cause a reduction in yield of only 10-15 per cent. This finding, in light of the increasing water scarcity in Syria, has encouraged ICARDA and the extension system of Syria to test a deficit supplemental irrigation strategy at farmers fields.

Under unlimited water resources, the farmers have normally no incentive to save on irrigation water. In this case full crop water requirement is applied to produce maximum yield with lower water productivity. However, when water is not enough to provide full irrigation for the whole farm, the farmer has two options: to irrigate part of the farm with full irrigation leaving the other part rainfed or to apply deficit supplemental irrigation to the whole farm. The advantage of applying deficit irrigation increased the yeild by over 50 per cent above the level obtained when the farmer practiced over irrigation. Applying deficit supplemental irrigation strategy, when water resources are limited, will eventually double the land area under irrigation. The results of this program can well demonstrate the possibility of producing more with less water.

The limited supply of land and water resources indicate that horizontal expansion of agricultural production is a limited option in the Arab region. In the past, water policies in the region were geared towards expansion of irrigated areas, irrigation investment, and construction of drainage networks (ESCWA, 1994). Initial increase in water supply for irrigation has increased irrigated areas under cultivation and thus, increased agricultural production. However, land and water policies, together with economic and financial policies, in the past contributed to the depletion of land and water resources in many Arab countries. Irrigation projects focused on expanding irrigated areas without being accountable for the associated rise in watertable and salinity. Lack of demand management practices also contributed to a low efficiency of water use and consequent waste. In addition, improvement in the availability of water use due to the introduction of high technology diverted attention from demand management and reduced emphasis on low cost alternatives such as improving efficiency, conservation and reduction of waste through maintenance of irrigation infrastructure.

Nearly by the year 2025, most of the Arab countries will have only 32-66 per cent of the water available to them in 1990. The situation for water deficit countries such as Oman, Saudi Arabia, Yemen, Jordan and Syria is predicted to be worse than others where the renewable water resources per capita are predicted to decline by around two-thirds in the next 30 years (ESCWA, 1994).

The overall efficiency of water use of 53 per cent in Jordan, a highly water-deficit country, is the highest in the region and much higher than the average for developing countries which is at 30 per cent. A large part of this is due to the wide adoption of high-technology, high-efficiency drip-irrigation systems, especially in the Jordan Valley. This compares favorably with an overall efficiency of water use of 30 per cent for Egypt and Syria, and 20 per cent for Yemen.

On-farm irrigation efficiency is the highest in Jordan at 70 per cent. For other countries, it is 60 per cent for Morocco, 50 per cent for Syria, and 40 per cent for Yemen.

It is found that the growth in world requirements for the development of additional water supplies varies between 25 per cent to 75 per cent. Thus, increasing irrigation efficiency reduces the need for development of additional water supplies for all the sectors in 2025 by roughly one-half (Seckler, *et al.*, 1998).

However, in most of the big irrigating countries, operators of irrigation systems do not have an incentive to supply farmers with a timely and reliable delivery of water that would be optimal for on-farm water efficiency and use of other inputs (Serageldin, 1998). Therefore, farmers generally tend to over-irrigate as a result of their perceptions of water requirements, and their expectations of rainfall and market conditions. Most of the evidence available in the region on water use efficiency is mainly based on experimental trials for monocrop system. Thus, it does not precisely reflect the complex production decisions at the farm level under different environmental, technological, and economic conditions. More recently an empirical study on economical assessment of on-farm water- use efficiency in agriculture, including two case studies, was conducted (Oweis, Shideed and Gabr, 2000). This study clearly demonstrates the low ratios of water use efficiency in crop production, implying the tendency of farmers to over-irrigate their crops.

Data and information on on-farm water use efficiency in Jordan and Egypt is limited if not available at all. The main objective of this study is to assess the on-farm water use efficiency under farm conditions in these two countries. For the purpose of this analysis, water use efficiency is defined as the ratio of the required amount of water to produce a target production level to the actual amount of water used. A methodology for the assessment of on-farm water use efficiency is developed within the framework of multicrop production system. The methodology is then tested in two case studies based on farm surveys data collected in Jordan and Egypt. The resulting indicators on on-farm water use efficiency are very useful in guiding policies toward improving irrigation efficiency. Improving water use efficiency is vital to sustain and improve crop production in the WANA region.

Box 1. Integrated water resources development and management

Objectives

The overall objective is to satisfy the freshwater needs of all countries for their sustainable development. Integrated water resources management is based on the perception of water as an integral part of the ecosystem, a natural resource and a social and economic good, whose quantity and quality determine the nature of its utilization. To this end, water resources have to be protected, taking into account the functioning of aquatic ecosystems and the perrineality of the resource, in order to satisfy and reconcile needs for water in human activities. In developing and using water resources, priority has to be given to the satisfaction of basic needs and the safeguarding of ecosystems. Beyond these requirements, however, water users should be charged appropriately.

Integrated water resources management, including the integration of land-and water-related aspects, should be carried out at the level of the catchment basin or sub-basin. Four principal objectives should be pursued:

(a) To promote a dynamic, interactive, iterative and multi sectoral approach to water resources management, including the identification and protection of potential sources of freshwater supply, that integrates technological, socio-economic, environmental and human health considerations;

(b) To plan for the sustainable and rational utilization, protection, conservation and management of water resources based on community needs and priorities within the framework of national economic development policy;

(c) To design, implement and evaluate projects and programmes that are both economically efficient and socially appropriate within clearly defined strategies, based on an approach of full public participation, including that of women, youth, indigenous people and local communities in water management policy-making and decision-making;

Box 1 (*continued*)

(d) To identify and strengthen or develop, as required, in particular in developing countries, the appropriate institutional, legal and financial mechanisms to ensure that water policy and its implementation are a catalyst for sustainable social progress and economic growth.

In the case of transboundary water resources, there is a need for riparian States to formulate water resources strategies, prepare water resources action programmes and consider, where appropriate, the harmonization of those strategies and action programmes.

All States, according to their capacity and available resources, and through bilateral or multilateral cooperation, including the United Nations and other relevant organizations as appropriate, could set the following targets;

(a) *By the year 2000*

  (i) To have designed and initiated costed and targeted national action programmes, and to have put in place appropriate institutional structures and legal instruments;

  (ii) To have established efficient water use programmes to attain sustainable resource utilization patterns.

(b) *By the year 2025*

  (i) To have achieved subsectoral targets of all freshwater programme areas.

It is understood that the fulfillment of the targets quantified in (a) (i) and (ii) above will depend upon new and additional financial resources that will be made available to developing countries in accordance with the relevant provisions of General Assembly resolution 44/228.

Source: Extracts from Agenda 21: The United Nations Programme of Action from RIO, page 167.

Fully aware about the water crisis in the Arab countries, the Ministers of Agriculture and Ministers of Water and Irrigation issued the Cairo Declaration of Arab cooperation principles regarding use, development and protection of Arab water resources at the Arab Ministerial Conference for Agriculture and Water Resources held in Cairo during the period 29-30 April 1997. In this declaration the Ministers declared their full commitment to take measures to contribute to ensure the targeted Arab water and food security. The following are some of these measures that are related to the subject of the study mentioned in the said declaration.[1]

(a) To consider water (factor of production) as a free natural resource, hence non-marketable; to stress on formulating policies and approaches determining cost of water used in agriculture based on the principle of cost recovery (partial or full), which is a function of making water available to farmers to meet social and economic development demand for each country, a situation that guarantees competitiveness of agricultural products;

(b) To emphasize the physical links between Arab water and food securities that guarantee sustainable development. We also stress on preparing strategies, formulating policies and providing national development tools embodying such links and national capacities which make it amenable for regional and international activities;

(c) To plan coordinated Arab strategies for the purpose of improving investment methods for common waterways with the aim of protecting Arab water resources from foreign and illegal aspirations;

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[1] Cairo Declaration of Arab Cooperation Principles Regarding Use, Development and Protection of Arab Water Resources, The Arab Organization for Agricultural Development.

(d) To strengthen the Arab Center for Waters which is initiated by the League of Arab States to be located in Damascus. The center will be supplied with all necessary means to carry out its functions of coordinating Arab views and activities related to water resources development and use at the regional and international levels;

(e) Intensification of water extension services and awareness programmes dealing with water use efficiency, especially in irrigated agriculture, which is considered a key element in efficient water use in Arab agriculture, and providing necessary means to build and to improve national capacity regarding this issue;

(f) Strengthening Arab cooperation for the purpose of protecting water qualities; emphasizing the importance of environmental issues in agricultural and water policies, taking all measures in order to protect and to conserve land and water resources from environmental degradation within a framework of balanced agricultural policies that help attain goals for a sustainable agriculture and rural development that meet present and future generation needs.

II. WATER USE EFFICIENCY

A. WATER EFFICIENCY AND PRODUCTIVITY

One of the most extensively used terms to evaluate the performance of an irrigation system is "water efficiency". In general terms, water efficiency is defined as the ratio between the amount of water that is used for an intended purpose and the total amount of water input within a spatial domain of interest. In this context, the amount of water applied to a domain of interest but not used for the intended purpose is a "loss" from that domain. Clearly, to increase the efficiency of a domain of iterest, it is important to identify losses and minimize them. Depending on the intended purpose and the domain of interest, many "efficiency" concepts are involved, such as crop water use efficiency, water-application efficiency, and others (Guerra, *et al.*, 1998).

For food production, the ultimate purpose of supplying water is to satisfy crop needs and evapotranspiration demand. On-farm water components such as seepage and percolation (S & P) are losses because they flow out of the farm without being consumed by the intended crop. Reducing the amount of S & P would lead to an improvement in water efficiency on-farm. But if this water can be recovered for crop consumption at some point downstream, these are not losses of the irrigation system.

The efficiency concept provides little information on the amount of food that can be produced with an amount of available water. In this respect, water productivity, defined as the amount of food produced per unit volume of water used is more useful. Because the water used may have various components (evaporation, transpiration, gross inflow, net inflow, etc.), it is important to specify which components are included when calculating water productivity. Similar to efficiency, for practical purposes the concept of water productivity needs a clear specification of the boundaries of the domain of interest.

Water productivity can be increased by increasing yield per unit land area, for example, by using better varieties or agronomic practices, or by growing the crop during the most suitable period. Water productivity is also determined by factors other than water management. To use this concept for the purpose of improving water management, the contributions of other factors that contribute to crop yield have to be taken into account. Higher productivity does not necessarily mean that the crop effectively uses a higher proportion of the water input. For this reason, water productivity alone would not be particularly useful in identifying water savings opportunities of the system under consideration.

In summary, water efficiency and productivity terms should be used complementarily to assess water management strategies and practices to produce more crops with less water. Both terms are scale-sensitive; therefore, failure to clearly define the boundaries of the spatial domain of interest can lead to erroneous conclusions. It is also important to specify the water use components that are taken into account when deriving water efficiency and productivity.

It should be emphasized that measurements of efficiency or loss are site-specific not only because of variation in physical environment but also because of variation in physical infrastructure and management capacity reflected at each location.

During the crop growth period, the amount of water usually applied to the field is much more than the actual field requirement. This leads to a high amount of surface runoff, and seepage and percolation. Seepage and percolation account for about 50-80 per cent of the total water input to the field.

On-farm productivity of irrigation water can be increased by doing one of the following: (1) increasing yield per unit evapotranspiration during crop growth; (2) reducing evaporation especially during land preparation; (3) reducing S & P during land preparation and crop growth periods; and (4) reducing surface runoff.

Box 2

All States, according to their capacity and available resources, and through bilateral or multilateral cooperation, including the United Nations and other relevant organizations as appropriate, could implement the following activities:

Water use efficiency

(a) Increase of efficiency and productivity in agricultural water use for better utilization of limited water resources;

(b) Strengthen water and soil management research under irrigation and rain-fed conditions;

(c) Monitor and evaluate irrigation project performance to ensure, inter alia, the optimal utilization and proper maintenance of the project;

(d) Support water user groups with a view to improving management performance at the local level;

(e) Support the appropriate use of relatively brackish water for irrigation.

Water resources development programmes

(a) Develop small scale irrigation and water supply for humans and livestock and for water and soil conservation;

(b) Formulate large-scale and long-term irrigation development programmes, taking into account their effects on the local level, the economy and the environment;

(c) Promote local initiatives for the integrated development and management of water resources;

(d) Provide adequate technical advice and support and enhancement of institutional collaboration at the local community level;

(e) Promote a farming approach for land and water management that takes account of the level of education, the capacity to mobilize local communities and the eco-system requirements of arid and semi-arid regions;

(f) Plan and develop multi-purpose hydroelectric power schemes, making sure that environmental concerns are duly taken into account.

Source: Extracts from agenda 21: The United Nations Programme of Action from RIO, page 182.

Efficiency is generally understood to be a measure of the output obtainable from a given input. In irrigation and water management, the output is related to crop consumptive use and to the water diverted to meet crop consumptive demands. This definition fails to take into consideration the fact that much of the water "lost" through runoff or seepage and percolation is recycled or captured and reused elsewhere (Oweis, *et al.*, 1999).

For the purpose of discussion, it is appropriate to avoid the confusion over the concept of efficiency and use the concept of productivity. Efficiency and productivity are related, but they are not the same. In measuring productivity, while the denominator remains the quantity of water diverted or depleted for particular use such as crop production, the numerator is measured as the crop output. The numerator and the denominator can be expressed in either physical or monetary terms. Given this, there are several different ways of expressing productivity:

(a) Pure physical productivity is defined as the quantity of the product divided by the quantity of the diversion or depletion;

(b) Combined physical and economic productivity is defined in terms of the economic value expressed as gross or net value, or net present value (NPV) divided by the amount of water diverted or depleted;

(c) Economic productivity is the NPV of the product divided by the NPV of the amount of water diverted or depleted, defined in term of its value, or opportunity cost, in the highest alternative use.

In this discussion, Oweis, *et al.* (1999) define water productivity (WP), using the first of the above definitions, as the ratio of the physical yield of a crop and the amount of water consumed, including both rainfall and supplemental irrigation. Yield is expressed as a mass (kg or ton), and the amount of water as a volume (m^3).

B. WATER USE EFFICIENCY

Water is likely to be the single most important regional and global resource issue in the coming years. Its "wise" use is becoming an immediate necessity. A criterion that perhaps is generally accepted to evaluate a wise use of water is what is referred to as Water Use Efficiency (WUE). The term indicates how much food and/or fiber a cubic meter of water may produce. Comparing WUE of Supplemental Irrigation (SI) of wheat with that of Full Irrigation (FI), a real opportunity for water use improvement was found. According to ICARDA trials and farmers demonstration fields in Syria, a cubic meter of water used in SI produced, on average, an extra 3 kg of wheat over rainfed yield (WUE = 3 kg/m^3), whereas a cubic meter used in FI produces about 0.5 kg, i. e., WUE = 0.5 kg/m^3. This large difference in the WUE is attributed to the conjunctive use of rainfall and SI water. In Jordan rainfall WUE in rainfed wheat in Mushagar (300 mm annual rainfall) is 0.33 kg/m^3, when the cubic meter of rainfall is combined with ½ m^3 supplemental irrigation, the over all WUE was increased to 3.5 kg/m^3. With such obvious advantages decision makers at the national level may need to consider the feasibility of diverting some irrigation water from FI to SI, or a combined use of both for optimal crop-water allocation (Oweis and Salkini, 1992).

The cost of water is an important factor in the economics of SI. This includes the cost of water source (i. e. making water available for use) and the cost of application to the field. A distinction between the cost and the real value of water is yet to be made in the region. In most of the cases, the cost of water, for farmers, is only the running cost needed to convey water from a canal or a river, or pumping it from the aquifer. The real value of water to the nation as a scare resource and as a common (or community) property is much higher than the current cost for farmers. A revision of water costing relative to the common interest of the society is vital so that such an important resource is not wasted in less than its real value. This is if we want it for present and future generations. Farmers in Syria were found to double or triple SI amount to realize a small fraction of yield increase (10-15 per cent only). Such practices cannot be avoided as long as water cost is very low.

Water Use Efficiency (WUE) is a measure of the productivity of water consumed by the crop. In areas with limited water resources, where water is the greatest limitation to production, WUE is the main criterion for evaluating the performance of agricultural production systems. No longer is productivity per unit area the main objective, since land is not as limiting factor to production as is water.

Average WUE of rain in producing wheat in the dry areas of WANA is about 0.35 kg grain/m^3, although with good management and favorable rainfall (amount and distribution), this can be increased to 1 kg grain/m^3. However, water used in SI can be much more efficient. Research at ICARDA showed that a cubic meter of water applied at the right time (when the crop is suffering from moisture stress), combined with good management, could produce more than 2.5 kg of grain over the rain-fed production. This extremely high WUE is mainly attributed to the effectiveness of a small amount of water in alleviating severe moisture stress during the most sensitive stage of crop growth and seed-filling. When SI water is applied before such conditions occur, the plant may reach its high yield potential (Oweis, 1997).

In comparison to the productivity of water in fully irrigated areas (when rainfall effect is negligible), the productivity is higher with SI. In fully irrigated areas with good management, wheat grain yield is about 6t/ha using 800 mm of water. Thus, the WUE is about 0.75 kg/m^3, one-third of that is under SI with similar management. This suggest that water resources may be better allocated to SI when other physical and economic conditions are favorable.

ICARDA has found that, in Syria, supplementing only 50 per cent of the crop irrigation requirements reduces the grain yield by only 10-20 per cent relative to full irrigation. Using the saved 50 per cent to irrigate an equal area gives a much greater return in the total production. In some areas, groundwater resources are being over-exploited for full irrigation and their quality is deteriorating. With such pressure on the existing water resources, sustainable use can be obtained only by producing more crops from less water, that is, improving water use efficiency.

Water-use efficiency in SI is a function of the amount of irrigation water applied. It was found that maximum WUE is attained when one- to two- thirds of the full irrigation water is applied. Given that many farmers over-irrigate, at least one-third of the full irrigation requirement can be saved without any losses in productivity.

Box 3. Water for sustainable food production and rural development

Sustainability of food production increasingly depends on sound and efficient water use and conservation practices consisting primarily of irrigation development and management, including water management with respect to rain-fed areas, livestock water-supply, inland fisheries and agro-forestry. Achieving food security is a high priority in many countries, and agriculture must not only provide food for rising populations, but also save water for other uses. The challenge is to develop and apply water-saving technology and management methods and, through capacity-building, enable communities to introduce institutions and incentives for the rural population to adopt new approaches, for both rain-fed and irrigated agriculture. The rural population must also have better access to a potable water-supply and to sanitation services. It is an immense task but not an impossible one, provided appropriate policies and programmes are adopted at all levels -local, national and international. While significant expansion of the area under rain-fed agriculture has been achieved during the past decade, the productivity response and sustainability of irrigation systems have been constrained by problems of waterlogging and salinization. Financial and market constraints are also a common problem. Soil erosion, mismanagement and overexploitation of natural resources and acute competition for water have all influenced the extent of poverty, hunger and famine in the developing countries. Soil erosion caused by overgrazing of livestock is also often responsible for the siltation of lakes. Most often, the development of irrigation schemes is supported neither by environmental impact assessments identifying hydrologic consequences within watersheds of interbasin transfers nor by the assessment of social impacts on peoples in river valleys.

Source: Extracts from Agenda 21: The United Nations Programme of Action from RIO, page 180.

Maximizing farmers profit may not necessarily result in maximum WUE just the same as maximizing WUE may not give maximum profit. When the cost of irrigation is low, farmers do not have much incentive (in term of profit) to try to maximize WUE; they tend to apply full crop water needs to achieve near- maximum yield. However, when the cost of water is high, or access to water is limited, maximum yield does not provide maximum profit. The relationship between wheat grain yield and total WUE under SI systems shows a non-linear increase in WUE with an increase in yield peaking at around 8 t/ha. However, the increase in WUE slows down after 50 per cent of this yield is reached. The proper management under these circumstances should take into consideration: (a) the interests of the farmer together with the long-term sustainability of the resource; and (b) the value of water at the national and farmer levels (Oweis, 1997).

Enhanced exploitation of groundwater for supplemental irrigation (SI) on vast areas, traditionally used to be rainfed, has helped bridging the gap in Syria's basic food production, recovering in particular the wheat balance. However, ignorance of crop water requirements, poor water management practices, the low efficiency of many irrigation systems and the generally low cost of water have led to overpumping and excessive water use.

Results show that improving the wheat price encourages the use of more water unless the rate of increases in the cost of water exceeds that of wheat. Optimal applications of SI are not determined by the input/output price ratio only, but also by weather conditions. In a specific price situation, different SI amounts are defined for different rainfalls (Salkini and Oweis, 1993).

In Syria, water from public (surface) irrigation schemes is given (almost) free to users; and groundwater costs do not reflect their real value because the energy required for pumping is obtained at a subsidized price. As a result, most farmers tend to over-irrigate. ICARDA research has shown that the SI amount for wheat reported by farmers is up to three times the optimal rate defined by research trials. It is common to see sprinklers operating on wheat in December, January and February, when the probability of rain is high, even though the crop water requirement in these months is low and the crop is not very sensitive to water stress.

Crop yield is primarily water-limited in areas of West Asia and North Africa with a Mediterranean climate. Ten years of supplemental irrigation (SI) experiments in northern Syria were conducted to evaluate water-yield relations for bread wheat and durum wheat, and optimal irrigation scheduling was proposed for various rainfall conditions.

Quadratic crop production functions with the total applied water were developed and used to estimate the levels of irrigation water for maximizing yield, net profit and levels to which the crops could be under irrigation without reducing income below that which would be earned for full SI under limited water resources. The analysis suggested that irrigation scenarios for maximizing crop yield and/or the net profit under limited land resource conditions should not be recommended. The SI scenarios for maximizing the profit under limited water resource conditions or for a targeted yield of 4-5 t/ha were recommended for sustainable utilization of water resources and higher WUE (Zhang and Oweis, 1999).

Water resources in West Asia and North Africa (WANA) are scarce. Improving water use efficiency (WUE) is vital to sustain and improve crop production. A trial was conducted in northern Syria over four seasons in 1992-1996 to examine the effect of applying different levels of supplemental irrigation (SI), nitrogen and sowing time on yield, evapotranspiration and water use efficiency (WUE) of durum wheat. WUE was calculated for rainwater (rain-WUE), for both rain and irrigation water (gross-WUE) and SI water only (WUESI) (Oweis and Zhang, 1998).

Mean WUESI ranged from 0 to 25 kg/ha/mm for grain and from 3 to 43 kg/ha/mm for total dry matter (TDM). Rain-WUE ranged from 8 to 11 kg/ha/mm. One third of full irrigation increased gross WUE from 11.5 to 13.6 kg/ha/mm. Highest gross-WUE and WUESI were achieved when 1/3 of full irrigation requirements was applied. The relationship between grain yield and total water applied was established using the data from this experiment and previous 6 years SI experiments. Different irrigation scenarios were suggested under different rainfall conditions and management options, following English (1996).

English and Raja (1996) outline four levels of applied water that could be defined as optimal, depending on whether the goal is to maximize profits or food production (yield) and whether the limiting resource is water or land:

(a) The level of applied water at which crop yields per unit of land are maximized;

(b) The level at which net income per unit of land is maximized;

(c) The level at which net income per unit of water is maximized;

(d) The level at which yields per unit of water are maximized.

The optimum level of applied water for a particular situation will be that which produces the maximum profit or crop yield, per unit of land or per unit of water, depending on the underlying objective function and the limiting factor (constraint).

Inadequate water resources make it imperative to evaluate the efficiency of the water utilization to arrive at a socially protective type of irrigation. The water use efficiency (WUE) would differ according to different systems of irrigation, crop-mix and environment. WUE has different dimensions-crop consumptive use (water requirement), an efficient crop –mix, meaning the maximum irrigable area for given water resources and maximum output and value per unit of water.

The water–use efficiency was evaluated in terms of crop output and value per unit of water. Protective irrigation system was found to perform better in terms of social efficiency and the perennial system in situational efficiency. The yield rates of rice, for example, in the system were higher than under the perennial systems, though the water requirement was lower. The average water- use efficiency of rice in physical and monetary terms was 2.48 kg/ha–mm and 2.65 Rs/ha-mm under the protective system of irrigation. All other crops had higher water- use efficiency. In the perennial system, the water-use efficiency of rice was lower, but the crop was widely grown during the rainy season because of the agroclimate (Girriappa, 1984).

Efficient use of irrigation systems is studied for three types of systems including trickle, solid-set sprinkler, and furrow irrigation system. It was found that irrigation efficiency of the sprinkler system was on the average about 22 per cent more that that of the furrow system and about 21 per cent less than that of the trickle system. Overall efficiency of the trickle system, however, was on the average about 28 per cent and 45 per cent more than those of the sprinkler and furrow systems, respectively (Dawood and Hamad, 1985).

Nine indicators are developed related to the irrigation and irrigated agricultural system. The main output considered is crop production, while the major inputs are water, land and finance. These indicators are output per cropped area ($/ha), output per unit command ($/ha), output per unit irrigation supply ($/m^3), output per unit water consumed ($/m^3), relative water supply, relative irrigation supply, water delivery capacity (%), gross return to investment (%) and financial self-sufficiency (Molden, *et al.*, 1999).

On-farm water use efficiency in agriculture is recently assessed (Oweis, Shideed and Gabr, 2000). On-farm water use efficiency in Radwania in Syria is found to be 0.61 for wheat, 0.45 for barley and 0.75 for cotton. The estimates suggest that farmers over-irrigate wheat by 39 per cent, barley by 55 per cent and cotton by 25 per cent.

III. METHODOLOGY DEVELOPMENT FOR ON-FARM WATER USE EFFICIENCY[2]

Predicting crop-level input allocation (use) is a major problem in a multicrop production decision. This is mainly attributed to deficient data in the sense that data on crop-level input use is generally not available, except for land use. The challenge, therefore, is to develop modeling approaches that permit prediction of input allocation from data on on-farm input use and crop level land use. These modeling approaches are highly needed for developing crop budgets and estimates of enterprise cost of production. Further, evaluating the effects of alternative policies for influencing input use frequently requires an understanding of how producers make decisions on crop-level input use (Moore, Gollehon and Carey, 1994). Previous research implications on multioutput input allocation were mainly based on two assumptions about producer behavior. These are profit maximization and satisfying behavior. The satisfying behavior means that farmers operate with rules-of-thumb stemming from bounded rationality. A simple form of which is that producers follow either a distributor's recommendation or other routine practices concerning a crop's input application rate per hectare. Crop acreage thus would effectively determine the allocation of an input among crops on a multicrop farm. Three alternative models of multicrop input allocation are proposed for this study. These include the fixed allocatable input model, the variable input model, and the satisficing model. In the short run, an input is considered to be a variable input in the long run it may actually be fixed and allocatable. Irrigation with ground water is an example, where it is modeled as a variable input in the long run. This is based on the assumption that groundwater is subject to market forces with groundwater pumping cost as a water 'price'. Yet, constraints on the number of wells pump capacity, and water distribution infrastructure may make groundwater a fixed, allocatable input in the short run (Moore, Gokkehon and Carey, 1994). Irrigation with surface water may pose similar short-run constraints, as well as long-run institutional constraints. Hired labor and farm machinery may also be variable in the long run, but fixed and allocatable in the short run.

Crop-level input use data are required to estimate the allocatable fixed input model. Farm-level water use serves as an exogenous variable in the allocatable fixed input model, with crop-level water use serving as the endogenous variable. Unlike the variable input and satisficing models, a procedure does not appear to be available for predicting the results of the allocatable fixed input model using deficient data because of the essential role of farm-level water as an exogenous variable. In contrast, farm-level water serves as the endogenous variable in the variable input and satisficing models estimated with deficient data. A data set that contains both crop-level irrigation water and acreage data from multicrop farms will be applied.

The three alternative models of short- run input used thus, can be directly estimated econometrically with the crop-level water data. The availability of crop-level microdata on water use effectively makes the data "non-deficient" in terms of information on water allocation in a multicrop system. In this study, the variable input model and the fixed, allocatable model are derived based on the profit maximization assumption using duality theory. Whereas, the satisfying model is a simple model of bounded rationality, these three models of multicrop water allocation will be compared using two techniques of model selection (i.e., model specification tests and prediction accuracy measures). The empirical application analyzes multicrop water irrigation in the Syrian Arab Republic using data from farm survey. The basic unit for the study will be the individual farm and the study will consider the whole cropping system as the target. The water use efficiency* will be assessed for all crops planted at a given season and for all seasons over the year. Different farms will be selected to cover the major conditions in the region. These include:

(a) Water sources: surface water, ground water and rainfall;
(b) Cropping systems: field crops, orchards, vegetables and mixed systems;
(c) Water management: rainfed, supplemental irrigation, full irrigation and mixed systems;
(d) Farm size and type: small, medium and large.

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[2] This methodological part is mainly based on the work done in Oweis, Shdeed and Gabr, 2000.

IV. THE MODELS OF WATER USE

Farmers involved in irrigated agriculture make a variety of decisions concerning crop-choice, land use, and irrigation water application. As an irrigator, the farmer also makes crop-level water decisions conditional on land allocations; thus reflecting water use within an irrigation season (Moore, *et al.*, 1994b).

In this analysis the farmer has made an intermediate-run production decision including the combination of crops to produce and the acreage in each crop. The subsequent short-run decision involves deciding the quantity of irrigation water to apply to each crop over the irrigation season. Thus, crop-specific acreages are exogenous to the water use decisions. The common thread across the three alternative models, according to Moore *et al.* (1994a) is that crop-level land use serves as one determinant of crop-level water use in each model.

To mathematically present the proposed models , the following notation is in order:

P is a vector of crop prices which are given to producers; pi is the price of crop i (i=1,...,m); w is water price; r is a vector of variable input prices other than water (v= 1,...,z)); wi is water allocated to crop i; W is farm-level quantity of water; ni is land allocated to crop i; x is a vector of variables taken as given in the short run (e.g., crop-level irrigation technology and weather; s=1,...,t); π(.) is the short-run restricted profit of crop i; and II(.) is the multioutput restricted profit function of the firm. Input nonjointness is assumed , so that the multicrop profit function decomposes into the sum of distinct crop-specific profit functions. The profit functions are assumed to be well-behaved in terms of the conventional assumptions.

Various functional forms can be used. However, flexible functional forms are more appropriate for multioutput production decisions. For this study it is proposed to apply the normalized quadratic profit function which is a flexible functional form of the profit function and has been widely used in previous multiouput agricultural production research. The full specification of the quadratic profit function includes linear, squared, and cross-product terms for all exogenous variables. Prices are expressed in relative terms, with one price serving as a numeraire; this maintains linear homogeneity of the function.

A. VARIABLE INPUT MODEL

The variable input model has commonly been used to the analysis of short-run irrigation water use (Moore, *et al.*, 1994a, 1994b; Chambers and Just, 1989; Just, *et al.*, 1983). Following the dual approach, application of Hotelling's lemma by taking the first-order partial derivative of the restricted profit function with respect to the water price variable gives crop-level water demand functions for the variable input model. These demand functions are as follows:

$$W_i \delta \pi(p_i, r, r_w, n_i; x) \delta r_w = w_i(p_i, r, r_w, n_i; x) \qquad i = 1,\ldots,m \qquad (1)$$

The forms of these derived crop-level demand functions to be estimated are linear functions of the independent variables.

B. FIXED, ALLOCATABLE INPUT MODEL

The fixed, allocatable input model of water use represents a second approach based on a profit maximization assumption. This model is based on a short-run water constraint in the sense that the available amount of water is fixed at a given time and this amount should be allocated among competing crops at the farm level. For example, groundwater represents the fixity of groundwater wells, pump capacity, and irrigation capital during the growing season. This constraint does not reflect a long-run, institutionally-defined water quota. Thus, the fixed, allocatable input model offers a more reflective model of multicrop decisions on the farm level than the variable input model. In this model, producers operate with a short-run constraint on farm-level water use because of fixed groundwater pumping capacity.

To obtain optimal short-run water allocation functions using duality theory, the following constrained profit maximization problem needs to be solved:

$$\Pi(p,r,n_1,n_2,\ldots,n_m,w;x) = MAX(\sum_{i=1}^{m} \pi(p_i,r,n_i,w_i;x){:}\sum w_i = W) \qquad (2)$$

Applying the first-order condition for profit maximization gives the input demand functions. The necessary (first-order) conditions for solving the problem are:

$$\delta\pi_i(p_i,r,n_i,w_i;x) / \delta w_i = L \qquad \text{for } i = 1,\ldots,m$$

Where L is the shadow price on water constraint. Optimal water allocation functions can be obtained by solving this equation system; these water demand functions are:

$$W_i{*} = w_i{*}(p,r,n_1,n_2,\ldots,nm,W;x) \qquad i = 1,\ldots,m \qquad (3)$$

The allocatable fixed input model has two distinct features. First, water allocations to one crop depend on the output prices and acreage levels of all other crops. Thus, in contrast to the variable input model of Equation (1), intercrop price and acreage variables supplement own-crop price and own-crop acreage as determinants of water use. Second, the farm-level water quantity constraint in Equation (3) replaces water price as a determinant of short-run crop-level water use.

Equation (3) is linear in the exogenous variables and it is the water demand function to be estimated for the fixed, allocatable model. The optimal allocation equations in (3) illustrate the apparent jointness created by fixed, allocatable input. Despite the assumption of input nonjointness, the fixed water input creates interdependence across crops. For example, consider a multicrop farm that grows wheat, potatoes and lentils, the water use on wheat depends on acreage in potatoes and acreage in lentils in addition to acreage in wheat.

C. SATISFICING MODEL

Under the satisficing model of short-run water use, crop-level land use virtually determines crop-level water use, with all price variables and the water constraint removed from the specification. Other variables (irrigation technology and weather) explain any additional variation in water use. The general form of this model is (Moore, *et al.*, 1994):

$$W_i = w_i(n_i;x) \qquad i = 1,\ldots,m \qquad (4)$$

To be consistent with previous research (e.g., Moore et al, 1994b) and the variable input model and fixed, allocatable input model, a linear specification is used to estimate equation (4).

In intuitive terms, the satisficing model is stemmed from the idea that longer- run decisions have a larger quantitative impact on profit relative to short-run decisions. Thus, producer behavior might conform more closely to the profit maximization assumption in the intermediate-or long-run periods. However, satisficing in the short run by following a rule-of-thumb or a distributor's recommendation may conserve on information requirements with little sacrifice in profit.

An alternative model may explain the producer decisions on water use in the short run. A "behavioral" model relating water use primarily to planted area in the crop is an example (Just , *et al.*, 1990). According to this model, producers apply a fixed water-land ratio in the short run. It describes variable input allocation in a region with a group of i producers (i = 1,2,..., I) producing K crops (k= 1, 2, ..., K) using water input, W . The statistical analysis consists of estimating the allocation of variable water input among crops. The two items of information used for these estimates are Lki, which is the area allocated by individual i to the production of crop k; and Wi , which is the aggregate quantity of water input used by individual i . Thus,

$$W_i = \sum W^*_{ki} \qquad (5)$$

Where, Xki is the unobserved quantity of water input allocated by individual i to production of crop k.

Information on Wi is relatively easy to obtain on farm-level compared to crop-level basis. Meanwhile, land allocation data are more likely to exist than data on allocation of water among competing crops.

Under this model, producers are assumed to act as though their production functions have constant returns to scale. Hence, their decision consists of the water/land ratios and land allocations (Just, *et al.*, 1990). This is based on the assumption that producers exchange information in assessing technologies and markets and to imitate one another. This allows water/land ratio decisions to be characterized by an overall average level and a systematic farmer deviation reflecting land quality, human ability, and perceptions. To develop the estimated form of this model, consider the following :

Let W*ki = Wki/Lki be the quantity of water per unit of land used by producer i in producing crop k. The systematic element of W*ki can be decomposed as follows:

$$W^*_{ki} = a_k + B_i \qquad (6)$$

Where a_k is an average regional use of water per unit of land in the production of crop k; Bi denotes deviations by farmer i from the regional average for use of water. Substitution of (6) into (5) gives:

$$W_i = \sum (a_k + B_i)L_{ki} + e_i \qquad (7)$$

Where ei is a random error term assumed to be normally distributed. Estimation of equation (7) requires regressing total use of water on the area allocated to each of the crops crossed with dummy variables correspond to the crop effect and farmer effect. The sum of estimated parameters (a_k + B_i), is an estimate for the per unit area allocation of water to crop k by farmer i. Multiplication of this estimate by the land allocated to the crop results in the behavioral estimate of the allocation of water to crop k.

$$\hat{W}^*_{ki} = (a_k + B_i)L_{ki} \qquad (8)$$

Equation (4) can be estimated using the ordinary least squares (OLS) procedure. In case of one-period cross–sectional data, this model can be estimated with no farmer differences.

Previous research has provided empirical evidence to the water allocation at the farm level using various modeling approaches. Caswell and Zilberman (1985) introduced an econometric technique to analyze the factors affecting the land shares of alternative irrigation technologies in agriculture. It estimates the likelihood of use of drip, sprinkler, and surface irrigation by fruit growers in the Central Valley of California. Higher water costs, the use of groundwater, the production of nuts, and location are found to increase the likelihood of using drip and sprinkler irrigation. The results are used to demonstrate the effectiveness of water price increases in inducing water conservation.

Applying a model of the multioutput firm, econometric results are reported for irrigated production in four multistate regions of the American West (Moore, Gollehan Carey, 1994a). Cross-sectional microdata and limited-dependent variable methods are used to estimate crop-choice, supply, land allocation, and water demand functions for field crops. Farm-level water demand is decomposed into the sum of crop-level water demand, and crop-level demands are further separated into an extensive margin (land allocations) and intensive margin (short-run water use). Response to water price (measured as groundwater pumping cost) occurs primarily at the extensive margin.

Moore, Gollehan, and Carey (1994b) compared three models of input allocation in multicrop systems. In addition to the variable input and satisficing models analyzed in previous research, an allocatable fixed input model of short-run input use is derived. The empirical application studies irrigation water use in the Central Plains region of the United States. Based on results from model specification tests and prediction accuracy measures, the allocatable fixed input model dominates both other models in explaining multicrop water allocation. In addition, the paper presents an alternative approach to the study of deficient data on multicrop production. By transferring econometric results from analysis of "non-deficient" crop-level data, input allocation in deficient data sets can be predicted.

Chamders and Just (1989) solved the problem of determining fixed but allocatable input allocations by dual methods. A flexible, profit function approach for estimating input-nonjoint technologies with allocatable fixed factors is developed. Variable input allocations can be calculated from the estimated technology. A correct test for input non jointness that discriminates between true and apparent jointness is derived in a framework that permits fully linear estimation of a second-order flexible technology.

Using data only on aggregate variable input use and land allocation, Just, *et al.* (1990) suggested a methodology for allocating variable input use among crops and improvement of regional crop budget information. Two approaches for estimation of variable input allocations among production activities are examined. One relies on behavioral rules whereby input allocative follows accepted rules of thumb. The alternative approach is derived from profit maximization where input use responds instantaneously to changes in input and output prices. The behavioral rules dominate instantaneous response to prices in explaining the data analyzed in this paper and suggest the validity of a sample behavioral approach for developing enterprise budgets and cost of production estimates.

The main problem in estimating non experimental agricultural production functions is that input data typically are not available by crop. A producer normally grows several crops, but the allocation of inputs among crops is not recorded. The most common case of data availability in agriculture is where total use of variable inputs, such as water, are observed but their allocations to various crop are not. On the other hand, allocation of the major fixed factor, land, is observed. Input and output prices and production are generally observable. Thus, a full information estimation approach must utilize the observed land allocations and compensate for the lack of information on allocation of other inputs. Just *et al.* (1983) addressed this issue of multicrop production function estimation with allocated inputs. The approach uses all available information from both technological and behavior assumptions in producing estimates of multi-output production functions where allocations of variable inputs among crops are unobserved.

Krulce, Roumasset, and Wilson (1997) modeled groundwater as a renewable resource and as replaceable at a fixed cost by a backstop resource (desalination). A steady state is reached when groundwater is depleted to the point where the efficiency price is equal to the unit cost of the backstop resource. Efficiency price (i. E., the marginal opportunity cost of water) is composed of three components: extraction cost, scarcity rent, and residual user cost (a term which is called "drawdown cost"). The drawdown cost, always equal zero for a nonrenewable resource, increases with depletion and in the steady state may be larger relative to extraction cost.

For cost recovery of water services in agriculture, three charging mechanisms were evaluated (Perry): (1) a flat rate, independent of crop type or cropping intensity; (2) a crop-based charge, broadly relating the service charge to water consumption; and (3) a volumetric charge. The results showed that full recovery of allocated costs to agriculture would reduce farm incomes by about 4.5 per cent. Imposition of flat rate charges has no impact on crop selection.

More interestingly, a crude crop-based charge (water charges set at levels proportional to typical farm demand, by crop) is almost exactly as efficient as full volumetric pricing in inducing beneficial shifts in cropping pattern toward more water-efficient crops. It is concluded that charges for water services will not induce significant charges in cropping patterns, or improvements in system performance, because the cost of system operation is low in relation to the benefits of irrigation.

Under present conditions of supply, volumetric charges for water are only marginally more successful in encouraging efficient water use than crop-based charges, which in turn are somewhat better than a flat land tax. Volumetric charges are an unrealistic means of encouraging significant reductions in demand, because very high charges are required to have a significant impact.

D. MODEL VALIDATION

Two methods are to be used to validate the proposed models. These are model specification tests and prediction accuracy measures. A pair-wise comparison approach is used for specification tests of the three models of short-run water use. Similarly, prediction performance measures will be used to estimate the prediction accuracy of the estimated models and thus, their validity. Potential prediction accuracy measures include Mean Absolute error (MAE), Root Mean Square Error

(RMSE), and Mean Absolute Percentage Error (MAPE). Like the model specification tests, the measures of prediction accuracy are calculated using a farm-level approach. The calculated measures thus, represent the accuracy of a model in predicting short-run water use for the set of m crops under consideration. Both in-sample and out-of-sample predictions are made to evaluate the alternative models.

The specified models of water use can be compared using model specification tests and prediction accuracy measures, following Moore et al. (1990). Using pairwise comparison, the multicrop approach described above applies the hypothesis tests as farm-level tests. This means that each comparison of farm-level models will be extended as a single equation test for the set of m crops. For empirical implementation, the crop-level water use data are combined simply by stacking the system of observations.

The first specification test can include the comparison of the variable input model and the satisfaction model by using a nested F-test. The empirical specification of the variable input model of equation (1) is:

$$\mathrm{i} = 1, \ldots\ldots, \mathrm{m}$$

$$\mathrm{W_i} = \alpha^i \beta^i p_i + \sum_{v=1}^{z} \gamma^i_v r_v + \delta^i r_w + \theta^i n_i + \sum_{s=1}^{t} \eta^i_s x_s \qquad (9)$$

The satisficing model of water use (Equation 4) is represented by a subset of variables in Equation (9), including crop acreage (n_i), weather, irrigation technology, and water management (X_s). Thus, the null hypothesis for the F-test is:

$$\beta^i = \gamma^i_v = \delta^i = 0 \qquad i = 1, \ldots\ldots, m \qquad (10)$$
$$i = 1, \ldots\ldots., z$$

This means that if the coefficients of own-price for the crop, variable input price, and water price are equal to zero, the null hypothesis is true and the satisficing model is the preferred model. Otherwise, the variable input model is the preferred model specification if the alternative hypothesis is true.

A second specification test would include the fixed, allocatable input model and the satisficing model using a nested F-test. The empirical specification of the allocatable fixed input model of Equation (3) is:

$$W_i = \alpha^i + \sum_{j=1}^{m} \beta^i_j p_j + \sum_{v=1}^{z} \gamma^i_v r_v + \sum_{k=1}^{m} \theta^i_k \eta_k + \psi^i w + \sum_{s=1}^{t} \eta^i_s x_s \qquad (11)$$

$$i = 1, \ldots., m$$

The null hypothesis for this test is that the coefficients on crop prices, variable input prices, crop acreage's (other own-crop acreage), and the farm-level water constraint are equal to zero, that means:

$$\beta_j^i = \gamma_v^i = \theta_k^i = \psi^i = 0 \qquad \begin{array}{c} i = 1,\ldots.,m \\ j = 1,\ldots.,m \\ v = 1,\ldots.,z \\ k = 1,\ldots.,m \\ i \neq k \end{array} \tag{12}$$

If the null hypothesis is true, the satisficing model is the preferred model. Otherwise, the fixed, allocatable input model is the preferred specification if the alternative hypothesis is true.

A third model specification test involves the variable input and fixed, allocatable input models using a non-nested F-test. This test includes every exogenous variable for the m crops' water use equation from these two models (i.e., combining equations 9 and 11). The empirical specification of the combined model is:

$$\begin{aligned} W_i = \alpha^i + \sum_{j=1}^{m} \beta_j^i p_j + \sum_{v=1}^{z} \gamma_v^i r_v + \delta^i r_w + \sum_{j=1}^{m} \theta_j^i \eta_j \\ + \psi^i w + \sum_{s=1}^{t} \eta_s^i x_s \qquad i = 1,\ldots,m \end{aligned} \tag{13}$$

The performance of the variable and fixed, allocatable input models are compared, independently, to the performance of the combined model (13). Water prices are the elements of the combined model that are unique to the variable input model. Thus, the first stage of the non-nested F-test is to test the null hypothesis that the coefficients on water price are equal to zero. This means:

$$\delta^i = 0 \qquad i = 1,\ldots,m \tag{14}$$

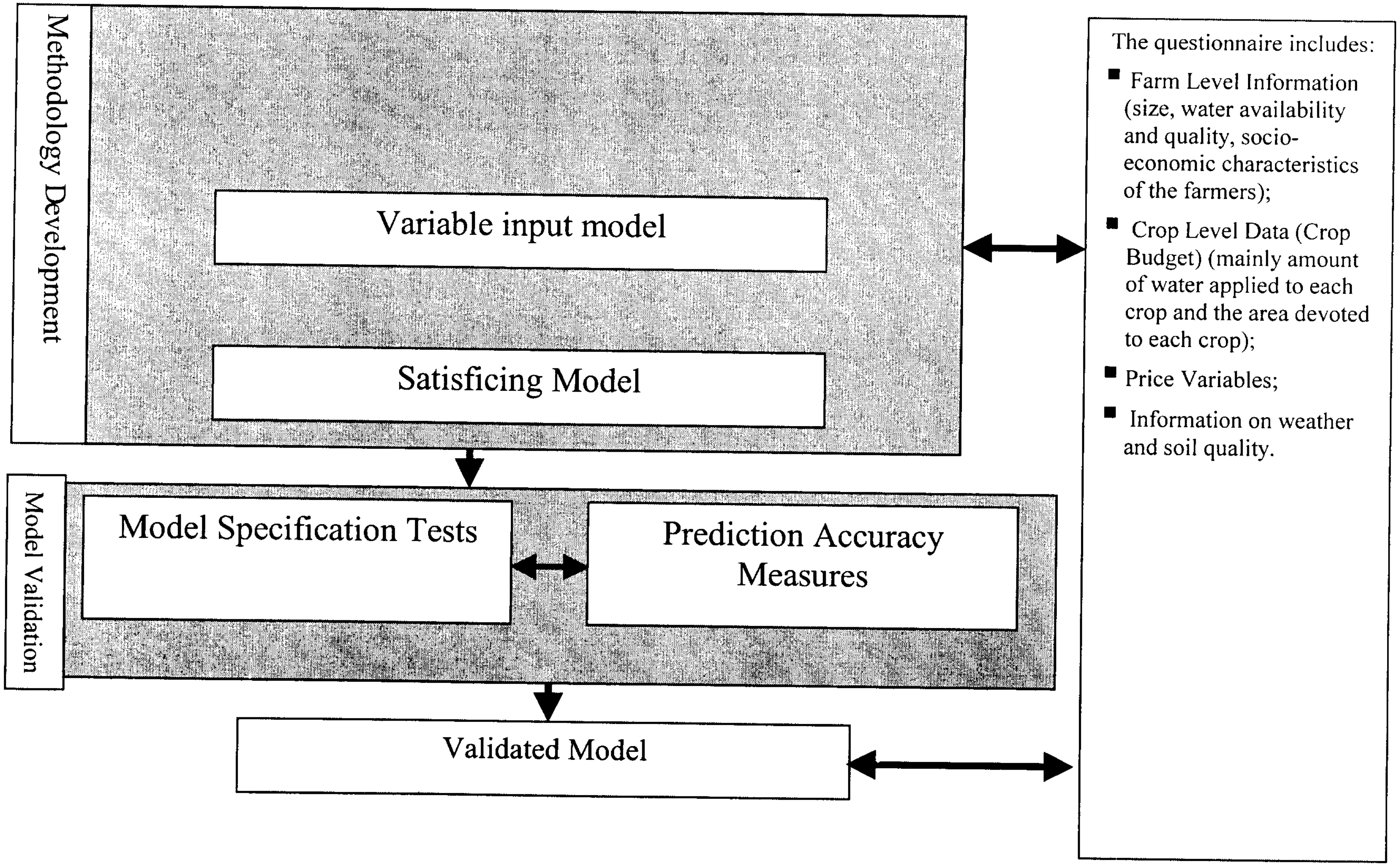
If the null hypothesis is true, the variable input model is rejected relative to the combined model. Otherwise, the variable input model is accepted as the preferred specification relative to the combined model, if the alternative hypothesis is true. The second stage of the non-nested F-test is to reject the fixed, allocatable input model if elements unique to this model (the farm – level water constraint and intercrop interdependencies in crop prices and acreages) do not independently explain variation in water use. The null hypothesis for this test is:

$$\beta_j^i = \theta_j^i = \psi^i = 0 \qquad \begin{array}{c} i = 1,\ldots,m \\ j=1,\ldots,m \\ i \neq j \end{array} \tag{15}$$

Otherwise, the allocatable, fixed input model is accepted as the preferred model specification relative to the combined model if the alternative hypothesis is true.

The above three tests of model specification are not necessarily conclusive as they can give either determinate or indeterminate results on model choice. For example, an indeterminate result would accur if the satisficing model is chosen over the variable input model in the first test and the fixed, allocatable input model is chosen over the satisficing model in the second test; but the variable input model is chosen over the fixed, allocatable input model in the third test. In contrast, a model will dominate if it is chosen in each of the two tests in which it is directly included.

Chart 1. Methodology development and data requirement



The questionnaire includes:

- Farm Level Information (size, water availability and quality, socio-economic characteristics of the farmers);
- Crop Level Data (Crop Budget) (mainly amount of water applied to each crop and the area devoted to each crop);
- Price Variables;
- Information on weather and soil quality.

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Similarly, a set of pairwise model specification tests can be implemented including variable input model, fixed, allocatable input model and satisficing model on one hand and the behavior model on the other hand.

The prediction accuracy measures support the findings of the model specification tests. Among various measures of prediction performance, three measures are commonly used and thus, recommended for this study. These are mean absolute error (MAE), root mean square error (RMSE), and mean absolute percentage error (MAPE). Mathematically, these measures can be presented as follows:

Where Y_t is the observed value of dependent variable for observation $\hat{Y}_t$, is the predicted value of dependent variable for observation t, and T_t is the number of observations.

Similar to the model specification tests, the prediction measures are calculated using farm-level data and conducted crop-by-crop. The measures thus, represent the accuracy of a model in predicting short-run water use for each of m crops under consideration. Both in-sample and out-of-sample predications need to be calculated for evaluating the alternative models of water use.

$$MAE = \frac{1}{T}\sum_{t=1}^{T} \left|\hat{Y}_t - Y_t\right|$$

$$RMSE = \sqrt{\frac{1}{T}\sum_{t=1}^{T} (\hat{Y}_t - Y_t)^2}$$

$$MAPE = \frac{1}{T}\sum_{t=1}^{T} \left[\frac{\left|\hat{Y}_t - Y_t\right|}{Y_t}\right]$$

Another methods for model validation include the plausibility of the estimated model. An example, is the comparison of water use recommendations by farm advisors in the region with the amount of water used calculated by a model (Just *et al.*, 1990). The recommendations represent a range of water application rates that the extension agents consider to reflect sound agricultural practices to the region. Other measures used to evaluate the reliability of the estimated models, include log-likelihood function and the percentage of correct predictions (Caswell and Zilberman, 1985).

E. DATA REQUIRED AND VARIABLE MEASUREMENTS

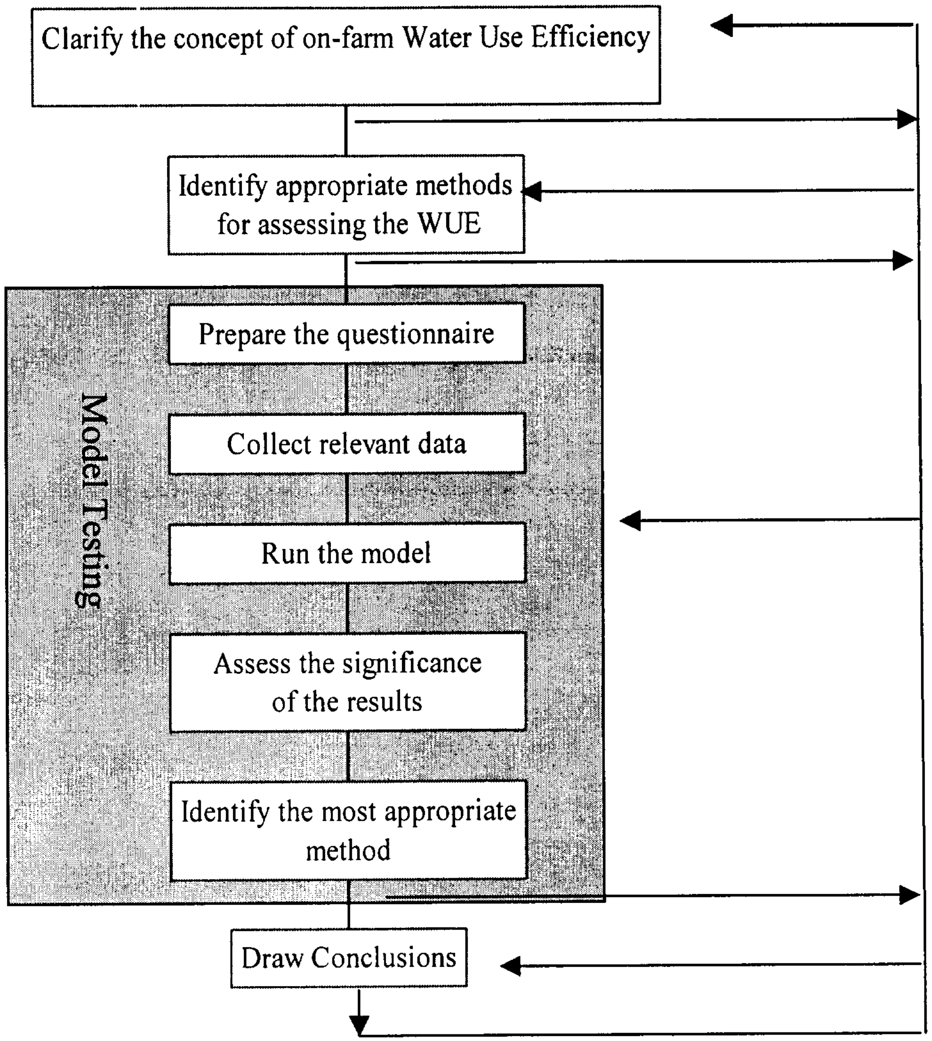
Different sets of information and data need to be collected from farm survey and secondary sources. These include farm-level data (e.g., size of the farm, total amount of water available to the farm and socio-economic characteristics of the producers), crop-level data (e.g., amount of water applied to each crop and area devoted to the crop), price variables, weather information and soil quality data. A detailed listing of data required is as follows:

(a) Irrigation water use by crop;
(b) Crop-level area;
(c) Irrigation technology for the whole farm and for each crop;
(d) On-farm irrigation practices (e.g., water sources, groundwater depth, and water management);
(e) Farm-level irrigation technology use in hectares;
(f) Crop-level qualitative and quantitative information on irrigation technology use;
(g) Farm-level qualitative information on water management;
(h) Size of the farm;
(i) Total amount of water applied and available for the whole farm;
(j) Water price (cost);

(k) Pumping depth;
(l) Pumping pressure;
(m) Fuel price;
(n) Fuel efficiency;
(o) Pumping pressure in pounds per square inch;
(p) Surface water availability;
(q) Pressure irrigation technology (sprinkler and drip);
(r) Yield levels for produced crops;
(s) Input use for each crop (e.g., fertilizers, seed, labor, pesticides, etc);
(t) Weather variables (total precipitation, solar energy availability, etc);
(u) Soil quality variables (e.g., sandy soils, restrictions on soil use etc);
(v) Socio-economic characteristics of the producers;
(w) Input prices (e.g., fertilizer prices, wage rate etc).

To collect required data for methodology testing and validation, a questionair has been developed and pre-tested. The questionnaire covers various farm-level and crop-specific informations including socioeconomic characteristics of producers, size of holdings. Sources of houseld income, soil characteristics, cropping pattern, water availability and cost. In addition, detailed information on input use and allocation, type of land tenure, output levels, input and output prices, amount of water applied, irrigation technology, and annual water budget are included for each crop. Similarly, groundwater quality and wells characterization as well as water management practices used in the farm are included in the questionnaire and will be collected from the farm survey.

Chart 2. The iterative process of model testing



V. CASE STUDY ONE: GHORS, JORDAN

A. CHARACTERISTICS OF SAMPLE FARMS

The sample farms in the Ghors area of Jordan comprised 70 producers, distributed among 23 villages. The villages are clustered into two districts (North Ghors and Deir Alla Ghors) with most of the producers located in the North Ghors district (63 per cent). The rest of the producers, 37 per cent are located in the Deir Alla Ghors.

Most of the sample farms (63 per cent) are located in a rainfall zone of 350-500 mm, with an average rainfall of 425 mm. Whereas, 37 per cent are in a rainfall zone of 150-300 mm, with an average annual rainfall of 225 mm. The producers' experience in irrigation ranged from 1 to 47 years, with an average of 17 years. The majority of the farmers (89 per cent) are full-time operators, and only 11 per cent are part-time producers. Farming is the main source of income, with 83 per cent of the producers completely dependent on farm income (which accounts for 100 per cent of the household income). The rest of the farmers (17 per cent) are only partially dependent on farm income (which accounts for 20 to 90 per cent of the household income). Crop production accounts for 100 per cent of the farm income, as reported by 97 of the producers interviewed.

Soil type is mainly medium on 79 per cent of the farms, while 13 per cent and 8 per cent of the producers indicated that their soil type was of sandy and heavy types, respectively. Most farms (67 per cent) are of medium soil, and deep and shallow soil account for 29 per cent and 4 per cent of the total farms, respectively. Meanwhile, 63 per cent of the farmers reported that soil salinity is low. Whereas, 29 per cent and 8 per cent of the farmers indicated that soil salinity is medium and high, respectively.

The current cropping pattern is mainly determined by market conditions, as indicated by 66 per cent of the sample farmers, whereas the cropping pattern of 27 per cent of the producers is jointly determined by market conditions and agricultural policies. Other factors explain the cropping pattern of the remaining 7 per cent of the producers. The amount of water available to the farm is strictly limited, as indicated by 86 per cent of the producers. Only 14 per cent of the farmers reported that available water is not limited. However, land use is not restricted as indicated by 71 per cent of the producers. Location of water source relative to the farm is not of main concern, since 94 per cent of the farms are of head water location. Many restrictions, in the form of quantity, quality and regulations, are imposed on water availability. Restrictions on water quantity and quality are reported by 98 per cent and 77 per cent of the producers, respectively.

Moreover, regulation restrictions are also imposed, as indicated by 94 per cent of the producers. Irrigation date is another type of water restrictions imposed on 96 per cent of the farms. The main reason for irrigating crops is that the amount of rainfall is not sufficient for an economic rainfed yield, as indicated by 97 per cent of the sample farmers. General rules and irrigation experience determine the amount of water the farmers apply to each crop, according to the survey sample.

Rented land is the predominant land tenure feature in the sample farms, as reported by 52 per cent. The rest of the sample farms are characterized by private ownership (17 per cent) and share-cropped land ownership (31 per cent). All farms are fully irrigated from surface water sources. Other features of the sample farms are depicted in table 1. Among the 70 sample farms, 26 farmers produce tomatoes, 21 farmers produce potatoes, 12 produce squash, 12 produce peppers, 21 produce cucumber, 10 produce cauliflower, 19 produce citrus crops, 7 produce melons, 6 produce wheat, 7 produce eggplant, 8 produce lettuce, 14 produce beans, 9 produce broad beans, 7 produce cabbage and 8 produce onions. The total farm size average is 5.90 ha. The average crop area for tomatoes is 1.13 ha, for potatoes 1.93 ha, for squash 1.02 ha, for peppers 0.65 ha, for cucumber 0.74 ha, for cauliflower 0.39 ha, for citrus 3.09 ha, for melons 0.37 ha, for wheat 0.60 ha, for eggplant 0.74 ha, for lettuce 0.95 ha, for beans 1.92 ha, for broad beans 1.36 ha, for cabbage 0.84 ha and for onions 0.53 ha.

Water applied to the whole farm is on average 12283.71 m^3 for the sample producers, at 4030.33 m^3 for tomatoes, 2212.46 m^3 for potatoes, 2203.2 m^3 for squash, 3780 m^3 for peppers, 4660.20 m^3 for cucumber, 2877.12 m^3 for cauliflower, 12125.56 m^3 for citrus, 3221.48 m^3 for melons, 2160 m3 for wheat, 7109.48 m^3

for eggplant, 2284.2 m^3 for lettuce, 2041.14 m^3 for beans, 3110.4 for broad beans and cabbage, each and 2770.2 m^3 for onions. The annual rainfall for the study area during the 2000/2001 season was 350.71 mm, with a standard division of 97.3 mm. The crop yield was the highest, for tomatoes 60.3 ton/ha, followed by cucumber, 52.2 ton/ha. The crop yields of other crops are presented in table 1. Water productivity, defined in technical terms as kg of output per m^3 of water, is the highest for tomatoes and lettuce (8.48 kg/m^3 and 7.22 kg/m^3, respectively). If the amount of rainfall is excluded, the crop water productivity will change considerably. The highest water productivity of 17.84 kg/m^3 is for potatoes and beans, each. The water productivity of tomatoes (16.89 kg/m^3) and lettuce (16.97 kg/m^3) comes second in order (table 1). These results indicate that water yields more output in the production of tomatoes, potatoes, lettuce and beans. This result, however, is mainly based on technical efficiency. To better represent farm economic conditions, output prices need to be taken into account as well. Thus, water productivity will be redefined in monetary terms as Jordanian Dinars (JD) of output per m3 of water (table 2). Under this definition, the water productivity is the highest for lettuce (1.877 JD/m^3), followed by beans (1.806 JD/m^3), then broad beans (1.01 JD/m^3). These results show that changing the definition of water productivity from technical to monetary terms has important implications on the ranking of crops with respect to water productivity. Although tomatoes come in the first order under the concept of technical efficiency, they come in the fourth place when monetary concept is used.

TABLE 1. DESCRIPTIVE STATISTICS FOR SAMPLE FARMS IN THE GHORS AREA

Item	Total farm	Crops						
		Tomatoes	Potatoes	Squash	Peppers	Cucumber	Cauliflower	Citrus
Number of farms	70	26	21	12	12	21	10	19
Area (ha)								
Mean	5.90	1.13	1.93	1.02	0.65	0.74	0.39	3.09
SD*	9.83	0.96	2.30	0.53	0.85	0.62	0.23	1.77
Crop yield (kg/ha)								
Mean		60267.86	20446.00	21700.00	NA[b/]	52230.55	NA[b/]	22503.74
SD*		22267.93	6534.40	8594.29		35986.14		15007.64
Water applied (m^3)								
Mean	12283.71	4030.33	2212.46	2203.2	3780.00	4660.20	2877.12	12125.56
SD*	6368.07	353.42	267.40	0	667.35	719.53	200.78	423.04
Irrigation (m^3/ha)	2082.0	3566.66	1146.35	2160.0	5815.38	6297.57	7377.23	3924.13
Experience in irrigation (year)	17	16	14	17	16	16	20	22
Rainfall (mm)								
Mean	350.71	353.57	339.28	341.67	341.67	333.33	345.0	393.42
SD*	97.33	97.59	101.42	102.98	102.98	101.79	103.28	79.93
Total water use (irrigation + rainfall) m^3/ha	5589.1	7102.36	4539.15	5576.7	9232.08	9630.87	10827.23	7858.33
Water productivity (kg/m^3)[a/]		8.48 16.89[c/]	4.50 17.84[c/]	3.89 10.05[c/]	NA[b/] NA[b/]	5.42 8029[c/]	NA[b/]	2.86 5.73[c/]

Item	Total farm	Crops							
		Melons	Wheat	Eggplant	Lettuce	Beans	Broad beans	Cabbage	Onions
Number of farms	70	7	6	7	8	14	9	7	8
Area (ha)									
Mean	5.90	0.37	0.60	0.74	0.95	1.92	1.36	0.84	0.53
SD*	9.83	0.25	0.26	0.43	0.56	5.22	1.07	0.62	0.27
Crop yield (kg/ha)									
Mean		NA[b/]	3083.33	35857.14	40812.5	18965.5	11355.56	33571.43	25125.0
SD*			482.35	20852.09	7652.9	5476.79	3055.78	11043.21	4397.64

TABLE 1 (*continued*)

Item	Total farm	Crops							
		Melons	Wheat	Eggplant	Lettuce	Beans	Broad beans	Cabbage	Onions
Number of farms	70	7	6	7	8	14	9	7	8
Water applied (m^3)									
Mean	12283.71	3221.48	2160.00	7109.48	2284.2	2041.14	3110.40	3110.40	2770.20
SD*	6368.07	623.47	529.09	1138.29	437.78	262.12	0	0	259.78
Irrigation (m^3/ha)	2082.0	8706.7	3600	9607.4	2404.42	1063.1	2287.06	3702.86	5226.8
Experience in irrigation (year)	17	10	16	18	17	13	16	17	14
Rainfall (mm)									
Mean	350.71	339.28	325.0	367.85	325.0	339.28	336.11	253.57	300.0
SD*	97.33	106.90	109.54	97.59	106.9	102.71	105.41	75.59	103.51
Total water use (irrigation + rainfall) m^3/ha	5589.1	12099.5	6850	13285.90	5654.42	4455.9	5648.16	6238.56	8226.8
Water productivity (kg/m^3)[a]		NA[b] NA[b]	0.45 0.86[c]	2.70 3.75[c]	7.22 16.97[c]	4.26 17.84[c]	2.01 4.96[c]	5.38 9.07[c]	3.05 4.81[c]

* SD = Standard deviation.

a/ Water – productivity = crop yield/total water used (irrigation + rainfall).

b/ Not available.

c/ Amount of rainfall is not included in the calculation of water productivity, i. e., water – productivity = crop yield/ irrigation water applied.

TABLE 2. WATER PRODUCTIVITY (JD/M^3)

Crop	Price (JD/kg)	Water productivity (kg/m^3)		Water productivity (JD/m^3)	
		With rainfall	Without rainfall	With rainfall	Without Rainfall
Tomatoes	0.101	8.48	16.89	0.856	1.706
Potatoes	0.160	4.50	17.84	0.720	2.854
Squash	0.173	3.89	10.05	0.673	1.739
Cucumber	0.138	5.42	8.29	0.748	1.144
Citrus	0.256	2.86	5.73	0.732	1.467
Wheat	0.200	0.45	0.86	0.090	0.172
Eggplant	0.175	2.70	3.73	0.481	0.653
Lettuce	0.260	7.22	16.97	1.877	4.412
Beans	0.424	4.26	17.84	1.806	7.564
Broad beans	0.500	2.01	4.96	1.005	2.480
Cabbage	0.157	5.38	9.07	0.845	1.424
Onions	0.131	3.05	4.81	0.400	0.630

To better assess water use efficiency, analyzing water allocation among competing crops in a multi-crop system is highly recommended. This study is directed toward this end.

B. MODEL ESTIMATION AND EMPIRICAL RESULTS

Producers in the Ghors are multi-crop farmers who choose among several crops commonly grown as a part of a multi-crop system in the area. Information from sample farms indicates that Ghors producers are multi-crop growers of tomatoes, potatoes, squash, peppers, cucumbers, cauliflowers, citrus, melons, wheat, eggplants, lettuce, beans, broad beans, cabbage and onions. All data is collected from a farm survey conducted in Jordan during the Summer of 2001, and includes information on crop production, input use, output and input price variables and water management practices for the 2000/2001 season. The survey also includes questions on crop-level acreage, irrigation technology, soil information, water sources, rainfall, annual water budget and on-farm irrigation practices. Irrigation water use by each crop represents the dependent variable for the analysis.

Several quantitative and qualitative independent variables are formed from the survey data. The quantitative variables include irrigated area (ha) planted in each crop, output price of each crop (JD/kg), amount of total water available to the farm (m^3), farmer experience in irrigation (year), amount of rainfall (mm), water price (JD/ha/year) and prices of variable inputs, such as fertilizers (JD/kg). The set of qualitative variables includes dummy variables on water location to the farm, soil type, soil salinity, soil depth, crop irrigation technology and water management practices.

Following methodology development for on-farm water use, the three specified models of the fixed allocatable input model, the variable input model and the satisficing (behavioral) model are estimated using the ordinary least squares procedure (Oweis, Shideed and Gabr, 2000). Comparing the estimated coefficients of the three models shows that the estimates are not plausible based on economic theory in terms of the signs of price and acreage variables. For example, it is expected a priori that the effect of a crop price on water use is positive. However, estimated coefficients demonstrate negative relationships between crop prices and amount of water use. Similarly, the estimates do not support the negative relationship between water price and its use. Therefore, the estimates of variable input model and fixed, allocatable input models are not used for the rest of the analysis. Instead, simplified estimates of the behavioral model are used. This is consistent with irrigation water use in the Ghors of Jordan. Results of the survey clearly demonstrate that water allocation among competing crops is mainly determined by the area planted in each crop. Economic conditions, according to sample farms, do not affect water allocation and application among crops. Further, the amount of water applied to each crop is mainly determined by general rules and farmers' experience. Under these circumstances the main problem facing farmers in the Ghors area is allocation of water resource among competing crops, and this can be easily done by using the behavioral model. Survey data indicate that the amount of irrigation water applied for squash, broad beans and cabbage is fixed for all farmers producing these crops. Consequently, no models were estimated for these three crops. The estimates of the behavioral model for the remaining crops are presented in table 1 of the appendix. The behavioral estimates provide a simple procedure for estimating water allocation among crops. The remaining of this section presents water allocation among competing crops and its deviation from actual water use.

C. WATER USE EFFICIENCY

Farmers rely on extension information and their irrigation experience to allocate water among competing crops. Since farmers are independent decision makers, there is a wide variation in the share of land allocated to different crops among farmers. The land allocation has a direct impact on the amount of water allocated there after. Results of farm survey reveal that farmers behave as if their production functions follow constant returns to scale. Therefore, farmers adapt recommended input- output ratios (norms) developed by extension system. However, individual farmers deviate from these norms according to their specific personal and locational characteristics (Just, *et al.*, 1990).

Table 3 presents estimated and actual water use, as an average of sample farms, derived from the behavioral model. Estimated (required) quantity of water represent the amount of water required to produce the output levels actually produced by the sample farms. Water-use efficiency (WUE) is defined as the ratio of the required amount of water to produce a target production level to the actual amount of water used. The target production levels of the crops are the average yield levels of the sample farms as reported in the table. To obtain the required amount of water to produce these average yield levels, the estimated crop equations of the behavioral model are used. This is done by calculating the amount of water required for each crop at the mean levels of the independent variables appearing in that equation. The calculated levels of required water are presented in table 3 and compared with the actual amount of water used. If the amount of rainfall is not included in the calculation of actual water used, the estimated WUE demonstrates perfect efficiency of water use in the production of all crops. In fact potatoes, peppers, lettuce and onions require more water than actual water applied to produce the achieved yield levels by sample farms. Above-average yields and a very efficient use of irrigation can explain these estimates of very high ratios of WUE for all crops. This explanation is particularly applicable to Jordan where water is very scarce resource and its use is well managed administratively and at the farm level using a high efficient technology of drip irrigation. If the amount of rainfall is taken into consideration in the calculation of WUE, the efficiency of irrigation water will drop sharply, implying that producers over-irrigate their crops. The percentage of over-irrigation ranged from a minimum of 23 per cent in the production of citrus crops to a maximum of 70 per cent in the production of wheat. Citrus and eggplant productions are relatively more efficient with a WUE of 0.77 per cent and 0.66 per cent, respectively. Farmers of potatoes, cauliflower, melons, wheat, lettuce, beans and onions are less efficient as they exceed water requirements by more than 50 per cent. Producers of tomatoes, peppers and cucumbers achieved medium level of water use efficiency as they exceed water requirements by less than 50 per cent.

Farmers over-irrigate crops because of their perceptions of water requirements and their expectations of rainfall and market conditions. The low ratios of water use efficiency in potatoes, cauliflower, melons, wheat, lettuce, beans and onion production suggest that a wide technology gap exists between the recommended irrigation in the study area. This result has important policy implications, since Jordan is classified as a water-scarce country. Therefore, improving water use efficiency for these crops can contribute to the overall water use efficiency for the agricultural sector.

There is an important observation that needs to be investigated further. Rainfall in Jordan is often not distributed adequately and timely in line with plant needs. Large gaps between rainfall periods negatively affect the plant. Also rainfall that occur when the plant doesn't need water can cause damage to the plant. Therefore farmers should always irrigate when necessary in line with the plant requirements due to the irregularities of rainfall. WUE estimations then can be misleading when rainfall is considered.

TABLE 3. ESTIMATED AND ACTUAL WATER USE IN THE GHORS AREA, JORDAN

Crop	Irrigated area	Yield (ton/ha)	Actual water used (m^3)	Required water (m^3)	WUE[a/]	WUE[b/]
Tomatoes	1.13	60.30	4 037.56	4 013.79	0.99	0.53
Potatoes	1.93	20.45	2 212.46	2222.24	1.00	0.40
Squash	1.02	21.70	2 203.20	N.A[c/]	N.A[c/]	N.A[c/]
Peppers	0.65	N.A	3 780.00	3823.81	1.00	0.53
Cucumber	0.74	52.23	4 660.20	4572.03	0.98	0.56
Cauliflower	0.39	N.A	2 877.12	2914.25	1.00	0.46
Citrus	3.09	22.50	12 125.56	12046.49	0.99	0.77
Melons	0.37	N.A	3 221.49	2938.01	0.91	0.44
Wheat	0.60	30.83	2 160.00	1684.13	0.78	0.30
Eggplant	0.74	35.86	7 109.48	6998.57	0.98	0.66
Lettuce	0.95	40.81	2 284.20	2304.84	1.00	0.40
Beans	1.92	18.97	2 041.14	2023.26	0.99	0.37
Broad beans	1.36	11.36	3 110.40	N.A[c/]	N.A[c/]	N.A[c/]
Cabbage	0.84	33.57	3 110.40	N.A[c/]	N.A[c/]	N.A[c/]
Onions	0.53	25.00	2 770.20	2808.74	1.00	0.45

Note: Water use efficiency (WUE) is defined as the ratio of the amount of required water to the actual water used.

a/ This figure does not include rainfall.

b/ This figure also includes rainfall water quantity estimated at 3500.17 m^3

c/ The amount of water applied is fixed for all farmers, thus required water would not be estimated.

VI. CASE STUDY TWO: NUBARIA, EGYPT

A. CHARACTERISTICS OF SAMPLE FARMS

In the Nubaria area of Egypt, the sample farms comprise 50 producers distributed equally among three villages. The producers' experience in irrigation ranges from 1 to 41 years, with an average of 17.4 years. Surface water is the main source of irrigation for all farmers in the survey. Main produced crops are wheat, faba beans and bersem for winter cropping, whereas, summer cropping includes water melons, tomatoes, green pepper, squash and corn. The soil type is predominantly medium (94 per cent of the sample farms). Most farms (66 per cent) are of deep soil, and the remaining 37 per cent are of medium and shallow soils. Meanwhile, 56 per cent of the farmers reported that soil salinity is low, whereas, 30 per cent and 14 per cent of the farms are of medium and heavy salinity, respectively.

The current cropping pattern is mainly determined by market conditions in the first place and agricultural rotation in the second place as indicated by 98 per cent of the sample farms. Meanwhile, the selection of crops is mainly made based on market conditions as indicated by 72 per cent of the farms. Labor requirements for crops is the second important factor in crop selection as reported by 24 per cent of the sample farms. Location of water source to the farm is the main concern to the sample farms, since only 36 per cent are of head location, while 64 per cent are of medium or tail locations. This is an important factor, since surface water is the main source of irrigation.

Most farmers (80 per cent) are full-time operators, whereas, 20 per cent are part time farmers. Farming is the main source of household income. Farm income accounts for 84 per cent of the total income, while off-farm income contributes to 16 per cent of the household income. Crop production is the main source of farm income (81 per cent), whereas livestock production accounts for 19 per cent of farm income.

Other characteristics of the sample farms are presented in table 4. Among the 50 samples, 43 farmers produce wheat, 34 produce faba beans, 28 produce bersem, 30 farmers produce water melons, 26 produce tomatoes, 7 produce green peppers, 22 produce squash and 21 produce corn. Other crops are produced by a negligible number of producers. The total farm size averages 5.7 feddan, while the average crop area is 2.16 feddan for wheat, 1.78 feddan for faba beans, 1.23 feddan for bersem, 2.30 feddan for water melons, 0.81 feddan for tomatoes, 0.57 feddan for green peppers, 2.98 feddan for squash and 0.64 feddan for corn. Among winter crops, wheat accounts for 36 per cent of total irrigated land, while 30 per cent and 21 per cent of the land is allocated for faba beans and bersem, respectively. For summer cropping, more land is devoted for water melons and squash compared to other crops.

Water available to the entire farm is 67100.66 m^3 as an average for the sample farms. The water application by crop for winter cropping is 2328.3 m^3/feddan for wheat, 1764.4 m^3/feddan for faba beans and 3500.73 m^3/feddan for bersem. For summer cropping, water application, as an average for the sample farms, is 1699.92 m^3/feddan for water melons, 2333.08 m^3/feddan for tomatoes, 3030.07 m^3/feddan for green peppers, 2139.0 m^3/feddan for squash and 2979.4 m^3/feddan for corn. According to the sample farms, the amount of water applied to each crop is mainly determined by the crop's water requirement as indicated by 90 per cent of the farmers. Extension recommendations explain the remaining 10 per cent of the sample in explaining the amount of water application to each crop.

Water productivity, defined in technical terms as kg of output per m^3 of water, is the highest for bersem (7.24 kg/m^3) in winter cropping and water melons (3.5 kg/m^3) in summer cropping. Therefore, water yields more output in bersem production, compared to wheat and faba beans in winter cropping. Each additional m^3 of water yields 7.24 kg of bersem output, whereas the output of other crops is much lower for each additional unit of water. For summer cropping, water gives more output in water melons production, compared to tomatoes, green peppers, squash and corn.

B. MODEL ESTIMATION AND EMPIRICAL RESULTS

Following methodology development of on-farm water use, the three specified models of fixed-allocatable input model, variable input model and satisficing (behavioral) model are estimated using on-farm data of 50 producers. The estimated models are presented in tables 5 to 7 for winter cropping and tables 8 to 10 for summer cropping. Having estimated these models, the second step involves the comparison of alternative models, using prediction accuracy measures as a mean of model validation.

Both in- sample and out-of-sample forecasts for crop-level water use are made and compared with the actual on-farm water applications. Three measures of prediction accuracy are used to judge the performance of alternative models, and thus provide evidence on model choice. The measures of MAE, RMSE and MAPE are calculated to compare the models of on-farm water use for each crop. A summarized calculations are presented in tables 11 and 12 for winter and summer cropping, respectively.

TABLE 4. DESCRIPTIVE STATISTICS OF SAMPLE FARMS IN NUBARIA, EGYPT

Item	Total farm	Winter cropping			Summer cropping				
		Wheat	Faba beans	Bersem	Water melons	Tomatoes	Green peppers	Squash	Corn
Number of farms	50	43	34	28	30	26	7	22	21
Area (Feddan)$^{a/}$									
Mean	5.97	2.16	1.78	1.23	2.30	0.81	0.57	2.98	0.64
SD*	0.16	1.32	1.50	1.56	1.92	0.98	0.53	2.77	0.76
Crop yield (Ton/Feddan)									
Mean		2.9	0.68	32.86	9.66	6.75	4.00	4.35	2.57
SD*		4.2	0.52	49.13	25.27	9.38	3.83	5.00	5.49
Water applied (m^3)									
Mean	10049.46	2328.23	1764.4	3500.73	1699.92		3030.07	2139.00	2979.40
SD*	4442.90	663.32	830.0	1145.98	511.32	2333.08	1165.07	1425.09	736.42
Experience in irrigation (year)	17.42	17.2	16.3	17.9	17.30	16.2	21.6	15.5	15.4
Water productivity (kg/m^3)		0.86 1.24$^{c/}$	0.24 0.39$^{c/}$	7.24 9.39$^{c/}$	3.5 5.68$^{c/}$	2.00 2.89$^{c/}$	0.98 1.32$^{c/}$	1.37 2.03$^{c/}$	0.64 0.86$^{c/}$

* SD = Standard deviation.

a/ Feddan = denotes area unit in Egypt (1 hectare = 2.38 Feddan).

b/ Water productivity = crop yield/total water applied (irrigation + rainfall).

c/ Amount of rainfall is not included in the calculation of water productivity, i. E., water- productivity = crop yield/irrigation water applied.

TABLE 5. ESTIMATES OF ON-FARM WATER USE IN NUBARIA, EGYPT FOR WINTER CROPPING: FIXED ALLOCATABLE INPUT MODEL

Independent variables	Wheat	Faba beans	Bersem
Intercept	-771.00	1267.13*	-496.13
	(1-.06)	(1.74)	(-0.64)
Bersem price (LE/ton)$^{a/}$	-83.22**	-100.41**	183.64**
	(-4.57)	(-5.51)	(9.47)
Faba bean price (LE/ton)	-6.68	-12.38	19.06
	(-0.48)	(-0.88)	(1.27)
Wheat price (LE/ton)	10.91*	-11.68**	0.774
	(2.40)	(-2.57)	(0.16)
Bersem area (Feddan)	148.12*	-123.65	-24.48
	(1.73)	(-1.44)	(-0.27)
Wheat area (Feddan)	191.82*	-104.57	-87.25
	(2.22)	(-1.21)	(-0.95)
Faba bean area (Feddan)	201.96**	-159.80**	-42.15
	(3.17)	(-2.51)	(-0.62)
Price of urea (LE/kg)	215.38	-8.07	-207.32
	(0.77)	(-0.03)	(-0.70)
Total water (m^3)	0.331**	0.334**	0.335**
	(8.28)	(8.35)	(7.87)

TABLE 5 (*continued*)

Independent variables	Wheat	Faba beans	Bersem
Soil salinity (0,1)c/	36.29 (0.18)	-222.65 (-1.13)	186.35 (0.89)
Soil depth (0,1)d/	-261.31 (-1.17)	-62.81 (-0.28)	324.12 (1.37)
Experience in irrigation (years)	11.60 (1.03)	1.82 (0.16)	-13.42 (-1.11)
R^2	0.71	0.74	0.91
D-W Statistics	1.86	1.52	1.83
F-Statistics	8.57**	9.60**	35.22**

Note: Numbers in parantheses refer to the calculated values of t - statistics.
* and **: Significant at 5 per cent and 1 per cent level of significance, respectively.

a/ LE = denotes Egyptian pound.
b/ Feddan = denotes area unit (1 hectare = 2.38 Feddan).
c/ Dummy variable for soil salinity, taking a value of 1 for low salinity and zero otherwise.
d/ Dummy variable for soil depth, taking a value of 1 for deep soil and zero otherwise.

TABLE 6. ESTIMATES OF ON-FARM WATER USE IN NUBARIA, EGYPT FOR WINTER CROPPING: VARIABLE INPUT MODEL

Independent variables	Wheat	Faba beans	Bersem
Intercept	958.04 (1.09)	785.39 (1.11)	973.74 (1.09)
Wheat area (Feddan)a/	-30.13 (-0.31)		
Wheat price (LE/ton)b/	7.95 (1.38)		
Faba bean area (Feddan)		5.45 (0.09)	
Faba beans price (LE/ton)		-0.91 (-0.05)	
Bersem area (Feddan)			-106.32 (-1.05)
Bersem price (LE/ton)			266.93** (10.74)
Water price (LE/Feddan/year)	66.89** (5.74)	58.35** (5.85)	-17.60 (-1.62)
Soil salinity (0,1)c/	140.98 (0.58)	133.53 (0.51)	218.68 (0.70)
Soil depth (0, 1)d/	-381.12 (-1.42)	-315.07 (-1.13)	203.52 (0.62)
Experience in irrigation (years)	-22.11 (-1.52)	-22.11 (-1.54)	-36.16* (-2.01)
Price of urea (LE/kg)d/	101.57 (0.28)	30.21 (0.09)	-9.48 (-0.02)
R^2	0.44	0.50	0.76
D-W Statistics	2.27	1.80	1.92
F-Statistics	4.8**	6.00**	18.75

Note: Numbers in parantheses refer to the calculated values of t - statistics.
* and **: Significant at 5 per cent and 1 per cent level of significance respectively.
a/ Feddan = denotes area unit (1 hectare = 2.38 Feddan).
b/ LE = denotes Egyptian pound.
c/ Dummy variable for soil salinity, taking a value of 1 for low salinity and zero otherwise.
d/ Dummy variable for soil depth, taking a value of 1 for deep soil and zero otherwise.

TABLE 7. ESTIMATES OF ON-FARM WATER USE IN NUBARIA, EGYPT FOR WINTER CROPPING: BEHAVIORAL MODEL

Independent variables	Wheat	Faba beans	Bersem
Intercept	-416.56 (-0.62)	-489.84 (-0.76)	591.29 (0.82)
Wheat area (Feddan)[a/]	-67.33 (-0.90)		
Faba bean area (Feddan)		-30.74 (-0.56)	
Bersem area (Feddan)			-70.28 (-0.83)
Soil salinity (0,1)[b/]	-103.47 (-0.56)	57.51 (0.26)	-41.30 (-0.16)
Soil depth (0,1)[c/]	66.22 (0.33)	-22.32 (-0.10)	-42.45 (-0.15)
Experience in irrigation (years)	3.33 (0.31)	-5.89 (-0.46)	-26.73* (-1.79)
Price of urea (LE/kg)[d/]	229.25 (0.87)	334.75 (1.21)	4.42 (0.01)
Crop effect (0,1)[e/]	2 427.09** (9.15)	1 774.12** (7.74)	3 516.58** (13.86)
R^2	0.66	0.61	0.83
D-W Statistics	2.31	2.06	2.04
F-Statistics	14.13**	11.14**	34.28**

Note: Numbers in parantheses refer to the calculated values of t - statistics.

* and **: Significant at 5 per cent and 1 per cent level of significance.

a/ Feddan = denotes area unit (1 hectare = 2.38 Feddan).

b/ Dummy variable for soil salinity, taking a value of 1 for low salinity and zero otherwise.

c/ Dummy variable for soil depth, taking a value of 1 for deep soil and zero otherwise.

d/ LE = denotes Egyptian pound.

e/ Dummy variable for crop effect, taking a value of 1 if the farmer produces that crop and zero otherwise.

TABLE 8. ESTIMATES OF ON-FARM WATER USE IN NUBARIA, EGYPT FOR SUMMER CROPPING: FIXED ALLOCATABLE INPUT MODEL

Independent variables	Water melons	Tomatoes	Green peppers	Squash	Corn
Intercept	1389.10 (1.47)	11.75 (0.01)	-1663.60 (-1.51)	478.43 (0.40)	-215.68 (-0.14)
Water melon area (Feddan)[a/]	-71.10 (-0.86)	-1.79 (-0.02)	-16.47 (-0.17)	-153.14 (-1.48)	242.51* (1.84)
Water melon price (LE/ton)[b/]	-0.02 (-0.29)	-0.039 (-0.67)	-0.038 (-0.57)	0.189* (2.62)	-0.094 (-1.02)
Tomato area (Feddan)	-198.03 (-1.30)	-88.90 (-0.57)	-89.83 (-0.51)	353.66* (1.85)	23.09 (0.09)
Tomato price (LE/ton)	0.043 (0.06)	0.036 (0.49)	-0.029 (-0.34)	-0.117 (-1.29)	0.066 (0.57)
Green pepper area (Feddan)	539.20 (1.38)	-321.40 (-0.80)	-232.93 (-0.51)	-560.72 (-1.14)	575.85 (0.92)
Green pepper price (LE/ton)	-1.20 (-0.80)	-0.282 (-0.18)	1.96 (1.13)	1.20 (0.64)	-1.68) (-0.70)
Squash area (Feddan)	64.22 (0.57)	-29.48 (-0.26)	-28.09 (-0.22)	150.92 (1.07)	-157.56 (-0.87)

TABLE 8 (*continued*)

Independent variables	Water melons	Tomatoes	Green peppers	Squash	Corn
Squash price (LE/ton)	-0.09 (-0.57)	-0.029 (-0.17)	0.002 (0.01)	-0.228 (-1.11)	0.348 (1.32)
Corn area (Feddan)	6.09 (0.025)	288.03 (1.15)	-127.80 (-0.45)	305.58 (1.01)	-471.92 (-1.21)
Corn price (LE/ton)	1.64 (1.43)	-0.326 (-0.27)	0.393 (0.29)	-2.33 (-1.61)	0.618 (0.34)
Soil salinity (0, 1)[c]	210.34 (0.60)	-291.52 (-0.81)	-19.33 (-0.05)	-849.97* (-1.93)	950.48 (1.69)
Soil depth (0, 1)[d]	-68.40 (-0.19)	148.96 (0.40)	309.67 (0.73)	-171.78 (-0.37)	-218.45 (-0.37)
Experience in irrigation (years)	-12.69 (-0.61)	14.87 (0.70)	37.47 (1.54)	7.77 (0.30)	-47.43 (-1.42)
Price of urea (LE/kg)	145.92 (0.39)	-308.00 (-0.80)	80.10 (0.18)	-235.51 (-0.50)	317.49 (0.53)
Total water (m^3)	-0.093 (-1.36)	0.365** (5.21)	0.251 (3.16)**	0.301** (3.52)	0.176 (1.61)
R^2	0.28	0.59	0.35	0.52	0.34
D-W Statistics	2.01	1.78	1.72	2.61	1.60
F-Statistics	0.89	3.26*	1.22	2.41	1.18

Note: Numbers in parantheses refer to the calculated values of t- statistics.

* and **: Significant at 5 per cent and 1 per cent level of significance, respectively.

a/ Feddan = denotes area unit (1 hectare = 2.38 Feddan).

b/ LE = Egyptian pound.

c/ Dummy variable for soil salinity, taking a value of 1 for low salinity and zero otherwise.

d/ Dummy variable for soil depth, taking a value of 1 for deep soil and zero otherwise.

TABLE 9. ESTIMATES OF ON-FARM WATER USE IN NUBARIA, EGYPT FOR SUMMER CROPPING: VARIABLE INPUT MODEL

Independent variables	Water melons	Tomatoes	Green peppers	Squash	Corn
Intercept	0.022 (0.003)	787.78 (1.21)	4.14 (0.01)	1 057.29 (1.09)	1 288.41* (1.81)
Crop area (Feddan)[a]	11.54 (0.22)	85.18 (0.77)	-158.40 (-0.83)	160.15 (1.28)	142.82 (0.68)
Crop price (LE/ton)[b]	-0.018 (-0.51)	0.0004 (0.007)	1.23 (1.75)	-0.26 (-1.46)	-1.45 (-1.55)
Water price (LE/Feddan/year)	48.06** (6.37)	87.92** (9.24)	120.71** (13.65)	74.38** (5.12)	110.26** (9.65)
Soil salinity (0, 1)[c]	296.12 (1.49)	129.89 (0.57)	-118.90 (-0.78)	-251.25 (-0.70)	535.07* (1.97)
Soil depth (0, 1)[d]	-87.01 (-0.40)	-218.79 (-0.90)	100.24 (0.63)	-774.84* (-2.23)	-587.03* (-2.12)
Experience in irrigation (years)	-9.73 (-0.81)	-23.13 (-1.70)	-5.99 (-0.66)	-4.88 (-0.24)	-33.83* (-2.26)
Price of urea (LE/kg)[d]	185.11 (0.71)	-63.18) (-0.22)	26.07 (0.14)	-93.12 (-0.22)	-122.81 (-0.37)
R^2	0.55	0.70	0.83	0.48	0.74
D-W Statistics	2.49	1.78	1.98	1.79	1.53
F-Statistics	7.35**	13.94**	30.06**	5.46**	17.06**

Note: Numbers in parantheses refer to the calculated values of t- statistics.

* and **: Significant at 5 per cent and 1 per cent level of significance, respectively.

a/ Feddan = denotes area unit (1 hectare = 2.38 Feddan).

b/ LE = Egyptian pound.

c/ Dummy variable for soil salinity, taking a value of 1 for low salinity and zero otherwise.

d/ Dummy variable for soil depth, taking a value of 1 for deep soil and zero otherwise.

TABLE 10. ESTIMATES OF ON-FARM WATER USE IN NUBARIA, EGYPT FOR SUMMER CROPPING: BEHAVIORAL MODEL

Independent variables	Water melons	Tomatoes	Green peppers	Squash	Corn
Intercept	-199.64 (-0.59)	-549.09 (-1.31)	49.39 (0.14)	-47.60 (-0.06)	247.58 (0.65)
Water melon area (Feddan)[a/]	14.97 (0.58)				
Tomato area (Feddan)		100.53 (1.51)			
Green pepper area (Feddan)			79.75 (0.79)		
Squash area (Feddan)				35.72 (0.34)	
Corn area (Feddan)					-11.82 (-0.14)
Soil salinity (0, 1)[b/]	79.37 (0.68)	-130.18 (-0.90)	-138.42 (-1.09)	-289.41 (-1.02)	62.77 (0.42)
Soil depth (0, 1)[c/]	-196.61 (-1.53)	-24.56 (-0.17)	25.51 (0.19)	-570.58* (-1.98)	-391.24** (-2.78)
Experience in irrigation (years)	-6.95 (-1.02)	-3.11 (-0.37)	-0.76 (-0.10)	5.40 (0.33)	-11.23 (-1.40)
Price of urea (LE/kg)[d/]	180.27 (1.19)	291.45 (1.58)	-6.80 (-0.04)	222.14 (0.61)	99.09 (0.56)
Crop effect (0, 1)[e/]	1729.11** (13.99)	2426.07** (16.87)	3052.67 (17.14)**	2174.43** (7.52)	2926.08** (21.04)
R^2	0.84	0.88	0.88	0.62	0.93
D-W Statistics	2.29	1.90	2.56	1.47	1.48
F-Statistics	37.64**	51.55**	51.72**	11.83**	89.01**

Note: Numbers in parantheses refer to the calculated values of t- statistics.

* and **: Significant at 5 per cent and 1 per cent level of significance, respectively.

a/ Feddan = denotes area unit (1 hectare = 2.38 Feddan).

b/ Dummy variables for soil salinity, taking a value of 1 for low salinity and zero otherwise.

c/ Dummy variable for soil depth, taking a value of 1 for deep soil and zero otherwise.

d/ LE = denotes Egyptian pound.

e/ Dummy variable for crop effect, taking a value of 1 if the farmer produces that crop and zero otherwise.

Two sets of forecasts are made, including one in-sample prediction and one out-of-sample prediction. For an out-of-sample prediction, the observations are randomly divided into two subsets, one with 80 per cent of the observations and one with the remaining 20 per cent of the sample. The 80 per cent subset is used to estimate each model's parameters. These parameter estimates are applied to the 20 per cent subset to make out-of-sample predictions and to apply the prediction performance measures (Moore et al., 1994a and 1994b). Applying the three measures to each of the two predictions generates six cases for evaluating the alternative models for each crop and provides evidence on model choice.

1. *Results for winter cropping*

With the in-sample prediction, the fixed-allocatable input model outperforms the other two models for winter crops (wheat, faba beans and bersem) according to the three prediction accuracy measures (table 11).

For out-of-sample predictions, the fixed-allocatable input model performance the best for wheat according to the three measures of prediction accuracy. This prediction model also performs the best for bersem according to the RMSE and MAE. It is also the best for faba beans according to the MAE. The behavioral model outperforms the other two models for faba beans and bersem, according to the RMSE and MAPE, respectively. Only in one case the variable input model performs the best for faba beans based on the MAE.

TABLE 11. PERFORMANCE OF ESTIMATED MODELS IN PREDICTING ON-FARM WATER USE IN NUBARIA, EGYPT FOR WINTER CROPPING

Type of prediction model of water use	Prediction accuracy measures: Mean absolute error (MAE)	Root mean square error (RMSE)	Mean absolute percentage error (MAPE)
Wheat			
In-sample prediction			
Fixed allocatable input model	339.01[b]	445.63[b]	0.154[b]
Variable input model	642.08	758.12	0.288
Behavioral model	578.32	738.86	0.244
Out-of-sample prediction[a]			
Fixed allocatable input model	232.17[b]	318.38[b]	0.095[b]
Variable input model	904.57	1 218.4	0.339
Behavioral model	691.71	925.03	0.234
Faba beans			
In-sample prediction			
Fixed allocatable input model	377.81[b]	497.11[b]	0.237[b]
Variable input model	606.43	857.0	0.355
Behavioral model	498.75	783.42	0.306
Out-of-sample prediction[a]			
Fixed allocatable input model	662.95	887.53	0.446[b]
Variable input model	631.22[b]	896.13	0.884
Behavioral model	635.051	727.96[b]	0.464
Bersem			
In-sample prediction			
Fixed allocatable input model	489.01[b]	668.40[b]	0.181[b]
Variable input model	1 037.72	1 243.68	0.356
Behavioral model	805.03	1054.35	0.927
Out-of-sample prediction[a]			
Fixed allocatable input model	404.34[b]	491.70[b]	0.127
Variable input model	947.27	1067.32	0.278
Behavioral model	415.40	547.71	0.124[b]

a/ For an out-of-sample prediction, the observations are randomly divided into two subsets, one with 80 per cent of the observations and one with the remaining 20 per cent of the observations. The 80 per cent subset is used to estimate each model's parameters. These parameters are applied to the 20 per cent subset to make out-of-sample predictions and to apply the prediction accuracy measures.

b/ Indicates the model that most accurately predicts short-term water use for a given accuracy and experiment.

The overall predictions performance of the estimated models can be judged on both in –sample and out-of-sample predictions. Regardless of the type of accuracy measures, the fixed-allocatable input model is the best for 9 times for in-sample predictions, and 6 times for out-of-sample predictions, whereas the behavioral model is the best for 2 times for out-of-sample predictions. The variable input model is the best for only 1 time for out-of-sample predictions. The overall performance of the three models, regardless of the type of predictions and accuracy measures, is that the fixed-allocatable input model outperforms the other two for 15 times out of 18 cases. Meanwhile, the behavioral model and the variable input model are the best for only 2 and 1 times, respectively. Accordingly, the results obtained from the application of the prediction accuracy measures clearly support the dominance of the fixed-allocatable input model. The estimated parameters of this model as well as those of the other two models (tables 5 to 7) can provide further insights in explaining the farmers' short-run decisions on water allocation among competing crops. These estimates reveal the following points:

(a) Own-and cross-crop area and price appear to be the most important variables in explaining the farmers' water use decisions in irrigating wheat, faba beans and bersem. The estimated coefficients of area and price variables have the correct signs and highly significant in the fixed-allocatable input model. Cross-acreage variables in this model support the multi-crop jointness in the study area, implying high degree of competition among wheat, faba beans and bersem on the available amount of water;

(b) Total water available to the farm is the most important factor explaining the water use for wheat, faba beans and bersem. The estimated coefficients of this variable in the fixed-allocatable input model provide important implications on water allocation among competing crops in a multi-crop system. An increase in water availability by 1 m^3 is allocated equally for the three crops by an amount of 0.33 m^3, each. This result implies that farmers give equal weights to the three winter crops in allocating water among them;

(c) The water constraint variable is positive and highly significant in the water use equations of wheat, faba beans and bersem. This result suggests that farmers perceive water as a fixed input in the short run. This is further supported by the fact that water price is not negative in the water demand equations of the three crops with the variable input model. This implies that after planting crops, producers do not respond to water prices in subsequent short-run decisions, implying that water price does not have a noticeable quantitative impact on water allocation. This result is further supported by the fact that the amount of water applied to each crop is solely determined by crop-water requirements and extension recommendations, as indicated by the sample farm;

(d) The values of the estimated coefficient of determination (R^2) indicated that the fixed-allocatable input model performs well in explaining crop-level water use for wheat, faba beans and bersem. Crop price, area, total water and soil variables explain more than 70 per cent in crop-level water use for wheat, faba beans and bersem. The estimated water use equations are significant at the 1 per cent level, according to the F-test (table 5).

2. *Results for summer cropping*

Alternative models are compared using the three prediction performance measures. With the in-sample prediction, the behavioral model outperforms the other two models for water melons, tomatoes, green peppers and corn. The fixed-allocatable input model performs the best for in-sample predictions of squash, according to the same accuracy measures. Meanwhile, the MAPE indicates that the variable input model outperforms the other two models for the in-sample predictions of water melons and green peppers.

For out-of-sample predictions, the behavioral model performs the best for water melons, tomato, and corn, based on the three mesures of prediction performance. The behavioral model also outperforms the other two models for squash, according to the RMSE. However, the fixed-allocatable input model is the best for squash according to the MAE and MAPE. The variable input model outperforms the other two models for green peppers based on the three prediction performance measures.

The overall prediction performance of the estimated models is finally judged based on both in-sample and out-of-sample predictions. Based on the accuracy measures, the behavioral model dominates the other two models for 15 times based on the MAE, RMSE and the MAPE. The RMSE alone also supports the choice of this model for 2 times. Similarly, the MAE supports the behavioral model for one case, as well. Regardless of the type of accuracy measures, the behavioral model is the best for 10 times for in-sample predictions, and 10 times for out-of-sample predictions. The variable input model is the best for 2 times and 3 times, for in-sample and out-of-sample predictions, respectively. The fixed-allocatable input model is the best for 3 times for in-sample predictions and 2 times for out-of-sample predictions.

TABLE 12. PERFORMANCE OF ESTIMATED MODELS IN PREDICTING ON-FARM WATER USE IN NUBARIA, EGYPT FOR SUMMER CROPPING

	Prediction accuracy measures		
Type of prediction model of water use	Mean absolute error (MAE)	Root mean square error (RMSE)	Mean absolute percentage error (MAPE)
Water melon			
In-sample prediction			
Fixed allocatable input model	594.43	733.06	0.343
Variable input model	558.60	682.78	0.327[b]
Behavioral model	369.67[b]	463.50[b]	0.924
Out-of-sample prediction[a]			
Fixed allocatable input model	3405.59	5492.80	2.14
Variable input model	513.71	589.40	0.319
Behavioral model	391.54[b]	460.71[b]	0.272[b]
Tomatoes			
In-sample prediction			
Fixed allocatable input model	640.10	816.46	0.278
Variable input model	700.82	892.80	0.299
Behavioral model	507.11[b]	597.64[b]	0.230[b]
Out-of-sample prediction[a]			
Fixed allocatable input model	869.75	1112.16	0.368
Variable input model	750.52	1020.06	0.336
Behavioral model	567.76[b]	624.46[b]	0.281[b]
Peppers			
In-sample prediction			
Fixed allocatable input model	1691.49	1919.98	0.556
Variable input model	818.05	1147.68	0.236[b]
Behavioral model	757.76[b]	1024.42[b]	0.252
Out-of-sample prediction[a]			
Fixed allocatable input model	2063.9	2444.04	0.654
Variable input model	840.59[b]	1387.19[b]	0.215[b]
Behavioral model	1080.07	1526.45	0.290
Squash			
In-sample prediction			
Fixed allocatable input model	770.76[b]	1079.81[b]	0.386[b]
Variable input model	1099.18	1434.16	0.688
Behavioral model	920.82	1248.23	0.643
Out-of-sample prediction[a]			
Fixed allocatable input model	945.63[b]	1320.93	0.777[b]
Variable input model	1261.56	1428.9	1.46
Behavioral model	1191.98	1288.46[b]	1.39
Corn			
In-sample prediction			
Fixed allocatable input model	1148.08	1361.33	0.375
Variable input model	921.29	1048.69	0.326
Behavioral model	503.94[b]	612.70[b]	0.188[b]
Out-of-sample prediction[a]			
Fixed allocatable input model	2232.40	2449.3	0.753
Variable input model	1568.17	1685.6	0.604
Behavioral model	753.57[b]	835.43[b]	0.285[b]

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a/ For an out-of-sample prediction, the observations are randomly divided into two subsets, one with 80 per cent of the observations and one with the remaining 20 per cent of the observations. The 80 per cent subset is used to estimate each model's parameters. These parameters are applied to the 20 per cent subset to make out-of-sample predictions and to apply the prediction accuracy measures.

b/ Indicates the model that most accurately predicts short-term water use for a given accuracy and experiment.

The overall performance of the three models, regardless of the type of predictions and accuracy measures, is that the behavioral model outperforms the other two for 20 times out of 24 cases. Meanwhile, both the variable input model and the fixed-allocatable input model are the best for 5 times, each. Accordingly, the results obtained from the application of the prediction accuracy measures support the choice of the behavioral model for water melons, tomatoes, and corn. The fixed-allocatable input model is the best for explaining the on-farm water application for squash, whereas, the variable input model is recommended for green peppers. To better explain the farmers' short-run decisions on water allocation among competing crops, the estimated models in tables 8-10 can provide further insights. These estimates support the following conclusions:

(a) The values of the estimated coefficient of determination (R^2) indicate that the behavioral model performs well in explaining crop-level water use in the multi-crop system for a cross-sectional data. The estimated R^2 is 0.84 for water melons, 0.88 for tomatoes and green peppers, 0.62 for squash and 0.93 for corn;

(b) Output and water prices do not have a noticeable effect on short-run decisions on water allocation among competing crops. Crop water requirements and extension recommendations are the main determinants for water allocation decisions. This conclusion is highly supported by the fact that the coefficient of the crop-effect variable in the behavioral model is positive and highly significant. In fact, the estimated coefficients of the water price variable in the variable input model are positive and highly significant, implying a positive rather than negative response to water prices;

(c) Estimates of the water constraint variable (total water) in the fixed-allocatable input model indicate the allocation among crops of a marginal increase in farm-level water availability for producers growing competing crops. Farmers give high priority to tomatoes, squash and green peppers in allocating an additional extra water. The estimated coefficients of the water constraint suggest that a 1 m^3 increase in water available to the farm will be used for tomatoes first (0.365 m^3), for squash second (0.301 m^3) and for green peppers in the third place (0.251 m^3). The lowest amount will be allocated for corn (0.176 m^3).

C. WATER USE EFFICIENCY

The target production levels of wheat, faba beans, bersem, water melons, tomatoes, green peppers, squash and corn are the average yield levels of the sample farms as reported in table 13. To obtain the required amount of water to produce these average yield levels, the estimated crop water – use equations are used. This is done by calculating the amount of water required for each crop at the mean levels of the independent variables appearing in that equation. For winter cropping, the fixed- allocatable input model is used in estimating the amount of water required for wheat, faba beans and bersem. For summer cropping, the behavioral model is used in calculating the amount of water required for water melons, tomatoes and corn. The fixed-allocatable input model is used for calculating the water required for squash, whereas the variable input model is used in estimating water required for green peppers.

The calculated levels of required water are presented in table 13 and compared with the actual amount of water used. On-farm WUE is the highest for bersem (0.76), green peppers (0.74) and corn (0.74), indicating that actual water use exceeds water requirements by about 24-26 per cent. The lowest WUE of 0.47 for squash suggests that producers over–irrigate this crop by a large amount compared to its requirements. Squash producers exceed water requirements of the crop by 53 per cent. Therefore, any improvement in the water-use efficiency of this crop will save a large amount of scarce water that can be used to expand the farm's irrigated area or for other crops. Either below- average yields or inefficient use of irrigation water can explain these low-ratio estimates of on-farm water use efficiency for squash and faba beans.

Farmers in the Nubaria area of Egypt over- irrigate all winter and summer crops by a large amount of water in excess of their requirements. Farmers over-irrigate their crops by 24 per cent to 53 per cent, depending on crop under consideration, compared to the required amount of water to produce the achieved yield levels (see table 13). These figures suggest that a big technology gap exists between the required irrigation practices for wheat, faba beans, bersem, water melons, tomatoes, green peppers, squash and corn, and the actual water application in the study area. This result has important policy implications in that improving WUE for these crops can contribute to the over all WUE in the study area. In this study, the overall WUE for winter cropping is 0.65 and for summer cropping is 0.61, suggesting a high potential for water saving once WUE is improved.

TABLE 13. ACTUAL AND REQUIRED AMOUNTS OF WATER USE BY CROP IN NUBARIA, EGYPT

Crop	Irrigated area (feddan)	Av. yield (ton/feddan)	Actual water use (m^3)*	Required water (m^3)	WUE[a/]
Winter cropping					
Wheat	2.16	2.90	3368.23	2181.07	0.65
Faba beans	1.73	0.663	2807.00	1554.25	0.55
Bersem	1.23	32.86	4540.73	3451.97	0.76
Summer cropping					
Water melons	2.30	9.66	2739.92	1696.20	0.62
Tomatoes	0.81	6.75	3373.08	2333.78	0.69
Green peppers	0.57	4.00	4070.07	3030.58	0.74
Squash	1.54	4.35	3179.00	1489.69	0.47
Corn	0.64	2.57	4019.40	2983.11	0.74

* This figure also includes rainfall water quantity estimated at 1040 m^3 (or 104 mm annually).

a/ WUE is defined as the ratio of required water to actual water use (irrigation water + rainfall).

VII. CASE STUDY THREE: BENI-SWEIF, EGYPT

A. CHARACTERISTICS OF SAMPLE FARMS

In the Beni-Sweif area of Egypt, the sample farms comprise 50 producers. The producer's experience in irrigation ranges from 1 to 53 years, with an average of 33 years. Surface water is the main source of irrigation for all farmers in the survey. Main produced crops are wheat and bersem for winter cropping. Whereas, summer cropping includes cotton, sunflower, tomatoes and corn. The soil type is mainly medium (66 per cent of the sample farms). The other 30 per cent of sample farms, are of heavy soil. Most farms (78 per cent) are of deep soil, and the remaining 22 per cent are of medium soils. Meanwhile, 90 per cent of the farmers reported that soil salinity is low. Whereas, only 10 per cent of the farms are of medium salinity.

The current cropping pattern is mainly determined by market conditions and family consumption and on-farm use as indicated by 84 per cent of the sample farms. Crop rotation explains the remaining 16 per cent of the sample. Meanwhile, the choice of crops are mainly made based on market conditions as indicated by 80 per cent of the farms. Labor requirements of crops and other factors explain the crop choice for the remaining 20 per cent of the sample farms. Location of water source to the farm is of main concern to the sample farms, since only 32 per cent are of head locations, while 36 per cent and 32 per cent are of medium and tail locations, respectively. This is an important factor, since surface water is the main source of irrigation.

Most farmers (80 per cent) are full-time operators, whereas 20 per cent are part time farmers. Farming is the main source of household income. Farm income accounts for 88 per cent of the total income, while off-farm income contributes to 12 per cent of the household income. Crop production is the main source of farm income (74 per cent), whereas livestock production accounts for 26 per cent of the farm income.

Other characteristics of the sample farms are presented in table 14. Among the 50 samples, 42 farmers produce bersem, 25 produce cotton, 38 produce wheat, 37 produce corn, 9 produce sunflower and 10 farmers produce tomatoes. Other crops are produced by negligible number of producers. The total farm size averages 4.85 feddan, while the average crop area is 1.54 feddan for bersem, 3.62 feddan for cotton, 1.2 feddan for sunflower, 2.31 feddan for tomatoes, 2.26 feddan for wheat and 1.89 feddan for corn. Among winter crops, wheat accounts for 59 per cent of total irrigated land, while 41 per cent is allocated for bersem. For summer cropping, more land is devoted for cotton (40 per cent) and tomatoes (25 per cent) compared to other crops.

Water available to the entire farm is 14001. 22 m^3/feddan as an average for the sample farms. The water application by crop for winter cropping is 4545.73 m^3/feddan for bersem and 2348.39 m^3/feddan for wheat. For summer cropping, water application, as an average for the sample farms, is 4530.77 m^3/feddan for cotton, 1971.89 m^3/feddan for sunflower, 2555.0 m^3/feddan for tomatoes and 2987.53 m^3/feddan for corn. According to the sample farms, the amount of water applied to each crop is mainly determined by the crop's water requirements as indicated by 80 per cent of the farms. Price of crops and extension recommendations explain the remaining 20 per cent of the sample in explaining the amount of water applied to each crop.

Water productivity, defined in technical terms as kg of output per m^3 of water, is the highest for bersem (9.79 kg/m^3) in winter cropping and tomatoes (2.85 kg/m^3) in summer cropping. Therefore, water yields more output in bersem production, compared to wheat in winter cropping. Each additional m^3 of water yields 9.79 kg of bersem output, whereas the output of wheat is much lower for an additional unit of water (0.68 kg/m^3). For summer cropping water gives more output in tomato production, compared to cotton, sunflower and corn. If the amount of rain water is not included in the calculation of water applied, water productivity of irrigation water increases considerably (table 14).

Table 14. Descriptive statistics of sample farms in Beni-Sweif, Egypt

Item	Total farm	Crops					
		Bersem	Cotton	Sunflower	Tomatoes	Wheat	Corn
Number of farms	50	42	25	9	10	38	37
Area (Feddan)[a]							
Mean	4.85	1.54	3.62	1.20	2.31	2.26	1.89
SD*	7.80	1.56	7.93	1.05	1.74	4.15	1.44
Crop yield (ton/Feddan)							
Mean		54.70	5.90	1.37	10.26	2.32	2.14
SD*		53.16	1.68	0.64	4.89	0.57	0.73
Water applied (m^3)							
Mean	14001.22	4545.73	4530.77	1971.89	2555.00	2348.39	2987.53
SD*	42725.88	857.89	717.16	282.26	412.61	275.24	645.53
Experience in irrigation (year)	33.4	33.38	36.5	31.33	29.5	34.84	33.20
Water productivity (kg/m^3)[b]		9.79 12.03[c]	1.06 1.30[c]	0.45 0.69[c]	2.85 4.02[c]	0.68 0.99[c]	0.53 0.72[c]

*SD = Standard deviation.

a/ Feddan = denotes area unit in Egypt (1 hectare = 2.38 Feddan).

b/ Water productivity = crop yield/total water applied (irrigation + rainfall). The amount of rainfall is 1040 m^3 annually.

c/ Amount of rainfall is not included in the calculation of water productivity, i. e., water-productivity = crop yield/irrigation water.

B. EMPIRICAL RESULTS

Following methodology development of on-farm water use, the three specified models of fixed-allocatable input model, variable input model and behavioral model are estimated using on-farm data of 50 producers. Having estimated these models, the second step involves the comparison of alternative models, using prediction accuracy measures as a mean for model validation. Both in-sample and out-of-sample forecasts for crop-level water use are made and compared with the actual on-farm water applications. Three measures of prediction accuracy are used to judge the performance of alternative models, and thus provide evidence on model choice. The measures of MAE, RMSE and MAPE are calculated to compare the models of on-farm water use for each crop. Summarized calculations are presented in table 15.

Observations are randomly divided into two subsets, one with 80 per cent of the observations and one with the remaining 20 per cent of the sample. The 80 per cent subset is used to estimate each model's parameters. The parameter estimates are applied to the 20 per cent subset to make out-of-sample predictions and to apply the prediction performance measures (Moore *et al.*, 1994a and 1994b). Applying the three measures to each of the two predictions generates six cases for evaluating the alternative models for each crop and provides evidence on model choice.

1. *Results for winter cropping*

With the in-sample prediction, the fixed-allocatable input model outperforms the other two models for wheat according to the three prediction accuracy measures (table 15). Whereas, both variable input model and behavioral model perform the best for bersem.

For out-of-sample predictions, the variable input model performs the best for wheat according to the MAE and MAPE measures of prediction accuracy. Whereas, the behavioral model outperforms the other two models for bersem according to the three measures of prediction accuracy.

TABLE 15. PERFORMANCE OF ESTIMATED MODELS IN PREDICTING ON-FARM WATER-USE IN BENI-SWEIF, EGYPT

Type of prediction model of water use	Prediction accuracy measures Mean absolute error (MAE)	 Root mean square error (RMSE)	 Mean absolute percentage error (MAPE)
Wheat			
In-sample prediction			
Fixed allocatable input model	326.8[b/]	391.56[b/]	0.137[b/]
Variable input model	329.64	508.64	0.138
Behavioral model	498.56	645.87	0.208
Out-of-sample prediction[a/]			
Fixed allocatable input model	702.12	1218.10	0.329
Variable input model	689.45[b/]	1122.80	0.322[b/]
Behavioral model	732.40	911.22[b/]	0.335
Bersem			
In- Sample prediction			
Fixed allocatable input model	940.90	1116.66	0.216
Variable input model	925.57[b/]	1109.03[b/]	0.216
Behavioral model	919.85	1109.03[b/]	0.214[b/]
Out-of-sample prediction[a/]			
Fixed allocatable input model	1845.43	2698.80	0.495
Variable input model	886.93	1155.04	0.242
Behavioral model	757.15[b/]	1026.58[b/]	0.211[b/]
Cotton			
In-sample prediction			
Fixed allocatable input model	799.15[b/]	951.06[b/]	0.174[b/]
Variable input model	1765.2	2034.92	0.377
Behavioral model	1900.16	2069.4	0.411
Out-of-sample prediction[a/]			
Fixed allocatable input model	2746.08[b/]	6495.02[b/]	0.697[b/]
Variable input model	4423.00	9596.97	1.10
Behavioral model	5140.17	11258.20	1.28
Corn			
In-sample prediction			
Fixed allocatable input model	462.49[b/]	621.86[b/]	0.154[b/]
Variable input model	600.20	954.12	0.197
Behavioral model	800.02	1005.74	0.252
Out-of-sample prediction[a/]			
Fixed allocatable input model	453.24[b/]	546.09[b/]	0.150[b/]
Variable input model	604.07	669.14	0.212
Behavioral model	1228.64	1527.30	0.410
Sunflower			
In-sample prediction			
Fixed allocatable input model	279.81	316.49	0.150
Variable input model	277.76[b/]	312.28[b/]	0.148[b/]
Behavioral model	1011.53	1085.4	0.509
Out-of-sample prediction[a/]			
Fixed allocatable input model	301.11	328.70	0.160
Variable input model	290.53[b/]	320.27[b/]	0.154[b/]
Behavioral model	1136.56	1028.49	0.526

TABLE 15 (*continued*)

Type of prediction model of water use	Prediction accuracy measures Mean absolute error (MAE)	Root mean square error (RMSE)	Mean absolute percentage error (MAPE)
Tomatoes			
In-sample prediction			
Fixed allocatable input model	1013.85[b/]	1239.39[b/]	0.391[b/]
Variable input model	1139.92	1273.46	0.441
Behavioral model	1250.75	1379.11	0.489
Out-of-sample prediction[a/]			
Fixed allocatable input model	1068.71[b/]	1287.99[b/]	0.406[b/]
Variable input model	1171.11	1371.19	0.447
Behavioral model	1302.40	1466.12	0.505

a/ For an out-of-sample prediction, the observations are randomly divided into two subsets, one with 80 per cent of the observations and one with the remaining 20 per cent of the observations. The 80 per cent subset is used to estimate each model's parameters. These parameters are applied to the 20 per cent subset to make out-of-sample predictions and to apply the prediction accuracy measures.

b/ Indicates the model that most accurately predicts short-term water use for a given accuracy and experiment.

The overall prediction performance of the estimated models can be judged on both in-sample and out-of-sample predictions. Regardless of the type of accuracy measures, the fixed-allocatable input model is the best for three times for in-sample predictions. This model was dominated by the other two models for out-of-sample predictions. The variable input model is the best for two times for out-of-sample predictions, and two times for in-sample predictions. Whereas, the behavioral model is the best for two times for in-sample predictions, and four times for out-of-sample predictions. The overall performance of the three models, regardless of the type of predictions and accuracy measures, is that the fixed-allocatable input model outperforms the other two for three times out of 12 cases. Meanwhile, the behavioral model is the best for six times out of 12 cases. The variable input models is the best for four times out of 12 cases. Accordingly, the results obtained from the application of the prediction accuracy measures are mixed. However, it can be concluded that both the fixed-allocatable input model and the variable input model are used for calculating the required amount of water application for wheat. Meanwhile, both the behavioral model and the variable input model are used to calculate the required amount of water application for bersem. The estimated parameters of three models (tables 16 to 18) can provide further insights in explaining the farmers' short-run decisions on water allocation among competing crops. These estimates reveal the following points:

(a) Own-and cross- crop area and prices appear to be the most important variables in explaining the farmers' water-use decisions in irrigating wheat and bersem. The estimated coefficients of area and/or price variables have the correct signs and are highly significant in the three estimated models. Cross-acreage variables in the fixed-allocatable input model support the multi-crop jointness in the study area, implying high degree of competition among wheat and bersem on the available amount of inputs;

(b) Total water available to the farm is not a limiting factor in explaining the water use for wheat and bersem. The estimated coefficients of this variable in the fixed-allocatable input model are negative and not significant, implying that water is available in abundant quantities for winter cropping. Thus, farmers do not perceive water as a fixed input in the short run;

(c) Water price, represented by operation cost of water charged by public authority, is not negative in the water demand equations for wheat and bersem with the variable input model. This implies that after planting crops, producers do not respond to water prices in subsequent short-run decisions, implying that water price does not have a noticeable quantitative impact on water allocation. This result is further supported by the fact that the amount of water applied to each crop is solely determined by crop-water requirements and extension recommendations, as indicated by the sample farms.

TABLE 16. ESTIMATES OF ON-FARM WATER USE IN BENI-SWEIF, EGYPT FOR WINTER CROPPING: FIXED ALLOCATABLE INPUT MODEL

Independent variables	Wheat	Bersem
Intercept	-237.88	565.79
	(-0.47)	(0.40)
Wheat area (Feddan)$^{a/}$	-59.69*	-123.40
	(-1.74)	(-1.35)
Bersem area (Feddan)	-107.68	625.10**
	(-1.67)	(3.46)
Wheat price (LE/ton)$^{b/}$	2.98**	1.01
	(7.03)	(0.85)
Bersem price (LE/ton)	-0.332	0.893
	(-0.25)	(0.24)
Soil salinity (0, 1)$^{c/}$	320.66	-378.38
	(0.93)	(-0.39)
Soil depth (0, 1)$^{d/}$	159.82	24.85
	(0.59)	(0.03)
Experience in irrigation (years)	0.403	25.11
	(0.05)	(1.10)
Price of manure (LE/ton)	40.59	159.99*
	(1.17)	(1.75)
Total water (m^3)	-0.003	-0.008
	(-0.92)	(-0.94)
R^2	0.71	0.29
D-W Statistics	2.40	1.77
F-Statistics	11.11**	1.86

Note: Numbers in parantheses refer to the calculated values of t- statistics.

* and **: Significant at 5 per cent and 1 per cent level of significance, respectively.

a/ Feddan = denotes area unit (1 hectare = 2.38 Feddan).

b LE = denotes Egyptian pound.

c/ Dummy variable for soil salinity, taking a value of 1 for low salinity and zero otherwise.

d/ Dummy variable for soil depth, taking a value of 1 for deep soil and zero otherwise.

2. *Results for summer cropping*

Alternative water-use models are compared using the three prediction performance measures. With the in-sample predictions, the fixed-allocatable input model outperforms the other models, according to the three prediction performance measures, for cotton, corn and tomatoes. The variable input model performs the best for in-sample predictions of sunflower, according to the same accuracy measures. The same performance of alternative models applies to the out-of-sample predictions, where the fixed-allocatable input model is the best for cotton, corn and tomatoes, whereas the variable input model is the best for sunflower (table 15). The results obtained from the application of the prediction accuracy measures are very conclusive in the choice of the fixed-allocatable input model to calculate the required amount of water for cotton, corn and tomatoes. Similarly, the results support the choice of the variable input model to estimate the required amount of water for sunflower. To better explain the farmers' short-run decisions on water allocation among competing crops, the estimated models in tables 19 to 21 can provide further insights. These estimates support the following points:

(a) Own-and cross-crop area and prices appear to be the most important variables in explaining the farmers' water-use decisions in irrigating cotton, corn, sunflower and tomatoes. The estimated coefficients of area and crop price variables have the correct signs and are highly significant in the three models. Cross-acreage and cross-price variables in the fixed-allocatable input model clearly support the multi-crop interdependence in the study area, implying high degree of competition among summer crops on the available amount of water;

TABLE 17. ESTIMATES OF ON-FARM WATER USE IN BENI-SWEIF, EGYPT FOR WINTER CROPPING: VARIABLE INPUT MODEL

Independent variables	Wheat	Bersem
Intercept	-698.81 (-1.63)	1166.52 (0.91)
crop area (Feddan)$^{a/}$	-130.49** (-3.04)	550.67** (3.20)
Crop price (LE/ton)$^{b/}$	3.20** (8.26)	1.05 (0.28)
Water price (LE/Feddan/year)	0.743** (2.56)	0.226 (0.41)
Soil salinity (0, 1)$^{c/}$	653.54* (1.94)	343.57 (0.36)
Soil depth (0, 1)$^{d/}$	379.24 (1.38)	647.37 (0.87)
Experience in irrigation (years)	0.346 (0.05)	15.42 (0.77)
Price of manure (LE/kg)	10.46 (0.41)	51.56 (0.72)
R^2	0.72	0.25
D-W Statistics	2.31	1.68
F-Statistics	15.40**	2.01

Note: Numbers in parantheses refer to the calculated values of t- statistics.

* and **: Significant at 5 per cent and 1 per cent level of significance, respectively.

a/ Feddan = denotes area unit (1 hectare = 2.38 Feddan).

b/ LE = denotes Egyptian pound.

c/ Dummy variable for soil salinity, taking a value of 1 for low salinity and zero otherwise.

d/ Dummy variable for soil depth, taking a value of 1 for deep soil and zero otherwise.

TABLE 18. ESTIMATES OF ON-FARM WATER USE IN BENI-SWEIF, EGYPT FOR WINTER CROPPING: BEHAVIORAL MODEL

Independent variables	Wheat	Bersem
Intercept	-189.36 (-0.29)	1288.71 (1.04)
Crop area (feddan)$^{a/}$	46.717 (1.11)	563.48** (3.39)
Soil salinity (0, 1)$^{b/}$	1178.20* (2.33)	214.40 (0.24)
Soil depth (0, 1)$^{c/}$	1110.76** (3.05)	471.92 (0.75)
Experience in irrigation (years)	7.95 (0.72)	16.53 (0.85)
Price of manure (LE/kg)$^{d/}$	-30.48 (-0.77)	65.47 (1.08)
R^2	0.24	0.25
D-W Statistics	2.58	1.67
F-Statistics	2.75*	2.89*

Note: Numbers in parantheses refer to the calculated values of t- statistics.

* and **: significant at 5 per cent and 1 per cent level of significance, respectively.

a/ Feddan = denotes area unit (1 hectare = 2.38 Feddan).

b/ Dummy variables for soil salinity, taking a value of 1 for low salinity and zero otherwise.

c/ Dummy variable for soil depth, taking a value of 1 for deep soil and zero otherwise.

d/ LE = denotes Egyptian pound.

(b) Total water available to the farm is one of the most important factor explaining the water use for cotton, corn and tomatoes. The estimated coefficients of this variable in the fixed-allocatable input model (table 19) provide important implications on water allocation among competing crops in a multi-crop system. An increase in water availability by 1 m^3 is allocated to cotton in the first place (0.62 m^3), a water-consuming crop, and corn in the second place (0.257 m^3). The least amount of water is allocated for tomatoes (0.083 m^3). Whereas, the sunflower appears to be a residual crop in terms of an additional amount of water;

(c) The water constraint variable is positive and highly significant in the water-use equations of cotton, corn and tomatoes. This result suggests that farmers perceive water as a fixed input in the short run. This result is further supported by the fact that water price is not significant in the water demand equations of the three crops with the variable input model. This implies that after planting crops, producers do not respond to water prices in subsequent short-run decisions, implying that water price does not have an impact on water allocation. This result is further supported by the fact that the amount of water applied to each crop is solely determined by crop water requirements and extension recommendations, as indicated by the sample farms.

TABLE 19. ESTIMATES OF ON-FARM WATER USE IN BENI-SWEIF, EGYPT FOR SUMMER CROPPING: FIXED ALLOCATABLE INPUT MODEL

Independent variables	Cotton	Corn	Sunflower	Tomatoes
Intercept	-1293.72	-375.51	-151.62	228.91
	(-1.52)	(-0.63)	(-1.12)	(0.41)
Cotton area (Feddan)$^{a/}$	50.51	-29.40	-0.228	-14.89
	(1.42)	(-1.17)	(-0.04)	(-0.64)
Sunflower area (Feddan)	381.91	-314.38	121.11	-140.62
	(0.85)	(-0.99)	(1.69)	(-0.48)
Tomatoes area (Feddan)	79.07	-385.61**	13.38	419.47**
	(0.37)	(-2.54)	(0.39)	(2.97)
Corn area (Feddan)	-443.85*	117.76	-12.42	155.97
	(-2.01)	(0.76)	(-0.35)	(1.08)
Cotton price (LE/ton)$^{b/}$	1.271**	-1.038**	-0.04	0.075
	(2.72)	(-3.15)	(-0.53)	(0.25)
Sunflower price (LE/ton)	-2.314**	0.440	2.01**	-0.277
	(-3.10)	(0.835)	(16.83)	(-0.56)
Tomatoes price (LE/ton)	-0.702*	0.084	0.028	0.354
	(-2.17)	(0.37)	(0.54)	(1.67)
Corn price (LE/ton)	-1.350	3.10**	0.049	-0.535
	(-1.50)	(4.90)	(0.34)	(-0.91)
Soil salinity (0, 1)$^{c/}$	-530.84	728.38	89.23	-9.54
	(-0.73)	(1.43)	(0.77)	(-0.02)
Soil depth (0, 1)$^{d/}$	801.68*	-150.51	62.71	-348.48
	(1.81)	(-0.48)	(0.88)	(-1.20)
Experience in irrigation (years)	37.82**	-19.46*	0.919	-2.63
	(2.98)	(-2.17)	(0.45)	(-0.32)
Price of manure (LE/ton)	-12.54	25.34	2.52	0.420
	(-0.26)	(0.73)	(0.32)	(0.013)
Total water (m^3)	0.620**	0.257**	-0.006	0.083*
	(9.31)	(5.50)	(-0.56)	(1.91)
R^2	0.86	0.82	0.97	0.70
D-W Statistics	1.52	1.88	2.23	1.83
F-Statistics	16.99**	12.21	82.09**	6.48**

Note: Numbers in parantheses refer to the calculated values of t- statistics.

* and **: significant at 5 per cent and 1 per cent level of significance, respectively.

a/ Feddan = denotes area unit (1 hectare = 2.38 Feddan).

b/ LE = Egyptian pound.

c/ Dummy variable for soil salinity, taking a value of 1 for low salinity and zero otherwise.

d/ Dummy variable for soil depth, taking a value of 1 for deep soil and zero otherwise.

TABLE 20. ESTIMATES OF ON-FARM WATER USE IN BENI-SWEIF, EGYPT FOR SUMMER CROPPING: VARIABLE INPUT MODEL

Independent variables	Cotton	Corn	Sunflower	Tomatoes
Intercept	-639.66	361.16	-115.56	391.71
	(-0.44)	(0.47)	(-1.08)	(0.79)
Crop area (Feddan)[a]	193.04	-86.69	123.99*	630.88**
	(1.72)	(-0.67)	(2.31)	(7.27)
Crop price (LE/ton)[b]	2.94**	4.534**	1.99**	0.422**
	(3.95)	(6.18)	(21.46)	(2.43)
Water price (LE/Feddan/year)	-0.886	-0.059)	-0.064	-0.110
	(-0.83)	(-0.18)	(-1.34)	(-0.50)
Soil salinity (0, 1)[c]	1395.30	683.50	37.235	-33.92
	(1.29)	(1.23)	(0.45)	(-0.08)
Soil depth (0, 1)[d]	1317.75	115.97	11.51	-230.53
	(1.68)	(0.27)	(0.18)	(-0.08)
Experience in irrigation (years)	11.35	-21.01*	0.839	0.252
	(0.53)	(-1.87)	(0.49)	(0.03)
Price of manure (LE/ton)[d]	-63.48	8.063	6.237	-2.37
	(-0.74)	(0.190)	(1.00)	(-0.08)
R^2	0.44	0.60	0.97	0.66
D-W Statistics	1.93	1.85	2.18	1.92
F-Statistics	4.79**	8.86	179.98**	11.40**

Note: Numbers in parantheses refer to the calculated values of t- statistics.
* and **: significant at 5 per cent and 1 per cent level of significance, respectively.
a/ Feddan = denotes area unit (1 hectare = 2.38 Feddan).
b/ LE = Egyptian pound.
c/ Dummy variable for soil salinity, taking a value of 1 for low salinity and zero otherwise.
d/ Dummy variable for soil depth, taking a value of 1 for deep soil and zero otherwise.

TABLE 21. ESTIMATES OF ON-FARM WATER USE IN BENI-SWEIF, EGYPT FOR SUMMER CROPPING: BEHAVIORAL MODEL

Independent variables	Cotton	Corn	Sunflower	Tomatoes
Intercept	-1 172.07	1 554.23	-52.21	695.72
	(-0.80)	(1.57)	(-0.14)	(1.43)
Crop area (Feddan)[a]	144.68*	369.09**	953.93**	667.67**
	(2.01)	(2.69)	(7.90)	(7.78)
Soil salinity (0, 1)[b]	1716.79	1 064.91	20.21	-330.73
	(1.51)	(1.47)	(0.07)	(-0.93)
Soil depth (0, 1)[c]	1 978.59*	394.75	89.41	-193.24
	(2.21)	(0.78)	(0.47)	(-0.74)
Experience in irrigation (years)	16.87	-20.257	2.83	-0.486
	(0.67)	(-1.33)	(0.49)	(-0.06)
Price of manure (LE/kg)[d]	-47.04	-47.52	1.82	-4.036
	(-0.47)	(-0.97)	(0.10)	(-0.16)
R^2	0.19	0.21	0.60	0.59
D-W Statistics	2.39	1.94	1.54	2.05
F-Statistics	2.13	2.41	13.44**	12.96**

Note: Numbers in parantheses refer to the calculated values of t- statistics.
* and **: Significant at 5 per cent and 1 per cent level of significance, respectively.
a/ Feddan = denotes area unit (1 hectare = 2.38 Feddan).
b/ Dummy variables for soil salinity, taking a value of 1 for low salinity and zero otherwise.
c/ Dummy variable for soil depth, taking a value of 1 for deep soil and zero otherwise.
d/ LE = Egyptian pound.

C. WATER-USE EFFICIENCY

The target production levels of wheat, bersem, cotton, corn, sunflower and tomatoes are the average yield levels of the sample farms as reported in table 22. To obtain the required amount of water to produce these average yield levels, the estimated crop water-use equations are used. This is done by calculating the amount of water required for each crop at the mean levels of the independent variables appearing in that equation. For winter cropping, both fixed allocatable input model and variable input model are used in estimating the amount of water required for wheat. Whereas, both behavioral model and variable input model are used to calculate the amount of water required for bersem. For summer cropping, the fixed-allocatable input model is used in calculating the amounts of water required for cotton, corn and tomatoes. The variable input model is used for calculating the amount of water required for sunflower.

The calculated levels of required water are presented in table 22 and compared with the actual amount of water used. On-farm WUE is the highest for cotton (0.75), bersem and corn (0.72, each), indicating that actual water use exceeds water requirements by about 25 to 28 per cent. The lowest WUE of 0.56 for tomatoes suggests that producers over-irrigate this crop by 44 per cent compared to its requirements. Therefore, any improvement in the water-use efficiency of this crop will save a large amount of scarce water that can be used to expand the farm's irrigated area or for other crops. Likewise, farmers of wheat and sunflower exceed crops' water requirements by 35 per cent. Either below-average yields or inefficient use of irrigation water can explain these low ratios of on-farm WUE for tomatoes, wheat and sunflower.

Farmers in Beni-Sweif area of Egypt over-irrigate all winter and summer crops by a large amount of water. Producers of this area over-irrigate their crops by 25 to 44 per cent, depending on the crop under consideration, compared to the required amount of water to produce the achieved yield levels (table 22). These figures suggest that a big technology gap exists between the required irrigation practices for wheat, bersem, cotton, corn, sunflower and tomatoes, and the actual water application in the study area. This result has important policy implications in that improving on-farm WUE for these crops can contribute to the overall WUE in the study area. In the Beni-Sweif area the overall WUE for winter cropping is 0.68 and for summer cropping is 0.68, suggesting a high potential for water savings once on-farm water use efficiency is improved.

TABLE 22. ACTUAL AND REQUIRED AMOUNTS OF WATER USE BY CROP IN BENI-SWEIF, EGYPT

Crop	Irrigated area (Feddan)	Av. yield (Ton/feddan)	Actual water use (m^3)*	Required water (m^3)	WUE[a/]
Winter cropping					
Wheat	2.26	2.32	3 388	2 214	0.65
Bersem	1.54	54.70	5 586	3 998	0.72
Summer cropping					
Cotton	3.62	5.90	5 571	4 190	0.75
Corn	1.89	2.14	4 027	2 898	0.72
Sunflower	1.20	1.37	3 012	1 940	0.64
Tomatoes	2.31	10.26	3 595	2 021	0.56

* This figure also includes rainfall water quantity estimated at 1040 m^3 (or 104 mm annually).

a/ WUE is defined as the ratio of required water to actual water use (irrigation water + rainfall).

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Annex

OLS ESTIMATES OF ON-FARM WATER USE IN THE GHORS, BEHAVIORAL MODEL

Independent variables	Tomatoes	Potatoes	Peppers	Cucumber	Cauliflower	Citrus
Intercept	132.86	-2.19	372.73**	-154.14	80.76*	-103.08
	(1.08)	(-0.03)	(3.01)	(0.69)	(2.43)	(-0.98)
Crop area (ha)	-14.13	-21.13	119.12	-109.57	80.22	41.39*
	(-0.31)	(-1.42)	(1.33)	(-0.75)	(0.87)	(2.25)
Crop effect (0,1)[a]	4027.92**	2243.37**	3704.68**	4681.60**	2834.03**	12005.10**
	(52.56)	(45.18)	(35.40)	(29.52)	(52.19)	(153.82)
Amount of rainfall (mm)	-0.28	0.001	-1.17**	0.03	-0.29**	0.17
	(-0.89)	(0.006)	(-3.60)	(0.04)	(-3.38)	(0.59)
Experience in irrigation (year)	-2.31	1.61	0.74	-3.39	1.06	-2.01
	(-0.75)	(0.88)	(0.25)	(-0.67)	(1.32)	(-0.78)
Soil depth (0,1)[b]	-80.74	-25.78	-5.33	-105.30	-28.21	32.79
	(-1.1)	(-0.56)	(-0.07)	(-0.79)	(-1.39)	(0.52)
Soil salinity (0,1)[c]	49.53	-24.97	34.56	-62.42	21.63	91.01
	(0.77)	(-0.62)	(0.49)	(-0.55)	(1.17)	(1.64)
Soil Type (0,1)[d]	29.75	-28.18	45.04	-88.76	-3.08	37.76
	(0.31)	(-0.46)	(0.4)	(-0.51)	(-0.11)	(0.45)
R^{-2}	0.98	0.97	0.97	0.96	0.99	0.99
D-W Statistics	1.91	2.08	1.62	1.23	1.97	2.10
F-Statistics	698.64**	460.12**	327.67**	269.58**	2210.77**	6667.69**

Independent variables	Melons	Wheat	Eggplant	Lettuce	Beans	Onions
Intercept	188.60*	-84.97	-263.15	-126.32*	150.22**	81.46*
	(2.29)	(-1.58)	(-1.64)	(-1.90)	(2.91)	(1.99)
Crop area (ha)	-408.58	-1140.08**	-773.23**	66.42	12.64*	96.85
	(-1.46)	(-6.01)	(-3.45)	(0.72)	(2.27)	(0.80)
Crop effect (0,1)[a]	3346.59**	2824.71**	7771.79**	2238.42**	2010.62**	2711.89**
	(26.36)	(22.67)	(41.33)	(24.71)	(60.83)	(38.71)
Amount of rainfall (mm)	-0.70**	0.39*	0.85*	0.41*	-0.55**	-0.27**
	(-3.28)	(2.78)	(1.95)	(2.32)	(-4.13)	(-2.61)
Experience in irrigation (year)	0.17	-1.48	-0.32	1.01	1.65	-0.31
	(0.08)	(-1.16)	(-0.08)	(0.63)	(1.31)	(-0.32)
Soil depth (0,1)[b]	60.29	-49.85	29.55	4.37	-2.53	15.36
	(1.22)	(-1.52)	(0.30)	(0.1)	(-0.07)	(0.63)
Soil salinity (0,1)[c]	37.78	-40.38	-51.47	-87.72**	13.46	19.16
	(0.86)	(-1.40)	(-0.60)	(-2.4)	(0.50)	(0.84)
Soil Type (0,1)[d]	128.32*	115.33*	75.52	117.17*	32.79	33.69
	(1.90)	(2.58)	(0.57)	(2.14)	(0.79)	(0.98)
R^{-2}	0.97	0.96	0.98	0.97	0.98	0.99
D-W Statistics	1.98	1.62	2.53	1.98	1.78	2.09
F-Statistics	347.00**	317.9**	625.95**	319.94**	669.73**	1196.16**

Note: Numbers in parantheses refer to the calculated values of t - statistics

* and ** = significant at 5 per cent and 1 per cent level of significance, respectively.

a/ Dummy variable for crop effect, taking a value of 1 if the farmer produce that crop and zero otherwise.

b/ Dummy variable for soil depth, taking a value of 1 for deep soil and zero otherwise.

c/ Dummy variable for soil salinity, taking a value of 1 for low salinity and zero otherwise.

d/ Dummy variable for soil type, taking a value of 1 for sandy soil and zero otherwise.

OLS = Ordinary Least Squares Estimation Procedure.