Distr.
GENERAL
E/ESCWA/AGR/1999/9
19 November 1999
ORIGINAL: ARABIC/ENGLISH

Economic and Social Commission for Western Asia

International Center for Agricultural Research in the Dry Areas

ECONOMIC ASSESSMENT OF ON-FARM WATER USE EFFICIENCY IN AGRICULTURE

METHODOLOGY AND TWO CASE STUDIES

United Nations
New York, 2000

00-0051

ACKNOWLEDGEMENT

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The contribution of Christoph Studer, Ahmed Mazid of ICARDA and Pierre Hayk in the discussions and development of the questions is highly appreciated.

CONTENTS

Page

Acknowledgement iii
Summary and conclusions vii
Introduction 1

Chapter

I. **WATER ISSUES AND POLICIES IN THE REGION** 3

A. Supply management 5
B. Demand management issues 6
C. Technical and policy options 6
D. Future challenges 7
E. Strategies for the future 9
F. Privatization and user participation in irrigation 12

II. **WATER-USE EFFICIENCY** 15

A. Water-use efficiency and water productivity 15
B. Water-use efficiency 16

III. **METHODOLOGY DEVELOPMENT FOR ON-FARM WATER-USE EFFICIENCY** 20

A. The models of water-use 21
B. Model validation 25
C. Data required and variable measurements 28

IV. **CASE STUDY ONE: RADWANIA** 30

A. Characteristics of sample farms 30
B. Model estimation and validation 31
C. Empirical results 32
D. Water-use efficiency 38

V. **CASE STUDY TWO: RABEA** 39

A. Characteristics of sample farms 39
B. Empirical results 40
C. Water-use efficiency 45

Annexes 49

LIST OF TABLES

1. Descriptive statistics for sample farms in the Radwania area 31
2. Estimates of on-farm water use in Radwania: fixed allocatable input model 32
3. Estimates of on-farm water use in Radwania: variable input model 34
4. Estimates of on-farm water in Radwania: satisficing model 35
5. Performance of estimated models in predicting on-farm water-use in Radwania 37
6. Actual and required amounts of water-use by crop in Radwania 38
7. Descriptive statistics for sample farms in Rabea 39
8. Estimates of on-farm water-use in Rabea: fixed allocatable input model 41

CONTENTS (*continued*)

Page

9. Estimates of on-farm water-use in Rabea: variable input model 42
10. Estimates of on-farm water-use in Rabea: satisficing model 42
11. Performance of estimated models in predicting on-farm water-use in Rabea 43
12. Actual and required amount of water-use by crop in Rabea 46

References 47

SUMMARY AND CONCLUSIONS

The dry areas of West Asia and North Africa face severe and growing challenges due 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 needs of urban areas and industry. Waterlogging, 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, so water is being over-used in many areas and sometimes wasted instead of being treated as a scarce resource.

Given that irrigation accounts for 80-90 per cent of all water consumed in the region, improving on-farm water-use efficiency can contribute directly to an increased supply of water for agriculture and other end-users. When the efficiency of irrigation is low, a significant portion of the total water applied leaves the field through runoff and deep percolation. Improving the efficiency of irrigation is achieved by a better matching application of water to crop needs in terms of both timing and quantity.

Farmers generally tend to over-irrigate, owing to their perceptions of water requirements, and their expectations of rainfall and market values. Most of the evidence available in the region on water-use efficiency is based mainly on experimental trials of mono-crop 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, if 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 to produce a target production level to the actual amount of water used. A methodology of the assessment of on-farm water-use efficiency is presented within the framework of a multi-crop production system. A fixed, allocatable input model, a variable input model and a satisficing model are identified. These models are then estimated and tested in two case studies based on the data collected in farm surveys conducted in two areas, Radwania in the northwest region of the Syrian Arab Republic and Rabea in northwest Iraq. The sample farms in the Radwania area comprise 80 producers, among which 78 farmers irrigate wheat, 27 farmers irrigate barley and 72 farmers irrigate cotton. Other crops are not of equal importance to the farmers in the study area. Water productivity, defined in technical terms as kilogram (kg) of output per cubic metre (m^3) of water, is the highest for wheat (0.9 kg/m^3); followed by cotton at 0.57 kg/m^3, then barley at 0.56 kg/m^3. In the Rabea area, the sample farms comprise 100 producers, among which 47 irrigate wheat, 45 irrigate potatoes, 22 irrigate sugar beet, and 71 irrigate tomatoes. Water productivity is the highest for potatoes (1.44 kg/m^3), followed by sugar beet at 0.97 kg/m^3, then tomatoes at 0.73 kg/m^3, and finally wheat at 0.70 kg/m^3.

Following the methodology developed for on-farm water use, the three specified models—fixed, variable and satisficing—are estimated, using on-farm data. The estimated models are then compared, 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. Application of the three measures of prediction accuracy is used to judge the performance of alternative models and thus provides evidence on model choice. The measures of mean absolute error (MAE), root mean square error (RMSE) and mean absolute percentage error (MAPE) are calculated to compare the models of on-farm water use for each crop. Applying these measures to estimated models reveal that the fixed, allocatable input model is the best model to represent on-farm water use in the Radwania area. For the Rabea area, the results are inconclusive, although the fixed, allocatable input model performed better in some crops.

The selected models are then used to calculate the required amount of water for each crop in the two study areas. This is done by calculating the amount of water required for each crop at the mean levels of independent variables appearing in each crop's equation.

The calculated levels of required water are compared with the actual amount of water use. As a result, on-farm water-use efficiency in Radwania 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. For the Rabea area, the estimated on-farm water-use efficiency is the highest for tomatoes (0.68) and the lowest for sugar beet (0.32). On-farm water-use efficiency for wheat is 0.37 and for potatoes 0.45.

These results suggest the following conclusions:

(a) There appears to be a wide technology gap between the required irrigation practices for wheat, barley, cotton, sugar beet, potatoes and tomatoes and the actual water application in the study areas. Therefore, improving water-use efficiency for these crops can contribute to the overall water-use efficiency in the study areas, and offers a high potential in water savings;

(b) The water constraint variable is positive in the water-use equations of the crops. This suggests that producers perceive water as a fixed input in the short run. The individual estimated coefficients of the water constraint suggest that an increase in water availability is allocated most heavily to crops with relatively higher requirements, like cotton, tomatoes, potatoes, and sugar beet, rather than to crops with relatively low water requirements, such as wheat and barley;

(c) Output prices and planted areas appear to be strong determinants in short-run decisions on water allocation among competing crops. Meanwhile, the water price variable is not negative in the water demand equations for most of the crops in the variable input model. This implies that after planting crops, producers do not respond to water price in making subsequent short-run decisions. Water prices in the study areas are highly subsidized and farmers are normally charged minimal prices. As a result, water price does not have a major quantitative impact on water allocation. Land allocation, crop choice, irrigation technology and output prices are the main determinants of multi-crop water use decisions;

(d) Comparing the yields of wheat under rainfed and supplemental irrigation in the Rabea area provides important findings. The average yield is 2.36 ton/hectare (ha) for supplementary-irrigated wheat and 1.36 ton/ha for rainfed wheat. The result is that supplemental irrigation increases wheat grain yield by 62 per cent under the same soil and environmental conditions, indicating that supplemental irrigation improves water productivity substantially. The water productivity is 0.6 kg/m^3 for rainfed wheat, whereas it increases to 0.7 kg/m^3 under supplemental irrigation. The other important advantage of using water to supplement rainfall in wheat production is yield stabilization. Using coefficient of variation (CV) as a measure of yield stabilization, it is found that the CV for wheat under rainfed is 71 per cent, whereas supplemental irrigation reduces it to 35 per cent. This is a very important result for producers adverse to risk, since supplemental irrigation increases yield stability and thus reduces the risk associated with rainfed farming;

(e) The methodology presented in this study proved to be a valid approach for assessing on-farm water-use efficiency within the framework of a multi-crop production system. Results obtained from this methodology are satisfactory and compared favourably with expert and technical recommendations. However, it is important to note that these results are only applicable to the study areas and cannot be generalized at regional and national levels. The major difficulty encountered in such studies is the calculation of actual crop-level water use, given the diversity at the farm level with respect to source of water and irrigation technology. Therefore, it is recommended that a water specialist be included in the team collecting farm-survey data, as was done in this study, which is considered a very useful first step in improving on-farm water-use efficiency.

Introduction

The mandate area of the International Centre for Agricultural Research in Dry Areas (ICARDA) and the Economic and Social Commission for Western Asia (ESCWA) mainly covers the dry areas of West Asia and North Africa, including Arab countries in the MENA. 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 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 will remain the prime component of agricultural growth. Waterlogging, 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 the incentive to conserve water; consequently, water is being overused in many areas and sometimes wasted instead of being treated as a scarce resource.

Water scarcity is specific relative to region, location and season. The criterion for water scarcity is that countries with freshwater resources in the range of 1,000-1,600 m^3 per capita per year face water stress, with major problems occurring in drought years. When annual internal renewable water resources are less than 1,000 m^3 per person annually, countries are considered water scarce. Below this threshold, water availability becomes a severe constraint on socioeconomic development and environmental quality. Currently, 28 countries worldwide, with a total population of 338 million, are considered water-stressed, and 20 of these countries are water scarce. Water shortages will increase dramatically in the next 25 years. By the year 2025, it is projected that 46 to 52 countries, with an aggregate population of about 3 billion, will be water-stressed (Rosegrant, 1997).

Tightened supplies have been accompanied by a rapid growth in demand for water. Between 1950 and 1990, water use 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.

Agriculture is the largest user of water, accounting for more than 70 per cent of water withdrawals worldwide and more than 90 per cent of water withdrawals in low-income developing countries. In middle-income and high-income countries, agriculture accounts for 69 per cent and 39 per cent of water withdrawals respectively.

The physical limitations on land and water resources indicates that the potential for 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 area, irrigation investment, and the construction of drainage networks (ESCWA, 1994). The initial increase in water supply for irrigation has increased irrigated area under cultivation, thus increasing agricultural production. In the past, however, land and water policies, together with economic and financial policies, contributed to the depletion of land and water resources in many countries in the region. Irrigation projects focused on expanding irrigated area without taking into account the associated rise in water table 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 the irrigation infrastructure.

New strategies for water development and management are urgently needed to avert the severe national, regional and local water scarcities that will depress agricultural production and other end-users.

Water resource management throughout the world will be one of the most important economic and social issues of the coming century. Water allocation, water quality, growing and changing social demands

for water, new technologies, water-use efficiency, economic feasibility and benefit/cost measurement are issues of great concern to research institutions and decision-makers at various levels. Given that irrigation accounts for 80-90 per cent of all water consumed in the region, improving on-farm water-use efficiency can contribute directly to an increased supply of water for agriculture and other end-users. When the efficiency of irrigation is low, a significant portion of water leaves the field through runoff and deep percolation. Low irrigation efficiency normally is associated with poor timing and a lack of uniformity in water applications, leaving parts of the field over- or under-irrigated relative to crop needs. To improve the efficiency of irrigation requires a better matching application of water to crop needs, in terms of both timing and quantity. Crops will consume more applied water, yields will be increased, and the amount of water that the irrigator must divert and deliver to the farm will be reduced (Whittlesey and Huffaker, 1995).

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

In most of the major irrigating countries, however, 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 in other inputs (Serageldin, 1998). Farmers, on their part, generally tend to over-irrigate as a result of their perceptions of water requirements and their expectations of rainfall and market values. Most of the evidence available in the region on water-use efficiency is mainly based on experimental trials in a mono-crop system, which 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, if available at all.

The main objective of this study is to assess the water-use efficiency under on-farm conditions. 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 presented within the farmework of a multi-crop production system. The methodology is tested in two case studies, based on the data collected in the farm surveys. The resulting indicators on on-farm water-use efficiency are very useful in guiding policies toward improving irrigation efficiency, which is vital to sustain and improve crop production in the West Asia and North Africa region.

I. WATER ISSUES AND POLICIES IN THE REGION

Annual renewable resources in the Middle East and North Africa (MENA) average about 350 billion cubic metres (BCM) or 1436 m^3/head, of which some 120 BCM are accounted for by river flows from outside the region. In 1990, of eighteen MENA countries only seven had a per capita availability of more than 1,000 m^3/year and by 2025 the regional average is projected and no more than 667 m^3 (30 per cent of the Asia estimate, 25 per cent of the Africa, and 15 per cent of that for the world). Water is becoming more scarce, and rivers are highly variable and difficult to manage. Many countries are mining groundwater, a temporary and often risky expedient. The region also accounts for 60 per cent of world desalination capacity but this option is open only to oil-rich countries.

Irrigation accounts for 80 per cent of withdrawals region-wide, but demand is expanding most rapidly in urban areas. The region is highly urbanized and the percentile share of domestic and industrial demand is already higher there than in other parts of the developing world. By 2025, the share of population living in urban areas will increase from 60 per cent to nearly 75 per cent. Withdrawals in The Libyan Arab Jamahiriya, Saudi Arabia, the Gulf States and Yemen already exceed renewable supplies, while Egypt and Jordan have essentially reached the limit; and Algeria, Morocco and Tunisia face several regional deficits even if in total they are in surplus. Though water transfers are sometimes feasible, they can be very expensive, and the full mobilization of surplus supplies is always impractical. Only Iraq and Lebanon appear to have adequate renewable supplies relative to population, and even these countries face significant problems of adjustment.

Major water resources in the region are shared between countries lying both within and beyond the region. The most significant river basins are those of Jordan, the Nile and the Euphrates/Tigris, all of which are subject to contentious riparian issues (the World Bank, 1994).

Deteriorating water quality is an increasing serious issue in many areas, owing to a combination of low river flows, inadequate treatment, agricultural runoffs, and uncontrolled effluent from industry. Declining quality directly affects the utility of the resource, and treatment costs will rise steeply if rivers and potable aquifers are to be sustained in usable forms.

Governments have typically emphasized supply management, but as new water sources become increasingly inaccessible, the costs of projects to augment supply escalate. Many countries are already dependent on groundwater and, despite the potential for further exploitation (from costly deep aquifers), most countries face severe problems of depletion. Nonconventional sources include wastewater treatment and reuse, and desalination. They are invariably more expensive than traditional sources, although in the case of wastewater treatment, costs can be offset against environmental concerns. Alternatives to such investment are conservation and improved management of existing supplies, both of which are normally very cost-effective. More problematic is reallocation between uses. Reallocation will be a key mechanism for adjusting to water scarcity, since relatively small shifts from irrigation can often satisfy the needs of other sectors. Abandoning irrigation in arid areas, however, destroys agricultural viability and has adverse multiplier and third-party effects. Increased efficiency should always be emphasized, but few governments are willing to commit themselves to a strategy of reducing irrigation areas—or even to the use of costly treated wastewater in irrigation—even if they recognize that this is inevitable in the long term.

Given the constraints on new water supplies, Governments must be persuaded to give far greater emphasis to demand management. Demand management covers both direct measures to control water use, such as regulation and technology, and indirect measures that affect voluntary behaviour, such as market mechanism, financial incentives and public education. The mix of demand management measures will vary, but in all cases they aim to conserve water through the increased efficiency—and perhaps equity—of water use (the World Bank, 1994).

Direct measures to control water use are difficult to administer, although rationing can be effective in responding to variability; and regulation of water quality, even if seldom successful, is a universal objective. Technical interventions are important in all sectors to reduce unaccounted-for water losses. Modernization of both distribution and on-farm systems has particular potential. Indirect measures notably include water charges and other financial instruments. In principle, opportunity cost-pricing would provide appropriate incentives for efficient use of water, and Governments should be strongly encouraged to bring resource pricing progressively closer to real economic levels. In practice, even if water use is measured and fees are charged according to the volume of water used, rates usually fall below those required to cover financial costs and do not have a significant impact on demand. In some countries, irrigation is provided to the farmers free, and in all countries there is strong resistance to effective water pricing.

Issues of efficiency, allocation and water quality must be effectively managed. Current policies indicate that considerable progress has been made in recent years in increasing efficiency-use of both land and water resources. In both supply- and demand-management issues, augmentation of supplies (through reallocation and desalinization) are currently being adopted in many Arab countries. Therefore, the water market offers good possibilities for future supply of water.

Agriculture is the prime user of water in the region, and, in most countries, farmers pay a low price for water use. As land and water become increasingly scarce, a link between the scarcity of resource and its price is a rational policy, which would improve efficiency in resource allocation, alleviate budget deficits and reduce environmental costs. It would not only reduce the problems of waterlogging and salinity, but would also reduce water shortage through demand management and avert the problem of environmental degradation. Furthermore, new water resource projects would not be required to enhance supply.

Given the fact of water scarcity, sustainable development dictates that the pricing of water reflect as closely as possible its long-run marginal cost. As a first step, water charges should be levied to recover operation and maintenance (O&M) costs plus a portion of the investment costs; and as a tool to improve efficient use of the resource (ESCWA, 1994).

Policy successes from the region include: introduction of water pricing in Sudan (full cost recovery), water pricing in the Jordan Valley through the installation of water meters (providing the possibility to charge a marginal price for water), and relaxing rent control in Egypt.

Water policies in the Arab region are linked to land policies and issues of food security. In the past, water policies have focused on the supply management of water resources and have been synonymous with irrigation through investments in irrigation and drainage systems. Water development projects included the construction of dams, reservoirs, well fields, canal or pipe networks. In some countries, government policy has encouraged and subsidized the digging of wells. The Syrian Arab Republic, in the last 10 years has devoted 60-70 per cent of its entire agricultural budget to irrigation. Eighty per cent of new farmland since 1987 has been irrigated through digging groundwater wells, supported by government subsidies on fuel for operating the pumps.

Demand management of water resources was not explicitly included in water policies in the past in most of the Arab region, partly because the focus initially was on expanding the supply and partly because water was socioculturally believed to be a free resource.

Lack of demand management practices in the past also contributed to a low efficiency of water use and its consequent waste. In addition, improvements in the availability of water owing to the introduction of high technology diverted attention from demand management and reduced emphasis on low-cost alternatives such as improving efficiency, conservation and the reduction of waste through maintenance.

Government interventions, in the form of controls on cropping patterns, such as in Egypt, Morocco and Jordan, also led to reductions in agricultural value added and an inefficient use of water resources. In

Egypt, although sugar cane and rice used 35 per cent of water, they contributed only 14 per cent of the value-added (ESCWA, 1994).

Past land and water policies have resulted in a reduction in food security, an increase in water scarcity and the degradation of natural resources. Of the 21 countries worldwide currently predicted to become water scarce, half are in the Arab region. Many countries in the region, such as Saudi Arabia and the Gulf countries, Jordan and Yemen, have already exceeded the renewable limits.

Groundwater resource in many countries of the Arab region is depleting at an increasing rate. Policies have contributed to a lowering of the water table beyond the minimum sustainable level. In the northern region of the United Arab Emirates, for instance, the water table is dropping at a rate of one metre per year. In Oman, over-exploitation of aquifers through the digging of thousands of diesel tubewells, has contributed to salinization of lands. In Kufra in The Libyan Arab Jamahiriya and in the new valley in Egypt, nonrenewable groundwater resources are already over-exploited. Groundwater depletion, in many of the Gulf countries, has contributed to desertification. Inappropriate technology; cheap credits which promoted digging of wells; water costs far below the economic, or even the financial prices; and subsidies on electricity are some of the causes which contributed to over extraction of groundwater.

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 of water deficit in countries such as Jordan, Oman, Saudi Arabia, the Syrian Arab Republic and Yemen is worse than others; the renewable water resources per capita in those countries are predicted to decline by around two-thirds in the next 30 years (ESCWA, 1994).

A. SUPPLY MANAGEMENT

Water resource development is the core issue of supply management policies. The main options for water resource development are given below.

1. *Desalinization*

Middle East and North Africa countries account for 60 per cent of the world desalinization capacity, of which half is in Saudi Arabia alone, where cheap sources of energy have been available. Desalinization remains an expensive way to augment water supplies, especially for energy-deficient and low-income countries.

2. *Urban wastewater treatment*

Reuse of treated urban wastewater is already a practice in many of the water-deficient countries in the Arab region. Availability of fresh water is being augmented by treated urban wastewater in Kuwait, Saudi Arabia, Tunisia and Yemen, among others. Although treated wastewater is expected to only modestly augment water supplies in most of the countries of the region, in water-scarce countries of the Gulf the contribution is substantial, especially since the cost of producing a unit of treated wastewater is estimated to be only 8-18 per cent of that of desalinized water and 20-40 per cent of desalinized brackish water.

3. *Reallocation of supplies*

Since irrigation accounts for about 80 per cent of total water use in the Arab region, even a small diversion to other uses, industrial or domestic, could release substantial amounts of water to fill a percentage of the requirements of these sectors. In Jordan a 5 per cent transfer from the agricultural sector could increase domestic supplies by 15 per cent, despite the fact that non-agricultural use in Jordan is already high at 30 per cent. In Morocco, a 5 per cent diversion would result in a doubling of the supplies to the domestic sector.

B. DEMAND MANAGEMENT ISSUES

Increasing conservation and efficiency of water use

The most cost-effective way to increase availability of water is through conservation and efficient use. Both these measures will release resources that can be utilized elsewhere.

The overall efficiency of water use at 53 per cent in Jordan, a severely water-deficient country, is the highest in the region and at 30 per cent, much higher than the average for the developing countries. A large part of this is due to the wide adoption of high-efficiency drip irrigation systems in Jordan, especially in the Jordan Valley. This compares favourably with a 30 per cent overall efficiency of water use for Egypt and the Syrian Arab Republic, and 20 per cent for Yemen.

Irrigation efficiency is the net amount of water added to the root zone divided by the amount of water taken from any source. On-farm irrigation efficiency is the highest in Jordan, at 70 per cent. For Morocco it is 60 per cent, for the Syrian Arab Republic 50 per cent and for Yemen 40 per cent.

In many countries of the region, combating the problem of over-exploitation of groundwater, low efficiency of water use, and a rapid degradation of the natural resource base requires formulation and strengthening of the institutional and regulatory framework.

C. TECHNICAL AND POLICY OPTIONS

There are many alternative solutions to water resource constraints, ranging from agricultural to technological to economic and public policies; but, as for any scarce resource, they all fall under two basic categories: increase supply or decrease demand. These water management options are listed below (Wolf, 1996).

1. *Unilateral options*

(a) *Increase supply*

An increased catchment of winter floodwater anywhere along the existing river system is a new natural source that can add to the water budget. This applies to small wadis, as well as to large water projects. When it is possible to store water underground through artificial groundwater recharge, even more water is saved, and not lost to evaporation in a surface reservoir. Less evaporation also means less salinity in the remaining water.

Underground is the only place to look for any new water supplies. To this end, Jordan, for example, has been carrying out a systematic underground evaluation project.

New sources through technology, which include projects such as iceberg towing and cloud seeding, do not seem to be the most likely direction in the technology option. The former involves great expense and the latter can be, at best, a small part of a local solution.

The two most likely technologies to increase water supply are desalination and wastewater reclamation. The Middle East has already spent more on desalting plants than any other part of the world. The region has 35 per cent of the world's plants, which account for 65 per cent of the total desalting capacity, mostly along the Arabian Peninsula.

High costs make desalinated water expensive for most applications. Although drinking water is a completely inelastic commodity (that is, people will pay almost any price for it), water for agriculture has to be cost-effective, in order that the agricultural end-product will remain competitive in the marketplace. The

present cost of about US$ 0.80 to US$ 1.5 per m^3 to desalt sea water and about US$ 0.3 per m^3 to treat brackish water do not make this technology an economical source for most water uses. Efforts are being made, however, to lower these costs through multiple-use plants (getting desalted water as a by-product in a plant designed primarily for energy generation), through increased energy efficiency in plant design, and by augmenting conventional plant power with solar or other energy sources.

One additional use of salt water is to mix it with fresh water in just the right quantity to make it useful for agricultural or industrial purposes, effectively adding to the freshwater supply. This method was used in the 1975/1976 season to add 141 million cubic metres (MCM) per year to the water budget of Jordan.

The other promising technology to increase supply is wastewater reclamation. The obvious limit of this technology is the amount of wastewater yearly generated by a population.

(b) *Decrease demand*

The guiding principle in decreasing demand for any scarce resource should be, "Can it be used more efficiently?"

To limit population growth in the region is not a likely option, owing to national, religious and ethnic considerations. However, there are other viable options.

In the agriculture sector, some aspects of decreasing agricultural water demand are noncontroversial and have made the region a showcase for arid-agriculture water conservation. Technological advances, such as drip irrigation, are about 20-50 per cent more efficient than standard sprinklers and much more so than the open-ditch flood method used in the region for centuries. Use of these techniques has been spreading throughout the region, and it is reasonable to assume that increased water efficiency will continue to be an important aspect of agriculture in the region.

As for the issue of economic efficiency, water distribution in the region is inefficient. The main problem is that the cost of water to the user is highly subsidized, especially water used for agriculture. The true cost of water reflects all of the pumping, treatment and delivery costs, most of which are not passed on to the farmer.

Economic theory argues that only when the price paid for a commodity reasonably reflects the true price can market forces work for efficient distribution. In other words, subsidized water leads to waste in agricultural practices, little incentive for research and development of conservation techniques and practices, and too much water allocated to the agriculture sector as opposed to industry. If subsidies are removed, greater water-use efficiency on the farm would result, and the saving in water use could be substantial. However, this is not always feasible due to overriding socio-political considerations that mainly prevail in developing countries.

2. *Cooperative options*

Cooperative options can be found in shared information and technology, interbasin water transfers and joint regional planning.

D. FUTURE CHALLENGES

Tightening supplies have been accompanied by a 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 (Rosegrant, 1997).

The challenges of the growing water scarcity are exacerbated by the increasing costs of developing new water sources, the wasteful use of already developed water supplies, the degradation of soil in irrigated areas, the depletion of groundwater, water pollution and its impact on human health, and by the massive subsidies and distorted incentives that govern water use.

New sources of water are increasingly expensive to exploit, limiting the potential for expansion of new water supplies. These increases in the costs of new irrigation, combined with declining cereal prices, have resulted in low rates of return on new irrigation construction in many Asian countries.

The cost of supplying water for household and industrial uses is also increasing rapidly. In Amman, the average incremental cost of water from groundwater has been US$ 0.41 per m^3. However, with shortages of groundwater, the city has begun to rely on surface water, which is pumped with a lift of 1,200 metres from a site 40 km from the city, at an average incremental cost of US$ 1.33 per m^3. Future schemes are estimated to cost US$ 1.50 per m^3.

One of the most important problems is that much of the water is wasted in agricultural, household and industrial uses. Water use efficiency in irrigation in much of the developing world is typically in the range of 25-40 per cent; that is, only 25-40 per cent of the water in the system is actually used beneficially. These inefficiencies seem to imply the potential for huge savings from the existing uses of water; but savings will not be dramatic in all regions or delivery systems, because some of the water "lost" from systems is reused elsewhere. However, the scope for water savings from existing uses remains large.

A particularly difficult challenge will be to improve the efficiency of agricultural water use to maintain crop productivity growth, while at the same time allowing reallocation of water from agriculture to urban and industrial uses. Nearly two-thirds of rice and wheat production in the world is grown on irrigated land; and a growth in output per unit of land and water is essential to feed growing populations. Nevertheless, because of the limited number of cost-effective new sources of water, the rapidly growing household and industrial demand for water will need to be met increasingly by water savings from irrigated agriculture.

A considerable area of irrigated agricultural land is degraded and lost annually due to waterlogging and salinization. Most of the waterlogging and salinization have occurred in irrigated croplands with high production potentials. Degradation of cropland because of salinization is a significant and growing problem and will further increase the pressure on existing irrigated production.

Another problem is that groundwater is depleted when pumping rates exceed the rate of natural recharge. The pumping of fossil water constitutes water mining, a one-time extraction from a depletable reserve. Overdrafting, or the mining of groundwater at a rate higher than recharge, increases pumping lifts and costs because of the lowered water table, causing degradation of water quality in the aquifer.

Fossil aquifers, which are typically deep underground systems that receive little or no recharge, are being used for irrigation in some arid regions of the world. Egypt is irrigating 17,000 hectares of cropland from fossil aquifers and has plans to increase these areas significantly. Three-fourths of Saudi Arabia's water supply comes from nonrenewable groundwater sources, and this share is expected to rise. Groundwater pumping in Saudi Arabia exceeds estimated recharge more than fivefold.

With regard to pollution, water quality and human health, the contaminated wastewater often used for irrigation creates serious risks for human health and well-being.

Despite these challenges and because of distorted incentives, most of the world does not treat water as a scarce resource. Both urban and rural water users are provided with massive subsidies on water use;

irrigation water is essentially unpriced; in urban areas the price of water does not cover the cost of delivery; and capital investment decisions in all sectors are divorced from management of the resource. In Jordan, despite severe water scarcity, water policies encourage overuse of water, and strict rationing is often required to allocate the resulting scarcities. Overuse of irrigation water is encouraged by massive subsidies. Irrigation water developed by the public sector is priced at only one-tenth of the actual cost of water produced by the private sector. In Egypt, annual irrigation subsidies are estimated at US$ 5.0 billion (Rosegrant, 1997).

With water provided by public systems at little or no cost to the user, no one in the allocation system—whether water managers, farmers or urban water consumers—has an incentive to conserve water. As a result, water is used to excess in all purposes, leading to inefficient agricultural production decisions, waterlogging, salinization, groundwater overdrafting, and return flows degraded by agricultural chemicals and industrial pollutants.

E. STRATEGIES FOR THE FUTURE

The challenges of water scarcity can be addressed through supply and demand management strategies. Supply management involves activities to locate, develop and exploit new sources of water; whereas, demand management addresses the incentives and mechanisms that promote water conservation and the efficient use of water. Both supply and demand management are required to make better use of existing supplies of water.

1. *Supply management*

The development of new water resources has slowed considerably since the late 1970s, as a result of increased construction costs for dams and related infrastructure, the relatively low prices of staple cereals, and concerns about environmental and social impacts, particularly the dislocation of residents in affected communities. Meanwhile, annual expenditures on irrigation have declined sharply since the late 1980s, and are reflected in the declining growth in crop areas under irrigation. The growth rate in irrigated areas has declined from 2.08 per cent per year during 1970-1982 to 1.28 per cent during 1982-1994 for both developed and developing countries. Some options of supply management are given below.

(a) *Groundwater*

Sustainable development of groundwater resources offers significant opportunities for many countries. The massive expansion of private sector tubewell irrigation in Bangladesh, India, and Pakistan is the most successful example of private sector irrigation development in the developing world.

Private tubewells have been installed largely in and around the command areas of large surface irrigation systems for three reasons: (a) deep percolation losses from the surface systems recharge the aquifers for tubewells; (b) the tubewells are often used together with surface irrigation water, which lowers pumping costs and concentrates those costs in periods of highest marginal returns; and (c) the tubewells ride piggyback on the infrastructure created for the systems.

With careful management, the potential for groundwater use is also substantial in North Africa and the Middle East. Large aquifers underlying this region include the Eastern Erg and the Nubian aquifers. The Eastern Erg in Algeria and Tunisia covers an area of almost 400,000 km^2 and stores an amount of water equal to about four times the average annual renewable supply of the entire North Africa and Middle Eastern region. Only 0.04 per cent of this volume is recharged annually, so this is essentially fossil water. The Nubian Sandstone Aquifer underlies parts of Egypt, the Libyan Arab Jamahiriya and Sudan, extending over an area of 1.8 million km^2. The volume of stored water is nearly 20 times the average annual renewable supply for North Africa and the Middle East, and the aquifer has an annual recharge rate equal to about 2.5 per cent of its volume; so this resource would be of great value if exploited prudently. Because of the nature

of these large fossil aquifers in North Africa, extensive investigation is required to determine their characteristics, possible exploitation rates, and the potential impact on neighbouring countries.

(b) *Conjunctive use of surface water and groundwater*

Conjunctive use of surface water and groundwater is often recommended but rarely practiced, except in the limited sense of farm-level water management when both surface and groundwater supplies are available. Nevertheless, conjunctive use of surface and groundwater has several potential advantages that could be expanded significantly. For example, wells can be used as an on-demand irrigation system, to supplement inadequate or unreliable flows of canal water, reduce moisture stress, and maximize irrigated crop yields. The pumping of groundwater into the canals can augment the canal water resources, lower the water table and reduce salinity. And a canal command and its embedded tubewells can be viewed as an integrated system for optimizing the use of canal and groundwater resources jointly.

(c) *Desalination*

The supply of freshwater through desalination is expensive. However, although desalination capacity increased 13-fold from 1970 to 1990, to more than 13 million m^3 per day, desalinated water accounts for just one-tenth of one percent of freshwater use. Nearly 60 per cent of desalination capacity in the world is in the oil-rich, water-scarce Arabian Gulf, and much of the rest of the capacity is in island nations and other arid countries.

Technology for desalination is improving rapidly, but prices remain high. The cost of production (not including transport costs) ranges from US$ 1.00 to US$ 2.0 per m^3 depending on the technology and salt loads in the water.

(d) *Recycling and wastewater reuse*

After being used once, freshwater can be used again in the same home or factory (usually called recycling) or collected from one or more sites, treated, and redistributed and used in another location (generally called wastewater reuse). Both of these concepts are distinct from the reuse of return flows from irrigation when only part of the water withdrawn from a stream or aquifer is consumptively used.

Developed countries have greatly expanded the use of water recycling in industry. Total industrial water use in Japan reached a high in 1973 and declined by a quarter by 1989. In the United States, between 1950 and 1990, total industrial water use fell 36 per cent, while industrial output increased nearly fourfold.

The reuse of wastewater has been more limited. Although the technology exists to upgrade wastewater for domestic consumption, it is expensive and consumer resistance has been high.

About 500,000 hectares of cropland worldwide are irrigated by treated municipal wastewater, amounting to only two-tenths of one per cent of the world's irrigated area.

(e) *Water harvesting*

Water harvesting, concentration of rainfall through runoff for beneficial use, has been used for centuries in traditional agriculture.

Some experiences show that in some local and regional ecosystems, water harvesting can provide farmers with improved water availability, increased soil fertility and higher crop production. Water harvesting can also provide broader environmental benefits through reduced soil erosion. However, given the limited areas where such methods appear feasible and the small amounts of water that can be captured,

water harvesting techniques are unlikely to have a significant impact on global food production and water scarcity.

2. *Demand management*

Demand management represents a comprehensive water policy reform in the region for the future. The potential measures it includes are outlined below.

(a) *Potential for water savings*

A large share of water to meet new demand must come from water saved from existing uses. This will require a comprehensive reform of water policy, which will not be easy, because both long-standing practice and cultural and religious beliefs have treated water as a free commodity and because entrenched interests benefit from the existing system of subsidies and administered allocations of water.

Overall irrigation efficiencies (the product of irrigation system efficiency and field application efficiency) in developing countries are low, ranging from 25-40 per cent for India, Mexico, Pakistan, the Philippines and Thailand to 40-45 per cent in Malysia and Morocco, compared with 50-60 percent in Japan and Taiwan. These low water-use efficiencies are often cited as evidence that very large savings in water use can be obtained. However, they are derived from individual system evaluations rather than from basin-wide assessments. For example, estimates of overall water-use efficiencies for individual systems in the Nile basin in Egypt are as low as 30 per cent, but the overall efficiency for the entire Nile system in that country is estimated at 80 per cent.

(b) *Policy instruments for demand management*

Among the types of policy instruments available for demand management are:

(i) Policies that include reform of water rights, privatization of utilities, and laws pertaining to water-user associations;

(ii) Market-based incentives, which directly influence the behaviour of water users by providing incentives to conserve on water use, including pricing reform and reduced subsidies on urban water consumption, water markets, pollution charges, and targeted taxes or other subsidies;

(iii) Non-market instruments, including restrictions, quotas, licenses, and pollution controls;

(iv) Direct interventions, including conservation programmes, leak detection and repair programmes, and investment in improved infrastructure.

The precise nature of water policy reform and the policy instruments to be deployed will vary from country to country depending on underlying conditions, such as the level of economic development and institutional capacity, relative water scarcity and the level of agricultural intensification.

(c) *Demand management for surface irrigation*

Surface water can be conserved by improving the mechanisms of administrative water allocation, by using volumetric water prices or by establishing markets in tradable water rights.

Administrative reforms have included the modification of water distribution methods (such as shifting from continuous to rotational flow allocation) and the institutional reform of public irrigation bureaucracies. Reform of water management methods within existing systems has had mixed results: some interventions showed increases in water-use efficiency and high rates of economic return; others appeared much less affective. It is unclear whether or not real water savings were achieved through these reforms.

The primary alternative to quantity-based allocation of water is incentive-based allocation, either through volumetric water prices or through markets in transferable water rights. The empirical evidence shows that farmers are price-responsive in their use of irrigation water. The four main types of response to higher water prices are: use of less water on a given crop, adoption of water-conserving irrigation technology, a shifting of water applications to more water-efficient crops, and a change in crop mix to higher-value crops.

(d) *Demand management for groundwater*

The problem of overdrafting of groundwater often occurs because individual pump irrigators have no incentive to optimize long-run extraction rates, since water left in the ground can be captured by other irrigators or potential future irrigators. To encourage rational exploitation of groundwater, the same types of policy instruments employed for surface water can be used. The three broad types of institutional arrangements for managing aquifers are: quantity-based controls, prices and charges, and tradable water rights (or exchangable permits) in stocks and flows of groundwater.

F. PRIVATIZATION AND USER PARTICIPATION IN IRRIGATION

The options underlying this title which help in improving water-use efficiency are outlined below.

1. *Reforming urban water systems*

To a significant extent, the poor performance of urban water systems is due to "flawed" policies. When incremental water can be obtained at low cost as a result of subsidies, there is little incentive to improve either physical efficiency (by, for example, investing in pipes or meters) or economic efficiency (collection of water tariffs). Considerable evidence shows that the use of incentive-based policy instruments can achieve substantial water savings and improve the delivery of services. These instruments have been used to raise efficiency and generate savings in urban water service and delivery and in household and industrial water use. The average level of unaccounted-for water in urban water projects assisted by the World Bank is about 36 per cent. Cairo, among other cities, has unaccounted-for water levels as high as 60 per cent, compared with 10-15 per cent in well-managed systems.

2. *Conservation through appropriate technology*

If improved demand management introduces incentives for water conservation, the availability of appropriate technology will be essential to generating water savings. As the value of water increases, the use of more advanced technologies (such as drip irrigation utilizing low-cost plastic pipes, sprinklers and computerized control systems, used widely in developed countries) could have promising results for developing countries. Any evaluation of the impacts of these technologies must take into account the difference between consumptive use of water and water withdrawals or applications. All of these advanced technologies can significantly reduce the amount of water applied to a field; but, to the extent that the saved water simply reduces the amounts of drainage water that is reused, the actual water savings will be lower than the apparent efficiency gains. Nevertheless, if the scarcity value of water is high enough, appropriate use of new technologies appears to offer both real water savings and real economic gains to farmers.

Field application efficiencies in flood irrigation in developing countries are typically in the range of 40-60 per cent. High pressure sprinklers save on drainage losses but may not reduce consumptive use, because of the high evaporative losses. Modern low-pressure, downward, sprinkling systems, however, can reduce evaporation considerably.

By the application of water directly to the root zones, drip irrigation can significantly reduce field evaporation losses. Drip irrigation can also increase the productivity of water in areas already affected by

salinity. Used in conjunction with tubewells, these systems can lower water tables and leach salts below the root zone of plants.

Technological opportunities also exist at the irrigation system level. In North Africa, modern irrigation systems using hydraulically-operated diversion and measuring devices were developed as early as the late 1940s and were employed in irrigation schemes constructed in the 1950s. Modern schemes in that region deliver water on demand to individual farmers, allowing water users to be charged according to the value of water delivered, thus encouraging conservation and the efficient use of water. Some of these irrigation techniques have been transferred to the Middle East and, in pilot projects, to other developing countries. The continued increases in the value of water could make these capital-intensive irrigation distribution systems more widely feasible in other regions of the world.

Scarcity of water has led to a demand for policy reform, but many questions remain concerning the feasibility, costs, and likely effects of alternative water allocation policies in developing countries. The International Food Policy Research Institute (IFPRI) has established a research programme to: (a) understand the productivity, equity and environmental impacts of alternative policies for intersectoral water allocation within the river basin; and (b) establish options for reform of the institutions and incentives which affect water resource allocation within the river basin (IFPRI, 1996).

The main results include overall assessment of the conditions that underlie the relative effectiveness of alternative water allocation mechanisms and the relative efficiency of allocation through market-based mechanisms as compared with administrative and user-based mechanisms of water allocation.

3. *Use of saline water*

There is a growing demand for freshwater for domestic, agricultural and industrial purposes, and this increases the need to use saline water for agriculture in the Arab World. The Arab Centre for the Studies of Arid zones and Dry Lands (ACSAD) investigated the use of saline water for irrigating alfalfa, barley and cotton by mixing drainage water with freshwater at different mixing ratios and leaching fractions. This experimental study also included predicting the increases in soil salinity as a result of using saline water for irrigation (ACSAD, 1993).

Irrigated land averages 30 per cent of the arable land in the low-income countries of West Asia and North Africa, 33 per cent in the medium-income countries and 19 per cent in the high-income countries. The agricultural sector in these countries uses 70-80 per cent of the freshwater, but its share is declining because of competition from the industrial and domestic sectors. Jordan, Lebanon and Tunisia are shifting from agricultural water management based on increasing water supply (construction of dams and conveyance systems, tapping unused sources of water, or re-use of water) to agricultural water management based on water demand (Rodriguez, 1997).

4. *Water conservation programme*

A popular notion among policy-makers is creating new water supplies by conserving water through increased efficiency in existing water uses. Given that irrigation accounts for 80-90 per cent of all water consumed in the region, it is not surprising that irrigated agriculture is usually the focus of such proposals. Unfortunately, most proposals fall into the dangerous trap of defining water conservation in terms of reductions in required diversions resulting from increased efficiency, rather than in terms of actual water savings.

In general, policy-makers and resource managers should always be wary of proposals to "conserve" water for other uses by increasing irrigation efficiency. A real improvement in irrigation efficiency will result in an increase, not a decrease, in water consumption by crops. To achieve real water conservation in irrigated agriculture, the measures to be taken must result in crops consuming less water than they presently

consume. There are viable options to achieve this goal, including irrigating fewer acres, switching to crops that require less water, and deficit irrigation. Each of these approaches is likely to decrease agricultural production or net farm income to some extent, but it is unlikely that producers will undertake such efforts unless compensated for doing so. However, it is in these areas that legitimate water conservation and transfer programmes may be developed (Whittlesey and Huffaker, 1995).

5. *Water markets*

Water markets can be a powerful tool for reallocating water to higher social needs, but policy-makers experimenting with the creation of water markets should do so with caution and full information. Third-party effects and impacts on the economy of the area of origin must be carefully considered. That is, we must guard against market failure.

Water policy in the new century may only be advanced by understanding the connections between water laws, water policy administration, technology, hydrology, and human values in our socioeconomic system.

II. WATER-USE EFFICIENCY

A. WATER-USE EFFICIENCY AND WATER PRODUCTIVITY

One of the most extensively used terms to evaluate the performance of an irrigation system is water-use efficiency (WUE). In general terms, water-use 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 interest, 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 evapotranspiration demand. On-farm water components, such as seepage and percolation, are losses, because they flow out of the farm without being consumed by the intended crop. Reducing the amount of seepage and percolation would lead to an improvement in on-farm water efficiency; but if this water can be recovered for crop consumption at some point downstream, these components are not losses of the irrigation system.

The efficiency concept is not directly related to 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, and others), it is important to specify which components are included when calculating water productivity. For practical purposes, the concept of water productivity, similar to WUE, needs clear specification of the domain of interest boundaries.

Water productivity can be increased by increasing yield per unit land area, by using a better variety of agronomic practices, for example, or by growing the crop during the most suitable period. Water productivity is also determined by factors other than water management. In using this concept to improve water management, other factors that contribute to crop yield have to be considered. 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-saving opportunities of the system under consideration.

Water efficiency and productivity terms should be used complementarily to assess the water management strategies and practices used to produce more crop 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 WUE 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 the 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 run-off and seepage and percolation, which accounts 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: increasing yield per unit evapotranspiration during crop growth; reducing evaporation, specially during land preparation; reducing seepage and percolation during the land preparation and crop growth periods; and reducing surface run-off.

For the purpose of discussion, it is appropriate to avoid the confusion over the concept of efficiency and 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 measure, there are several different ways of expressing productivity:

(a) Pure physical productivity, 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 divided by the amount of water diverted or depleted;

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

In this discussion, Oweis et al. (1999) define water productivity (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 generally accepted to evaluate the wise use of water is what is referred to as WUE (water-use efficiency). The term indicates how much food and/or fiber a cubic metre of water may produce. Comparing the WUE of the supplemental irrigation (SI) of wheat with that of full irrigation (FI), a real opportunity for water-use improvement was found. According to ICARDA's research trials and farmers' demonstration fields in the Syrian Arab Republic, a cubic metre of water used in SI produced, on average, an extra 3 kg of wheat over rainfed yield, whereas a cubic metre used in FI produced about 0.5 kg/m^3. This large difference in the WUE is attributed to the conjunctive use of rainfall and SI water. In Jordan, WUE in rainfed wheat in Mushagar (300 mm annual rainfall) is 0.33 kg/m^3, when the cubic metre of rainfall is combined with a supplemental ½ m^3, the overall 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 combining the 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 making the water available for use and the cost of application to the field. A distinction between the cost and the real value of water has yet to be made in the region. In most cases, the cost of water for farmers is only the running cost needed to convey it from a canal or a river or pump it from the aquifer. The real value of water to the nation, as a scarce resource and as a common property, is much higher than the cost for farmers. A revision of water is costing relative to the common interest of the society is vital, so that such an important resource not wasted (deemed less than its real value). Farmers in West Asia and North Africa 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 remains very low.

In water-scarce areas, 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 criterion and objective, since land is not as limiting to production as is water.

The average WUE of rain in producing wheat in the dry areas of West Asia and North Africa is about 0.35 kg grain/m^3, although with good management and favourable rainfall (in amount and distribution), this

can be increased to 1 kg grain/m^3. However, water used in SI can be much more efficient. ICARDA research showed that a cubic metre 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 6 ton/ha using 800 mm of water. Thus, the WUE is about 0.75 kg/m^3, one-third of that under SI with similar management. This suggests that water resources may be better allocated to SI when other physical and economic conditions are favourable.

ICARDA found that, in the Syrian Arab Republic, supplementing only 50 per cent of the rainfed crop irrigation requirements reduces the grain yield by only 10-20 per cent relative to FI. 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.

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

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 terms 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 increase in yield peaking around 8 ton/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 (Oweis, 1997).

Enhanced exploitation of groundwater for SI on vast areas, which traditionally used to be rainfed, has helped bridge the gap in the Syrian Arab Republic's basic food production, recovering in particular the wheat balance. However, it has led to over-pumping and excessive water use.

Results show that improving the wheat price encourages the use of more water, unless the rate of increase in the cost of water exceeds that of wheat. Optimal applications of SI are determined by both the input/output price ratio and weather conditions. In a specific price situation, different SI amounts are defined for different rainfalls (Salkini and Oweis, 1993).

In most of West Asia and North Africa, water from public (surface) irrigation schemes is provided 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 studies have shown that the SI amounts 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 SI experiments in the northern Syrian Arab Republic

northern Syrian Arab Republic were conducted to evaluate water-yield relationships 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 needed for maximizing yield and the levels to which the crops could be under-irrigated without reducing income below that which would be earned by 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 ton/ha were recommended for sustainable utilization of water resources and higher WUE (Zhang and Oweis, 1999).

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

The mean WUESI ranged from 0 to 2.5 kg/m^3 for grain and from 0.3 to 4.3 kg/m^3 for total dry matter (TDM). Rain-WUE ranged from 8 to 11 kg/m^3. One third of full irrigation increased gross WUE from 1.15 to 1.36 kg/m^3. The highest gross-WUE and WUESI were achieved when one third of FI requirements was applied. The relationship between grain yield and total water applied was established using the data from both this experiment and the SI experiments of the previous six years. Different irrigation scenarios were suggested under different rainfall conditions and management options, following English and Raja (1996).

An analysis of deficit irrigation in three quite different situations was conducted to better understand the potential benefits and risks associated with this irrigation strategy. Existing crop yield and cost functions were used to estimate the levels of applied water that would produce maximum net income in each situation. Results suggest that deficits of between 15 per cent and 59 per cent would be economically optimal, although the estimated margin for error in these estimates is quite wide.

Deficit irrigation, the deliberate and systematic under-irrigation of crops, is a common practice in many areas of the world. The potential benefits of deficit irrigation derive from three factors: increased irrigation efficiency, reduced costs of irrigation and the opportunity costs of water.

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 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 is 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 constraint.

Inadequate water resources make it imperative to evaluate the efficiency of water utilization to arrive at a socially protective type of irrigation. The WUE would differ according to different systems of irrigation, crop mix and environment, and is comprised of 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 WUE has been evaluated in terms of crop output and crop value per unit of water. A protective irrigation system was found to perform better in terms of social efficiency, and the perennial system in terms of situational efficiency. The yield rates of rice, for example, in the irrigation system were higher than under the perennial system, although the water requirement was lower. The average water-use efficiency of rice in physical and monetary terms was 0.25 kg/m^3 and 0.265 Rs/m^3 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 agro-climate (Giriappa, 1984).

Efficient use of irrigation has been studied for three types of systems: the trickle, solid-set sprinkler, and furrow irrigation systems. It was found that irrigation efficiency of the sprinkler system was on the average about 22 per cent more than 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). Meanwhile, nine indicators have been developed related to irrigated agricultural systems. 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 (per cent), gross return to investment (per cent), and financial self-sufficiency (Molden et al., 1999).

III. METHODOLOGY DEVELOPMENT FOR ON-FARM WATER-USE EFFICIENCY

As previously noted, water use efficiency is defined in this study as the ratio of the required amount of water to produce a target production level to the actual amount of water used. Expert criteria, such as extension recommendations, are an example of the required amount of water. However, these recommendations are not necessarily based on actual crop requirement, they are built on a technical basis within the framework of the mono-cropping system, whereas actual farm production is based on the multi-crop system. In addition, technical factors are not sufficient to determine crop water requirements. Economic conditions, such as water limitations, play a major role in determining the amount of water farmers apply to each crop. Therefore, this study will calculate the required amount of water, based on the technical and economic conditions of farmers.

Using this definition of on-farm water-use efficiency, the value of WUE is greater than zero and less than or equal to one. A value of one means that farmers are fully efficient, in the sense that they apply exactly the amount of water required, whereas lower values indicate that farmers over-irrigate their crops much above the level required. In general, the closer the value of WUE is to one, the more efficient the farmers are.

Predicting crop-level input allocation is a major problem in a multi-crop production decision. This is mainly attributed to deficient data, since data on crop-level input are generally not available, except for land use. The challenge, therefore, is to develop modeling approaches that permit the 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 estimating the enterprise cost of production. Furthermore, evaluating the effects of alternative policies in influencing input use frequently requires an understanding of how producers make decisions on crop-level input use (Moore et al., 1994a and 1994b). Previous research on multi-crop output/input allocation were mainly based on two assumptions regarding producer behaviour: profit maximization and satisficing behaviour. Satisficing behaviour means that farmers operate on a rule-of-thumb level stemming from bounded rationality. Thus, crop acreage would effectively determine the allocation of input among crops on a multi-crop farm. Three alternative models of multi-crop input allocation were proposed for this study. These include a fixed allocatable input model, a variable input model, and a satisficing model. In the short run, an input is considered to be a variable input, but in the long run it may actually be fixed and allocatable. Irrigation with groundwater is an example, whereby 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 affecting water price. However, constraints on the number of wells, the pump capacity and the water distribution infrastructure may make groundwater a fixed, allocatable input in the short run (Moore et al., 1994a and 1994b). Irrigation with surface water may pose similar short-run constraints, as well as long-run institutional constraints. Hired labour and farm machinery may also be variable in the long run, but fixed and allocatable in the short run.

Crop-level input 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 by using insufficient 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 when estimated with insufficient data. Therefore, data set that contains both crop-level irrigation water and acreage data from multi-crop farms will be applied.

The three alternative models of short-run input, thus, can be directly estimated econometrically with the crop-level water data. The availability of crop-level micro-data on water use effectively makes the data non-deficient in terms of information on water allocation in a multi-crop system. In this study, the variable input model and the fixed, allocatable model are derived on the basis of the profit maximization assumption

using the duality theory; whereas, the satisficing model is a simple model of bounded rationality. These three models of multi-crop water allocation can be compared using two techniques of model selection (model specification tests and prediction accuracy measures). The empirical application analyses multi-crop water irrigation in the Radwania area of the Northwest Syrian Arab Republic, using data from a farm survey. The basic unit for the study will be the individual farm, and the study will consider the entire cropping system as the target. The WUE will be assessed for all crops planted in a given season and for all seasons over the year. Different farms will be selected to cover the major conditions in the region.

A. 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 made an intermediate-run production decision, including the combination of crops to produce and the acreage of each crop. The subsequent short-run decision involved 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 price of crop i (i = 1,...,m); γ^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 multi-output restricted profit function of the farm. Input non-jointness 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 multi-output 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 multi-output 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.

1. *Variable input model*

The variable input model has commonly been used in the analysis of short-run irrigation water use (Moore et al., 1994a and 1994b; Chambers and Just, 1989; Just et al., 1983). Following the dual approach, an 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 $\sigma\alpha$ input model. These demand functions are as follows:

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

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

2. *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 multi-crop 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 (Moore et al., 1994b):

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

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

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

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:

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

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), inter-crop 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 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 non-jointness, the fixed water input creates interdependence across crops. For example, consider a multi-crop farm that grows wheat, potatoes and lentil. The water use on wheat depends on acreage in potatoes and acreage in lentil, in addition to acreage in wheat.

3. *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., 1994b):

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

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

In intuitive terms, the satisficing model stems from the idea that long-run decisions have a greater quantitative impact on profit relative to short-run decisions. Thus, producer behaviour might conform more closely to the profit maximization assumption in the intermediate or long-run periods.

An alternative model may explain the producer decisions on water use in the short run. A behavioural model relating water use primarily to planted area 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 L_{ki}, 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,

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

in which, W^*_{ki} 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 decisions consist 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 that they imitate one another. This allows water/land ratio decisions to be characterized by an overall average level and by a systematic farmer deviation reflecting land quality, human ability and perceptions. To develop the estimated form of this model, consider the following:

Let $W^*_{ki} = W_{ki}/L_{ki}$ 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:

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

Whereby 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 equation (6) for (5) gives:

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

Where e_i 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 corresponding 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 behavioural estimate of the allocation of water to crop k:

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

Equation (8) can be estimated using the ordinary least squares procedure. In case of one-period cross-sectional data, this model can be estimated with no farmer differences.

Previous research has provided empirical evidence of 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 the 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 multi-output farm, econometric results are reported for irrigated production in four multi-state regions of the American West (Moore et al., 1994a). Cross-sectional micro-data 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 et al. (1994b) compared three models of input allocation in multi-crop systems. In addition to the variable input and satisficing models analyzed in previous research, a fixed allocatable 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 multi-crop water allocation. In addition, the paper presents an alternative approach to the study of deficient data on multi-crop production. By transferring econometric results from an analysis of non-deficient crop-level data, input allocation in deficient data sets can be predicted.

Chambers and Just (1989) solve the problem of determining fixed allocatable input allocations by dual methods. A flexible, profit function approach for estimating input-non joint 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 a fully linear estimation of a second-order flexible technology.

Using data only on aggregate variable input use and land allocation, Just et al. (1990) suggest a methodology for allocating variable input use among crops and improving of regional crop budget information. Two approaches for the estimation of variable input allocations among production activities are examined. One relies on behavioural rules, whereby input allocations follow accepted rules-of-thumb. The alternative approach is derived from profit maximization, whereby input use responds instantaneously to changes in input and output prices. The behavioural rules dominate instantaneous response to prices in explaining the data analysed in this paper and suggest the validity of a sample behavioural 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 when total use of variable inputs, such as water, is observed but their allocations to various crops 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 allocations of other inputs. Just et al. (1983) addressed this issue of multi-crop production function estimation with allocated inputs. The approach uses all available information from both technological and behavioural assumptions in producing estimates of multi-output production functions, in which 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 (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 to zero for a non-renewable resource, increases with depletion and in the steady state may be greater relative to extraction cost.

For cost recovery of water services in agriculture, three charging mechanisms were evaluated (Perry, 1996): (a) a flat rate, independent of crop type or cropping intensity, (b) a crop-based charge, broadly relating the service charge to water consumption, and (c) 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, nor improve 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 water demand, because very high charges are required to have a significant impact.

B. Model validation

Two methods can be used to validate the proposed models. These are model specification tests and prediction accuracy measures. A pair-wise comparison approach may be used for specification tests of the three models of short-run water use. Similarly, prediction performance measures can 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. (1994b). Using pair comparison, the multi-crop 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:

$$W_i = \alpha^i + \beta^i p_i + \sum_{v=1}^{z} \gamma_v^i r_v + \delta^i r_w + \theta^i n_i + \sum_{s=1}^{t} \eta_s^i x_s \qquad \text{(equation 9)}$$

$i = 1,....,m$

The satisficing model of water use in 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:

$$\beta^i = \gamma_v^i = \delta^i = 0 \qquad i = 1,\ldots\ldots,m \qquad i = 1,\ldots\ldots\ldots,z \qquad \text{(equation 10)}$$

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, if the alternative hypothesis is true, the variable input model is the preferred model specification.

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:

$$W_i = \alpha^i + \sum_{j=1}^{m} \beta_j^i p_j + \sum_{v=1}^{z} \gamma_v^i r_v + \sum_{k=1}^{m} \theta_k^i \eta_k + \psi^i w + \sum_{s=1}^{t} \eta_s^i x_s \qquad \text{(equation 11)}$$

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

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

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

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

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 (combining equations 9 and 11). The empirical specification of the combined model is:

$$W_i = \alpha^i + \sum_{j=1}^{m} \beta_j^i p_j + \sum_{v=1}^{z} \gamma_v^i r_v + \delta^i r_w + \sum_{j=1}^{m} 1 + \psi^i w + \sum_{s=1}^{t} \eta_s^i x_s \qquad i = 1,\ldots,m \qquad \text{(equation 13)}$$

The performance of the variable and fixed allocatable input models are compared, independently, to the performance of the combined model (equation 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:

$$\delta^i = 0 \qquad i = 1,\ldots,m \qquad \text{(equation 14)}$$

If the null hypothesis is true, the variable input model is rejected relative to the combined model. Otherwise, if the alternative hypothesis is true, the variable input model is accepted as the preferred specification relative to the combined model. 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 inter-crop interdependencies in crop prices and acreages) do not independently explain variation in water use. The null hypothesis for this test is:

$$\beta'_i = \theta'_i = \psi' = 0 \qquad i = 1,\ldots,m \quad j=1,\ldots,m \quad i \neq j \qquad \text{(equation 15)}$$

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

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

Similarly, a set of pair model specification tests can be implemented, including a variable input model, a fixed, allocatable input model and a satisficing model on the one hand and the behaviour 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 are 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:

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

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

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

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 are conducted crop-by-crop. The measures thus represent the accuracy of a model in predicting short-run water use for each of the m crops under consideration. Both in-sample and out-of-sample predictions need to be calculated for evaluating the alternative models of water use.

Another method for model validation is 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 in 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).

C. 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 (size of the farm, total amount of water available to the farm and socio-economic characteristics of the producers), crop-level data (amount of water applied to each crop and the area devoted to the crop), price variables, and information on weather and soil quality. 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 (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) Surface water availability;
(o) Pressure irrigation technology (sprinkler and drip);
(p) Yield levels for produced crops;
(q) Input use for each crop (fertilizers, seed, labour, pesticides, etc.);
(r) Weather variables (total precipitation, solar energy availability, etc.);
(s) Soil quality variables (sandy soils, restrictions on soil use, etc.);
(t) Socioeconomic characteristics of the producers;
(u) Input prices (fertilizer prices, wage rate, etc.).

To collect required data for methodology testing and validation, a questionnaire was developed and pre-tested. The questionnaire provides various farm-level and crop-specific information, including socioeconomic characteristics of producers, size of holdings, sources of household income, soil characteristics, cropping pattern, and water availability and cost. In addition, detailed data 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 characterization of wells, as well as water management practices used on the farm, are included in the questionnaire and collected from the farm survey.

To finalize the questionnaire, a pre-testing stage was implemented by interviewing several producers in two villages in the Aleppo province in the northwest Syrian Arab Republic. The surveyed villages, which were the targeted sites for the formal collection of the data, are Radwania village of the Al-Safera district, Al-Gena village of the Jabal Samaan district. A total of four farmers were interviewed during the pre-testing stage. The Radwania village is located in the agricultural stability zone 3 and receives an annual rainfall of 250-300 mm. The cropping pattern for the growers of this village includes wheat, corn, cotton, sugar beet, cucumber, tomatoes and green pepper. Both surface and groundwater are available as water sources in the village. Winter crops mainly depend on surface water alone, whereas summer crops depend on both sources, with groundwater contributing up to 70 per cent and the remaining irrigation provided by surface water. The surface water is available on the farms for a period of seven months a year, while the groundwater is available for six months annually. During the first months of winter cropping, the farmers do not irrigate and mainly depend on rainfall.

For the farmers of Al-Gena village, the main source of water is groundwater, with sprinkler irrigation as the dominant technology. This village is located near the agricultural stability zone 1 with an annual rainfall of >450 mm. The cropping pattern adopted by the producers of this village include wheat, cotton, potatoes, sugar beet, onion, garlic, tomatoes, eggplant and green pepper. Irrigation cost in this village accounts for approximately 60 per cent of total production costs.

After careful consideration of the results of the pre-testing stage, the initial form of the questionnaire was revised. A final version of the questionnaire is presented in annex III. A team of interviewers, including a socioeconomist, a water specialist and an extension agent, successfully completed the farm survey.

To fully test the developed methodology in accurately assessing on-farm water-use efficiency, the survey was implemented at two sites located in two countries. One site is Radwania, in the northwest Syrian Arab Republic, where farmers use only groundwater or both surface water and groundwater. The other site is Rabea, in northwest Iraq, where producers use only surface water.

IV. CASE STUDY ONE: RADWANIA

A. CHARACTERISTICS OF SAMPLE FARMS

The sample farms in the Radwania area of the Syrian Arab Republic comprised 80 producers, distributed among 24 villages, with more of the producers located in the villages of Radwania (10 per cent), Aum-Hosh (11.3 per cent) and Kanater (10 per cent). The villages are clustered into 9 subdistricts, with 22.5 per cent of the sample farms located in Al-Safira Centre, 32.5 per cent in Kanaser and 23.8 per cent in Mareel subdistrict. The rest of the producers are scattered in the remaining six subdistricts. Most of the farms (56.3 per cent) are located in Al-Safira Centre, and the remaining 28.8 per cent and 15 per cent are located in the Azaz and Jabal Samman districts, respectively.

Most of the sample farms (63.8 per cent) are located in rainfall zone 2 (250-350 mm annual rainfall), while 36.3 per cent are in zone 4 (200-250 mm annual rainfall). The producers' experience in irrigation ranged from 1 to 49 years, with an average of 16 years. The majority of the farmers (91.1 per cent) are full-time operators, and only 8.9 per cent are part-time producers. Farming is the main source of income, with about 89 per cent of the producers completely dependent on farm income (which accounts for 100 per cent of the household income). Crop production accounts for 100 per cent of the farm income, as reported by 62 of the producers interviewed.

Soil type is mainly heavy on 41.3 per cent of the farms, while 26.3 per cent and 32.5 per cent of the producers indicated that their soil type was of sandy and medium types, respectively. Most farms (57.5 per cent) are of deep soil, and medium and shallow soils account for 13.8 per cent and 28.8 per cent of the total farms, respectively. Meanwhile, 79 farmers reported that soil salinity is low.

The current cropping pattern is mainly determined by market conditions, as indicated by 93.8 per cent of the sample farmers, whereas agricultural policies explain the cropping pattern of the remaining 6.2 per cent of the producers. The amount of water available to the farms is not limited, as indicated by 61 per cent of the producers. Only 39 per cent of the farmers reported that water available is limited. Location of water source relative to the farm is not of main concern, since 78.8 per cent of the farms depend on groundwater as the only source of irrigation, and surface water is the source for the remaining 21 per cent. No major restrictions, in the form of quantity, quality and regulations, are imposed on water availability. The main reason for irrigating crops is that the amount of rainfall is not sufficient for an economic rainfed yield, as indicated by 87.3 per cent of the sample farmers. Rule-of-thumb factors determine the amount of water the farmers apply to each crop, according to the survey sample.

Private ownership is the predominant land tenure feature in the sample farms, as reported by 82.3 per cent. The rest of the sample is characterized by rented or share-cropped land ownership. Other features of the sample farms are depicted in table 1. Among the 80 sample farms, 78 producers irrigate wheat, 27 irrigate barley and 72 irrigate cotton. Other crops are of minor importance to the farmers of the study area. For example, only 2 producers grow corn, 13 grow potatoes, 1 grows sunflower, 3 grow watermelon, 21 grow tomatoes and 3 grow green pepper. Therefore, our analysis will concentrate on wheat, barley and cotton, since they account for about 87 per cent of the total crop land in the sample farms. The total farm size average is 14.79 ha, of which the average crop area for wheat, barley and cotton is 5.21 ha, 3.27 ha, and 4.35 ha, respectively.

Water applied to the whole farm is on average 19,831.29 m^3 for the sample producers, at 4,833.09 m^3 for wheat, 3,770.35 m^3 for barley, and 15,385.03 m^3 for cotton. The annual rainfall for the study area during the 1997/1998 season was 284.4 mm, with a standard deviation of 52 mm; and the crop yield was 3.391 ton/ha for wheat, 2.245 ton/ha for barley, and 3.636 ton/ha for cotton. Water productivity, defined in technical terms as kg of output per m^3 of water, is the highest for wheat (0.90 kg/m^3), followed by cotton (0.57 kg/m^3), then barley (0.56 kg/m^3), indicating that water yields more output in wheat production compared to barley and cotton. This result, however, is mainly based on technical efficiency. To better represent actual farm conditions, economic criteria need to be taken into account as well. This can only be done by analysing water allocation among competing crops in a multi-crop system. This study is directed to that end.

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

Item	Total farm	Crop		
		Wheat	Barley	Cotton
Number of farms	80	78	27	72
Area (ha)				
Mean	14.79	5.21	3.27	4.35
SD*	19.92	8.85	2.78	6.60
Water applied (m^3)				
Mean	19 831.29	4 833.09	3 770.35	15 385.03
SD*	12 338.74	3 287.39	2 280.86	9 239.12
Irrigation (m^3/ha)	1 340.86	927.66	1 153.01	3 536.79
Experience in irrigation (year)	16			
Rainfall (mm)				
Mean	284.44			
SD*	51.94			
Total water use (irrigation + rainfall) m^3/ha	4 185.26	3 772.66	3 997.41	6 381.19
Crop yield (kg/ha)				
Mean		3 390.90	2 244.85	3 635.97
SD*		843.13	798.46	1 108.26
Water productivity (kg/m^3)[a/]		0.90	0.56	0.57

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

* SD = standard deviation.

B. MODEL ESTIMATION AND VALIDATION

The econometric model involves multi-crop producers of irrigated agriculture in Radwania and Rabea. Producers in both countries are multi-crop farmers who choose among several crops commonly grown as part of a multi-crop system in each province. Information from sample farms indicates that Radwanian producers are multi-crop growers of wheat, barley and cotton, while farmers in Rabea are multi-crop growers of wheat, sugar beet, potatoes and tomatoes. All data are collected from farm surveys conducted in both countries during the summer of 1999, and cover information on crop production, input use, output and input price variables and water management practices for the 1997/1998 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 (unit/kg), amount of total water available to the farm (m^3), farmer experience in irrigation (year), water price (unit/ha/year) and prices of variable inputs, such as fertilizers (unit/kg). The set of qualitative variables includes dummy variables on water location to the farm, soil type, soil salinity, soil depth, crop irrigation technology water application and water management practices.

The multi-crop production system applies an econometric issue, in that equations might be connected not because they interact, but because their error terms are contemporaneousely related. For example, a shock affecting demand for water in the production of one crop may spill over and affect water demand for other crops. In this case, estimating these equations as a set using a seemingly unrelated regression estimation (SURE) procedure, should improve efficiency (Kennedy, 1985). Other studies applied a limited-dependent variable model to obtain unbiased estimates for multi-crop systems (Moore et al., 1994a and 1994b). The multi-crop system for on-farm water allocation allows a contemporaneous correlation between the error terms across equations. This implies that the error terms in equation (9) is correlated with the error terms in equation (10), and thus the variance-covariance matrix of the system's error term will not be

diagonal. Estimating these error correlations and the diagonal elements, by using the residuals from each equation estimated separately by the means of ordinary least squares procedure (OLS), should allow for efficient estimates of the parameters. This can be done by estimating the multi-crop system using the SURE procedure. The gain in efficiency provided by the SURE estimator over OLS increases directly with the correlation between disturbances from the different equations and decreases as the correlation between the different sets of explanatory variables increases. The SURE estimator reduces to OLS if either the correlations are all zero or the explanatory variables are identical in all equations (Johnston, 1984). For this study, the SURE procedure is not expected to provide more efficient estimates compared to the OLS procedure. This is because the explanatory variables are identical in all equations and the correlation between equation disturbances is very small. Under these circumstances, the result will be estimates with greater standard errors than those of the OLS coefficients. Even if the true correlation between disturbances of different equations is zero, the sample OLS residuals may give non-negligible co-variances, and one might mistakenly compute SURE estimates. But as the correlations increase, the efficiency of the SURE over the OLS estimates increases substantially.

C. EMPIRICAL RESULTS

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 model are estimated. Using these on-farm 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. Application of the three measures of prediction accuracy is used to judge the performance of alternative models and thus provides 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 detailed presentation of the calculated measures are shown in appendix A, tables A1-A3, and a summarized calculation is presented in table 5.

Four sets of forecasts are made, including one in-sample prediction and three out-of-sample predictions. 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, which are applied to the 20 per cent subset to make out-of-sample predictions and to apply the prediction performance measures. This producer is repeated three times (Moore et al., 1994a and 1994b). Applying the three measures to each of the four predictions generates twelve cases for evaluating the alternative models for each crop and provides evidence on model choice. This process of comparison among alternative models is repeated for each crop. With the in-sample prediction, the fixed allocatable input model out-performs the two alternative models (the variable and the saticficing) according to each of the three measures in the case of both wheat and cotton. For barley, the fixed allocatable input model outperforms the other two models according to RMSE and MAPE, while the variable input model is superior based on the MAE measure.

TABLE 2. ESTIMATES OF ON-FARM WATER USE IN RADWANIA:
FIXED ALLOCATABLE INPUT MODEL

Independent variables	Wheat	Barley	Cotton
Intercept	5 886.03*	3 366.39	-9 854.55*
	(1.62)	(1.17)	(-2.04)
Wheat area (ha)	-179.29*	-73.41	239.95**
	(-2.05)	(-1.07)	(2.07)
Cotton area (ha)	110.90	1 119.67	-377.75**
	(1.12)	(1.39)	(-2.61)
Barley area (ha)	110.90*	-46.37	-66.139
	(1.12)	(-0.59)	(-0.502)

TABLE 2 (*continued*)

Independent variables	Wheat	Barley	Cotton
Wheat price (SL/kg)	197.70*	21.36	-215.66
	(1.82)	(0.25)	(-1.50)
Cotton price (SL/kg)	-101.58**	-19.71	124.38**
	(-3.42)	(-0.84)	(3.15)
Barley price (SL/kg)	194.62*	486.19**	-714.26**
	(2.11)	(6.73)	(-5.87)
Total water (m^3)	0.203**	0.031*	0.772**
	(8.46)	(1.63)	(24.29)
Experience in irrigation (years)	-44.02*	-15.41	55.01*
	(-1.79)	(-0.795)	(1.69)
Water location (0,1)[a/]	-528.04	192.51	290.25
	(-0.301)	(0.139)	(0.125)
Soil type (0,1)[b/]	670.29	-175.24	-476.09
	(0.941)	(-0.312)	(-0.504)
Soil salinity (0,1)[c/]	-2 965.49	-3 866.45*	7 027.64*
	(-1.004)	(-1.66)	(1.79)
Soil depth (0,1)[d/]	-728.74	-43.48	900.39
	(1.36)	(-0.103)	(1.27)
Crop irrigation technology (0,1)[e/]	-2 259.02**		
	(-2.75)		
Diesel price (SL/liter)	-16.64	79.185	-29.30
	(-0.126)	(0.76)	(0.167)
Water application (0,1)[f/]	80.36	167.90	-190.16
	(0.094)	(0.25)	(-0.168)
Water management (0,1)[g/]	127.72	739.91	-1 001.63
	(0.102)	(0.75)	(-0.601)
Price of urea (SL/kg)	192.37	-3.744	-261.18
	(1.14)	(-0.029)	(-1.20)
Price of phosphate (SL/kg)	-366.44**	15.35	436.91*
	(-2.12)	(0.114)	(1.94)
R^{-2}	0.65	0.53	0.93
R^2	0.75	0.63	0.95
D - W Statistics	1.62	1.61	1.29
F - Statistic	9.05**	5.81**	61.34**

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

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

SL denotes Syrian liras.

a/ Dummy variable for water location refers to the location of the farm to water source, taking the value of 1 for tail location and zero otherwise.

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

e/ Dummy variable for supplemental irrigation technology, taking a value of 1 for sprinkler and drip irrigation technology and zero otherwise.

f/ Dummy variable of water application according to calendar schedule, taking a value of 1 if water application is according to calendar schedule and zero otherwise.

g/ Dummy variable for water management, taking a value of 1 if farmers rely on advanced management practices and zero otherwise.

TABLE 3. ESTIMATES OF ON-FARM WATER USE IN RADWANIA: VARIABLE INPUT MODEL

Independent variables	Wheat	Barley	Cotton
Intercept	2 760.45 (0.483)	2 508.75 (1.24)	-8 238.88 (-0.612)
Wheat area (ha)	15.44 (0.28)		
Cotton area (ha)			-269.77 (-1.46)
Barley area (ha)		-39.11 (-0.52)	
Wheat price (SL/kg)	243.35 (1.38)		
Cotton price (SL/kg)			499.39** (4.35)
Barley price (SL/kg)		524.46* (7.78)	
Total water (m^3)			
Experience in irrigation (years)	-77.03* (-1.99)		-136.95 (-1.34)
Water location (0,1)[a/]	-1 240.95 (-0.43)	-43.82 (-0.03)	-2 958.90 (-0.40)
Soil type (0,1)[b/]	1 805.81* (1.98)	-244.78 (-0.47)	-3 101.59 (-1.29)
Soil salinity (0,1)[c/]	-474.23 (-0.11)	-2 724.84 (-1.60)	4 221.10 (0.40)
Soil depth (0,1)[d/]	-1 055.15 (-1.29)	-262.84 (-0.67)	-187.81 (-0.08)
Crop irrigation technology (0,1)[e/]	-2 043.95 (-1.53)		
Diesel price (SL/liter)	251.39 (1.19)	66.85 (0.69)	1 008.98* (1.79)
Water application (0,1)[f/]	707.93 (0.53)	286.47 (0.46)	-77.79 (-0.02)
Water management (0,1)[g/]	613.31 (0.30)	642.82 (0.66)	-452.05 (-0.08)
Water price (SL/ha/year)	0.035 (0.69)	-0.039* (-1.64)	0.102 (0.77)
Price of urea (SL/kg)	-192.48 (-0.73)	-44.25 (-0.35)	-1 674.43* (-2.43)
Price of phosphate (SL/kg)	54.11 (0.196)	48.02 (0.37)	1 979.61** (2.76)
R^{-2}	0.07	0.53	0.25
R^2	0.23	0.60	0.37
D - W Statistics	1.71	1.52	1.82
F - Statistic	1.40	8.28**	2.76*

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

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

SL denotes Syrian liras.

a/ Dummy variable for water location refers to the location of the farm to water source, taking the value of 1 for tail location and zero otherwise.

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

e/ Dummy variable for supplemental irrigation technology, taking a value of 1 for sprinkler and drip irrigation technology and zero otherwise.

f/ Dummy variable of water application according to calendar schedule, taking a value of 1 if water application is according to calendar schedule, and zero otherwise.

g/ Dummy variable for water management, taking a value of 1 if farmers rely on advanced management practices and zero otherwise.

TABLE 4. ESTIMATES OF ON-FARM WATER USE IN RADWANIA: SATISFICING MODEL

Independent variables	Wheat	Barley	Cotton
Intercept	10 278.3*	10 823.8**	10 496.6
	(2.03)	(4.83)	(0.718)
Wheat area (ha)	11.103		
	(0.214)		
Cotton area (ha)			-80.80
			(-0.41)
Barley area (ha)		102.52	
		(1.34)	
Experience in irrigation (years)	-53.44	0.258	-111.23
	(-1.45)	(0.013)	(-0.945)
Water location (0,1)[a/]	-2 636.33	294.05	-6 153.65
	(-1.08)	(0.230)	(-0.79)
Soil type (0,1)[b/]	276.96	-1 405.29*	-3 082.32
	(0.239)	(-2.12)	(-0.835)
Soil salinity (0,1)[c/]	980.48	-355.14	4 318.04
	(0.231)	(-0.192)	(0.361)
Soil depth (0,1)[d/]	-434.89	616.57	-83.24
	(-0.557)	(1.49)	(-0.033)
Amount of rainfall (mm)	-21.35*	-33.61**	-14.76
	(-2.11)	(-6.26)	(-0.46)
Water application (0,1)[f/]	602.35*	160.10	7 091.37*
	(0.47)	(0.247)	(1.78)
Water management (0,1)[g/]	931.32	1 679.98*	-2.50
	(0.47)	(1.63)	(-0.004)
R^{-2}	0.10	0.44	-0.04
R^2	0.20	0.50	0.08
D - W Statistics	1.64	1.69	1.97
F - Statistic	1.93	7.79**	0.66

Note: Numbers in parentheses 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 water location refers to the location of the farm to water source, taking the value of 1 for tail location and zero otherwise.

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

e/ Dummy variable for supplemental irrigation technology, taking a value of 1 for sprinkler and drip irrigation technology and zero otherwise.

f/ Dummy variable of water application according to calendar schedule, taking a value of 1 if water application is according to calendar schedule, and zero otherwise.

g/ Dummy variable for water management, taking a value of 1 if farmers rely on advanced management practices and zero otherwise.

Results with the out-of-sample predictions demonstrate a similar pattern of performance. For both wheat and cotton, the fixed allocatable input model dominates the two alternative models according to the three measures of prediction performance. The numerical values of MAE, RMSE, and MAPE of the fixed allocatable input model are considerably lower than those of the variable input model and saticficing model for both wheat and cotton. For barley, the variable input model outperforms the other two alternative models, according to MAE, RMSE and MAPE. Accordingly, results obtained from the application of the prediction accuracy measures support the conclusion that the fixed allocatable input model represents a better model for explaining short-run water allocation for both wheat and cotton in multi-crop systems than the variable input model or the saticficing model. For barley, however, the results of out-of-sample predictions provide evidence to support the choice of the variable input model to explain on-farm water use for this crop, whereas in-sample predictions favour the selection of the fixed allocatable input model. Estimated models can provide additional information on the model selection process for each crop. A close look at the estimated models presented in tables 2-4 supports the choice of the fixed allocatable input model. A key factor is the multi-crop jointness evident in the crop acreage variables, as shown in the estimates of the fixed allocatable input model (table 2). For each of the wheat and cotton equations, water use depends strongly on own- and cross-acreages. The relative performance of the water constraint variable (represented by the variable of total water available to the farm) provides additional support to the choice of fixed allocatable input model. The water constraint variable is positive and highly significant, especially in wheat and cotton equations of the fixed allocatable input model. This result suggests that producers perceive irrigation water as a fixed input in the short run. In contrast, water price is not negative for wheat and corn equations. It is only negative, but not significantly so, for the barley equation under the estimation of both fixed allocatable input model and variable input model. This implies that after planting crops, producers do not respond to water price in subsequent short-run decisions. In this regard, Moore, Gollehon and Carey (1994a and 1994b) argue that in terms of the effect of water price on multi-crop profits, this result indicates that the major impact originates through crop choice, irrigation technology, and land allocation decisions. Once crop land is allocated, the level of water price appears not to have a major quantitative impact on profit; otherwise, water price would be a significant determinant of short-run water use. This conclusion is further supported by the fact that water prices in the study area are fixed and determined by official agricultural authorities, and thus have no major influence on the amount of water allocated to each crop. A fixed allocatable input model may explain producer decisions on short-run water use better than the variable input model (Moore et al., 1994a and 1994b). This model offers a more complex model of multi-crop decisions than the behavioural model. In the fixed allocatable input model, producers operate with a short-run constraint on farm-level water use because of the fixed amount of surface water available to the farm (according to the rationing system of water allocation among farms). Meanwhile, groundwater is subject to fixed pumping capacity in the short-run. This constraint of fixed water invokes a competition among crops for water.

As a result, it can be concluded that the fixed allocatable input model is a better model to study on-farm water use in a multi-crop system. As the fixed allocatable input model performs best in explaining short-run water use, it needs additional description. The estimates of table 2 reveal the following points:

(a) The values of the adjusted coefficient of determination (R^{-2}) indicate that the model performs well in explaining crop-level water use in the multi-crop system for a cross-sectional data. The estimated R^{-2} is 0.93 for cotton, 0.65 for wheat and 0.53 for barley. Even the lowest value of 0.53 for barley indicates relatively good performance for a crop which is mainly dependent on rainfall. Only a small portion of the sample farms (27 producers) supplement irrigation water for barley during spring. The estimated water demand equations for wheat, barley and cotton are significant at the 1 per cent level of significance according to F test.

(b) Output prices appear to be a strong determinant for short-run decisions on water allocation among competing crops. Own-price variables for wheat, barley and cotton are positive and significant in explaining water use. An increase in wheat price (in Syrian liras) by 1 SL/kg, holding other variables constant, will increase water use for wheat by 197.7 m^3. Similarly, a 1 SL/kg increase in cotton price will increase water demand for cotton by 1,240.4 m^3. Cross-price variables reflect inter-crop interdependence, namely, a change in the price of one crop induces water reallocation among other crops, given that water is a fixed allocatable input. An increase in cotton price by 1 SL/kg will reduce the amount of water allocated to wheat by 101.6

m^3, whereas a 1 SL/kg increase in wheat price will induce a 215.7 m^3 reduction in water use for cotton. The performance of the cross-price variables demonstrates the competition among wheat, barley and cotton in a multi-crop system for a fixed quantity of water.

(c) Estimates on the water constraint variable (total water) indicates the allocation among crops of a marginal increase in farm-level water availability for producers growing competing crops. The individual estimated coefficients of the water constraint suggest that a 1 m^3 increase in water available to the farm will be used for cotton first (0.77 m^3), for wheat second (0.20 m^3) and for barley in a negligible amount (0.03 m^3). These figures indicate that an increase in water availability is allocated most heavily to crops with relatively high water requirements, like cotton, rather than to crops with relatively low water requirements, such as wheat and barley. In fact, barley is considered as a residual crop in terms of on-farm water use, and thus only a minimal amount of marginal increment in water will be allocated to this crop.

TABLE 5. PERFORMANCE OF ESTIMATED MODELS IN PREDICTING ON-FARM WATER-USE IN RADWANIA

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 predictions			
Fixed allocatable input model	1 260.87 b/	1191.06 b/	0.391 b/
Variable input model	2 163.83	2053.04	0.750
Saticficing model	2 076.23	2096.21	0.708
Out-of-sample predictions a/			
Fixed allocatable input model	1 672.28 b/	772.03 b/	0.628 b/
Variable input model	3 159.22	1263.30	1.106
Saticficing model	2 434.98	1077.85	0.899
Barley			
In-sample predictions			
Fixed allocatable input model	958.80	947.17 b/	0.811 b/
Variable input model	924.85 b/	990.27	0.894
Satisficing model	1 045.76	1103.64	0.811 b/
Out-of-sample predictions			
Fixed allocatable input model	1 479.95	641.64	0.813
Variable input model	1 241.45 b/	587.64 b/	0.746 b/
Satisficing model	1 306.21	624.52	0.911
Cotton			
In-sample predictions			
Fixed allocatable input model	1 823.76 b/	1 593.94 b/	0.168 b/
Variable input model	6 007.06	5 522.27	0.485
Saticficing model	7 577.48	6 687.58	0.768
Out-of-sample predictions			
Fixed allocatable input model	2 641.95 b/	1 090.40 b/	0.262 b/
Variable input model	9 052.96	3 865.78	1.156
Saticficing model	7 469.60	3 780.25	0.851

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. This procedure is repeated three times. The calculated measures of prediction accuracy are then averaged for the three draws and presented in this table.

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

D. WATER-USE EFFICIENCY

For the purpose of this study, 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 level for wheat, barley and cotton are the average yield levels of the sample farms as reported in table 6. To obtain the required amount of water to produce these average yield levels, the estimated crop equations with the fixed allocatable input 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 6 and compared with the actual amount of water used. It is clear that WUE is 0.61 in wheat production, indicating that actual water use exceeds water requirement by about 39 per cent. The WUE in barley production is 0.45, suggesting that barley producers over-irrigate their crop by about 55 per cent compared to the required amount of water. Cotton producers, on the other hand, exceed water requirement by 24 per cent. The WUE of cotton, at 0.76, is relatively high, given that cotton is a very water-demanding crop and its growing season expands for about nine months. Either above-average yields or a very efficient use of irrigation can explain these estimates of relatively high ratios of WUE for cotton in the study area.

TABLE 6. ACTUAL AND REQUIRED AMOUNTS OF WATER USE BY CROP IN RADWANIA

Crop	Irrigated area (ha)	Av. yield (ton/ha)	Actual water used* (m^3)	Required water (m^3)	WUE[a/]
Wheat	5.21	3.391	7 677.49	4 720.59	0.61
Barley	3.27	2.245	6 614.75	2 971.54	0.45
Cotton	4.35	3.636	18 229.43	13 836.81	0.76

* This figure also includes rainfall water quality estimated at 2,844.4 m^3.

Farmers over-irrigate wheat, barley and cotton crops because of their perceptions of water requirements and their expectations of rainfall and market conditions. More cases of over-irrigation occur in barley production, suggesting that recommendations for supplemental irrigation of barley could benefit some farmers. The low ratio of water-use efficiency in wheat and barley production suggests that a wide technology gap exists between the recommended supplemental irrigation practices for wheat and barley and the actual water application in the study area. This result has important policy implications, since the Syrian agricultural plan assigns quotas of land to be planted with wheat, which accounts for 35 per cent of total irrigated land in the sample farms. Therefore, improved water-use efficiency for wheat can contribute to the overall water-use for the agricultural sector. In this study, the overall (combined) water-use efficiency for wheat, barley and cotton is 0.621.

V. CASE STUDY TWO: RABEA

A. CHARACTERISTICS OF SAMPLE FARMS

In the Rabea area of Iraq, the sample farms comprise 100 producers located in a moderate rainfall zone (350-450 mm). The producer experience in irrigation ranges from 1 to 20 years, with an average of 11 years. Surface water is the main source of irrigation for all farmers in the survey. Meanwhile, sprinkler irrigation is the predominant supplemental irrigation technology for winter crops (wheat, sugar beet and potatoes), whereas flood irrigation is used for summer crops (tomatoes). The soil type is predominantly medium to heavy. Most farms (87 per cent) are of deep soil, and the remaining 13 per cent are of medium and shallow soils. Meanwhile, 68 per cent of the farmers reported that soil salinity is low.

The current cropping pattern is mainly determined by market conditions and agricultural policies. The amount of water available to the farms is limited, as indicated by 69 per cent of the farmers. Only 31 per cent of them reported that the amount of water is not limited. Location of water source to the farm is of main concern to the sample farms, since only 27 per cent are of head location, while 73 per cent are of medium or tail locations. This is an important factor, since surface water is the main source for irrigation.

Rented and sharecropped land are the predominant types of land tenure, as reported by 76 per cent of the farms. The rest of the sample (24 per cent), are of privately-owned land tenure.

Other characteristics of the sample farms are presented in table 7. Among the 100 samples, 47 farmers irrigate wheat, 45 irrigate potatoes, 22 irrigate sugar beet and 71 irrigate tomatoes. While wheat is supplementarily irrigated, the other crops are subject to full irrigation. No other irrigated crops are produced in the study area. Therefore, the rest of the analysis will concentrate on wheat, potatoes, sugar beet and tomatoes. The total farm size averages 37.02 ha, while the average irrigated area is 25.35 ha for wheat, 8.92 ha for potatoes, 3.48 ha for sugar beet and 4.83 ha for tomatoes. Among winter crops, wheat accounts for 68 per cent of total irrigated land while 32 per cent is allocated for potatoes and sugar beet.

Water available to the entire farm for winter cropping is 448,005.45 m^3 as an average for the sample farms. The water application by crop is 5,423.83 m^3 for wheat, 75,215.56 m^3 for potatoes and 4,028.64 m^3 for sugar beet (as indicated in table 7). For summer cropping, water available to the whole farm is 210,969.84 m^3 as an average for the sample farms, of which 70,762.69 m^3 is used for tomatoes. Annual rainfall for the study area during the 1997/1998 season was 292.78 mm, with a standard deviation of 89 mm. Crop yield was 2.184 ton/ha for wheat, 16.311 ton/ha for potatoes, 14.091 ton/ha for sugar beet and 12.761 ton/ha for tomatoes. Water productivity, defined in technical terms as kg of output per m^3 of water, is the highest for potatoes (1.44 kg/m^3), followed by sugar beet (0.97 kg/m^3), tomatoes (0.73 kg/m^3) and finally wheat (0.70 kg/m^3). Therefore, water yields more output in potato production, compared to wheat, sugar beet and tomatoes. Each additional m^3 of water gives 1.44 kg of potato tubers, whereas the output of other crops is much lower for each additional unit of water.

TABLE 7. DESCRIPTIVE STATISTICS FOR SAMPLE FARMS IN RABEA

		Crop			
Item	Total farm	Wheat	Potatoes	Sugar beet	Tomatoes
Number of farms	100	47	45	22	71
Area (ha)					
Mean	37.02	25.35	8.92	3.48	4.83
SD	74.19	43.83	11.44	5.25	6.52
Water applied (m^3)					
Mean	448 005.45	5 423.83	75 215.56	40 288.64	70 762.69
SD	318 506.39	8 228.16	93 095.74	48 652.66	88 200.52
Water application rate (m^3/ha)	12 101.71	213.96	8 432.24	11 577.20	14 650.66

TABLE 7 (*continued*)

Item	Total farm	Crop			
		Wheat	Potatoes	Sugar beet	Tomatoes
Rainfall (mm)					
Mean	292.78				
SD	88.96				
Total water used (irrigation + rainfall)	15 029.51	3 141.76	11 360.04	14 505	17 578.46
Crop yield (kg/ha)					
Mean		2 184.04	16 311.11	14 090.91	12 760.56
SD		772.57	5 704.15	8 058.77	6 931.22
Water productivity[a/] (kg output/m^3 water)		0.7	1.44	0.97	0.73

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

Comparing the WUE of wheat under rainfed and supplemental irrigation provides important findings. Among the 100 sample farms, 53 farmers grow wheat under rainfed conditions and 47 use supplemental irrigation. The average grain yield is 2.36 ton/ha for supplementally irrigated wheat and 1.36 ton/ha for rainfed wheat. As a result, supplemental irrigation increases wheat grain yield by 62 per cent under the same soil and environmental conditions, improving water-productivity substantially. The water productivity is 0.6 kg/m^3 for rainfed wheat and increases to 0.70 kg/m^3 under supplemental irrigation, taking into consideration the amount of rainfall. The other important advantage of using water to supplement rainfall in wheat production is yield stabilization. Using CV as a crude measure for yield stabilization, it is found that the CV for rainfed wheat yield is 71 per cent, whereas the supplemental irrigation reduces it to 35 per cent. This is a very important result for producers adverse to risk, since supplemental irrigation increases yield stability, and thus reduces risk associated with rainfed farming. This result compares favorably with other findings in the region. Average water-productivity of rain in producing wheat in the dry areas of West Asia and North Africa is about 0.35 kg grain/m^3, although with good management and favourable rainfall, this can be increased to 1 kg grain/m^3. However, water used in supplemental irrigation can be much more efficient.

B. EMPIRICAL RESULTS

Following methodology development for on-farm water use, the three specified models of fixed allocatable input model, variable input model and satisficing model are estimated using on-farm data of 100 producers. The estimated models are presented in tables 8 to 10. 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. Application of the three measures of prediction accuracy is used to judge the performance of alternative models, and thus provides 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 detailed presentation of the calculated measures are shown in appendix B, tables B1-B4, while summarized calculations are presented in table 11.

Four sets of forecasts are made, including one in-sample prediction and three out-of-sample predictions. 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. This procedure is repeated three times (Moore et al., 1994a and 1994b). Applying the three measures to each of the four predictions generates twelve cases for evaluating the alternative models for each crop and provides evidence on model choice. This process of comparison among alternative models is repeated for each crop. With the in-sample prediction, the variable input model outperforms the other two models for wheat, potatoes and sugar beet according to the MAE. The satisficing model performs the best for in-sample predictions of

tomatoes, according to the same accuracy measure. Meanwhile, the RMSE indicates that the fixed allocatable input model outperforms the other two models for the in-sample predictions of the four crops. However, according to the MAPE, the satisficing model gives the best in-sample prediction for the four crops.

TABLE 8. ESTIMATES OF ON-FARM WATER-USE IN RABEA: FIXED ALLOCATABLE, INPUT MODEL

Independent variables	Wheat	Potatoes	Sugar beet	Tomatoes
Intercept	-5 231.42**	-758.42	-1 155.23	46.81
	(-2.88)	(-0.18)	(-0.39)	(0.066)
Wheat area (ha)	14.17	20.41	4.88	-30.18
	(0.72)	(0.76)	(0.25)	(-0.605)
Potato area (ha)	-6.61	53.55*	-16.73	-18.04
	(-0.91)	(2.30)	(-1.38)	(-0.61)
Sugar beet area (ha)	-1.35	-39.31	354.37**	-186.88
	(-0.04)	(-0.48)	(5.45)	(-1.02)
Tomato area (ha)	9.87*	-8.54	-8.05	138.74**
	(1.56)	(-0.61)	(-0.77)	(5.13)
Wheat price (ID/kg)	-7.29	-17.81	-75.95*	47.25
	(-0.35)	(-0.39)	(-2.12)	(0.43)
Potato price (ID/kg)	330.99*	7 750.59**	845.92**	1 641.21*
	(2.01)	(20.56)	(3.13)	(2.47)
Sugar beet price (ID/kg)	-361.16	1 045.15	6 101.63**	4 709.68**
	(-0.98)	(1.29)	(9.57)	(3.05)
Tomato price (ID/kg)	-217.54	287.54	759.96*	8 197.68**
	(-1.13)	(0.67)	(2.43)	(3.05)
Water limitation (0,1)[a/]	141.94	-2 932.91	-2 023.13	-3 215.84
	(0.12)	(-1.14)	(-1.06)	(-0.67)
Total water (m^3)	0.011**	0.795	0.119	0.018*
	(6.05)	(0.19)	(0.40)	(2.09)
Crop irrigation technology (0,1)[b/]	-115.33	5 785.26	6 031.97*	
	(-0.048)	(1.31)	(1.79)	c
Wage rate (ID/hr)	1.96*	-10.82*	-2.14	0.497
	(2.14)	(-1.89)	(-0.67)	(0.11)
R^2	0.41	0.98	0.92	0.94
R^{-2}	0.33	0.98	0.91	0.93
D - W Statistics	2.08	2.12	2.07	1.65
F - Statistic	5.04**	332.28**	85.43**	122.35**

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

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

ID denotes Iraqi dinars.

a/ Dummy variable for water limitation, taking a value of 1 if the amount of water available to the farm is limited and a value of zero otherwise.

b/ Dummy variable for supplemental irrigation technology, taking a value of 1 for sprinkler and drip irrigation technology and a value of zero otherwise.

TABLE 9. ESTIMATES OF ON-FARM WATER-USE IN RABEA: VARIABLE INPUT MODEL

Independent variables	Wheat	Potatoes	Sugar beet	Tomatoes
Intercept	-267.80 (-0.15)	1 015.52 (0.44)	1 124.44 (0.637)	3 285.14 (0.551)
Wheat area (ha)	3.267 (0.315)			
Potato area (ha)		8 106.29** (52.98)		
Sugar beet area (ha)			8 662.93** (21.91)	
Tomato area (ha)				12 641.6** (26.48)
Wheat price (ID/kg)	11.20 (0.48)			
Potato price (ID/kg)		44.19* (2.02)		
Sugar beet price (ID/kg)			205.92** (5.22)	
Tomato price (ID/kg)				116.13** (3.75)
Water price (ID/ha/year)	0.043 (0.071)	0.013 (0.115)	0.039 (0.404)	0.033 (0.125)
Water limitation (0,1)[a/]	227.56 (0.173)	-1 605.45 (-0.647)	-1 976.17 (-0.958)	-4 429.18 (-0.758)
Crop irrigation technology (0,1)[b/]	124.39 (0.044)	5 559.09 (1.35)	4 088.71 (1.17)	-7 385.81 (-0.27)
Wage rate (ID/hr)	3.146** (3.02)	-11.55* (-2.14)	-3.68 (-1.05)	-10.64* (-2.09)
R^{-2}	0.06	0.98	0.89	0.89
R^2	0.11	0.98	0.90	0.90
D -W Statistics	1.85	2.11	2.18	1.94
F - Statistic	1.96	667.93**	135.31**	139.70**

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

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

ID denotes Iraqi dinars.

a/ Dummy variable for water limitation, taking a value of 1 if the amount of water available to the farm is limited and a value of zero otherwise.

b/ Dummy variable for supplemental irrigation technology, taking a value of 1 for sprinkler and drip irrigation technology and a value of zero otherwise.

TABLE 10. ESTIMATES OF ON-FARM WATER-USE IN RABEA: SATISFICING MODEL

Independent variables	Wheat	Potatoes	Sugar beet	Tomatoes
Intercept	899.85 (0.383)	-1 459.19 (-0.33)	5029.50 (1.23)	5 985.94 (0.564)
Wheat area (ha)	-5.99 (-0.54)			
Potato area (ha)		8 101.19** (56.68)		

TABLE 10 (*continued*)

Independent variables	Wheat	Potatoes	Sugar beet	Tomatoes
Sugar beet area (ha)			9 113.31**	
			(22.92)	
Tomato area (ha)				13 055.5**
				(26.23)
Water limitation (0,1)[a/]	-301.82	-881.32	-3 538.60*	-4 133.54
	(-0.22)	(-0.34)	(-1.51)	(-0.65)
Crop irrigation technology (0,1)[b/]	3 023.49*	2 994.90	4 190.55*	3 195.28
	(1.63)	(1.18)	(1.51)	(0.109)
Land Tenure (0,1)[c/]	99.77	-23.83	69.98	-967.60
	(0.24)	(-0.031)	(0.099)	(-0.518)
Rainfall (mm)	-5.264	6.825	-7.03	13.720
	(-0.68)	(0.52)	(-0.582)	(0.429)
Water location (0,1)[d/]	3 733.45*	-1 622.66	-687.02	-6 791.38
	(2.53)	(-0.596)	(-0.279)	(-1.02)
R^2	0.09	0.98	0.87	0.89
R^{-2}	0.03	0.97	0.86	0.88
D - W Statistics	2.02	2.09	2.30	1.78
F - Statistic	1.52	635.80**	100.68**	120.51**

Note: Numbers in parentheses 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 water limitation, taking a value of 1 if the amount of water available to the farm is limited and a value of zero otherwise.

b/ Dummy variable for supplemental irrigation technology, taking a value of 1 for sprinkler and drip irrigation technology and a value of zero otherwise.

c/ Dummy variable for the type of land tenure, taking a value of 1 for individually-owned land and zero otherwise.

d/ Dummy variable for water location refers to the location of the farm to water source, taking the value of 1 for tail location and zero otherwise.

For out-of-sample predictions, the results are mixed. The satisficing model performs the best for potatoes, sugar beet and tomatoes, according to the MAE. Similarly, this prediction model is the best for wheat, potatoes and tomatoes, based on the MAPE. The satisficing model also outperforms the other two models for sugar beet and tomatoes, according to the RMSE. However, the variable input model is the best for wheat according to the MAE and RMSE. This model is also the best for sugar beet, according to the MAPE (see table 11).

TABLE 11. PERFORMANCE OF ESTIMATED MODELS IN PREDICTING ON-FARM WATER-USE IN RABEA

	Prediction accuracy measures		
Type of prediction model of water use	Mean absolute error (MAE)	Root mean square error (RMSE)	Mean absolute percentage error (MAPE)
Wheat			
In-sample predictions			
Fixed allocatable input model	3 286.12	3 765.50[b/]	1.360
Variable input model	3 008.20[b/]	4 619.41	1.560
Satisficing model	3 126.98	4 679.47	1.165[b/]

TABLE 11 (*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)
Out-of-sample predictions[a/]			
Fixed allocatable input model	4 221.90	2 152.12	1.728
Variable input model	2 860.71[b/]	1 511.17[b/]	2.041
Satisficing model	3 365.61	1 579.51	1.329[b/]
Potatoes			
In-sample predictions			
Fixed allocatable input model	6 170.86	8 341.24[b/]	0.214[b/]
Variable input model	5 844.88[b/]	8 596.58	0.229
Satisficing model	5 939.38	8 806.14	0.214[b/]
Out-of-sample predictions			
Fixed allocatable input model	8 752.02	4 322.70[b/]	0.409
Variable input model	7 576.27	4 974.63	0.410
Satisficing model	7 189.70[b/]	4 730.12	0.366[b/]
Sugar beet			
In-sample predictions			
Fixed allocatable input model	4 703.02	6 158.02[b/]	0.346[b/]
Variable input model	3 910.26[b/]	7 058.68	0.362
Satisficing model	4 813.20	8 041.80	0.382
Out-of-sample predictions			
Fixed allocatable input model	6 128.90	3 998.68	0.681
Variable input model	5 716.14	6 092.71	0.558[b/]
Satisficing model	5 249.01[a/]	3 636.60[b/]	0.664
Tomatoes			
In-sample predictions			
Fixed allocatable input model	13 849.51	15 739.06[b/]	0.326
Variable input model	13 271.13	20 106.01	0.315
Satisficing model	12 638.69[b/]	21 477.86	0.245[b/]
Out-of-sample predictions			
Fixed allocatable input model	17 433.14	13 656.70	0.367
Variable input model	14 153.38	10 586.69	0.348
Satisficing model	12 581.47[b/]	9 837.75[b/]	0.281[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. This procedure is repeated three times. The calculated measures of prediction accuracy are then averaged for the three draws and are presented in this table.

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

The overall prediction performance of the estimated models can be judged on both in-sample and out-of-sample predictions. Based on the accuracy measures, the MAE favours both the variable input model and the satisficing model four times each. Meanwhile, the RMSE favours the fixed allocatble input model for five times, and the variable input model and satisficing model for one time each. The MAPE supports the choice of satisficing model for six times, and the other two models for one time each.

Regardless of the type of accuracy measures, the satisficing model is the best for 8 times for out-of-sample prediction, and 4 times for in-sample prediction. The variable input model is the best for 3 times, for each of the in-sample and out-of-sample- predictions, whereas the fixed allocatable input model is the best for 5 times for in-sample predictions and 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 statisficing model outperforms the other two for 12 times out of 24 cases. Meanwhile, both the fixed allocatable input model and the variable input model are the best for 6 times. Accordingly, the results obtained from the application of the prediction accuracy measures are inconclusive, although they are in favour of the satisficing model. 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 reveal the following points:

(a) Own-crop area and price appear to be the most important two variables in explaining the farmers' water-use decision in irrigating potatoes, sugar beet and tomatoes. The estimated coefficients of these two variables are positive and highly significant in each water-use equation of the three crops. This is the case for the estimates of both the fixed allocatable input model and the variable input model. With the fixed allocatable input model, total water available is the most important factor, explaining the water use for wheat. The irrigated crop area is also positive, but not significant in the water demand equation for wheat. Total water available to the farm is also a key variable in the water-use equation for tomatoes, with the fixed allocatable input model. Cross-acreage variables in the fixed allocatable input models do not fully support the multi-crop jointness in the study area. This can be attributed to the fact that wheat is mainly considered as a rainfed crop; only a residual amount of water supplemented the rainfall by only 47 per cent of the farmers. For the two other crops, potatoes and sugar beet, water is available in sufficient amounts and is not a limiting factor in their production. For tomatoes, as a summer crop, the amount of water available to the farm is less than that available during winter, but there are no competing crops for tomatoes.

(b) The water constraint variable is positive in the water-use equations of the four crops, but it is significant in the wheat and tomato equations. This result suggests that producers 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 four crops with the variable input model. This implies that after planting crops, producers do not respond to water price in subsequent short-run decisions. Furthermore, water prices in the study area are highly subsidized and farmers are normally charged minimal prices. As a result, water price does not have a major quantitative impact on water allocation. Land allocation, crop choice, irrigation technology and output prices are the main determinants of multi-crop water use decisions.

(c) The values of the adjusted coefficient of determination (R^{-2}) indicate that the three models perform well in explaining crop-level water use for potatoes, sugar beet and tomatoes. The estimated R^{-2} exceeds 0.90, supporting the high explanatory power of the three models. For wheat, only the fixed allocatable input model gives an acceptable explanation for water use. Even the low value of 0.33 for wheat indicates a relatively fair performance for a crop which is mainly dependent on rainfall and to which only a residual amount of supplemental irrigation is allocated. All estimated water-use equations for potatoes, sugar beet and tomatoes are significant at the 1 per cent level, according to the F-test. For wheat, however, only the water-use equation of the fixed allocatable input model is significant.

(d) Estimated coefficients of total water available to the farm 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 for potatoes in the first place (0.79 m^3), for sugar beet in the second place (0.12 m^3), and for wheat and tomatoes in the third place with minimal amounts of 0.011 m^3 and 0.018 m^3 respectively. This is consistent with the fact that potatoes actually use more water than other winter crops (wheat and sugar beet).

C. WATER-USE EFFICIENCY

The target production levels of wheat, potatoes, sugar beet and tomatoes are the average yield levels of the sample farms as reported in table 12. To obtain the required amount of water to produce these average yield levels, the estimated crop water-use equations with the three models 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 12 and compared with the actual amount of water used. Both the variable input model and the satisficing model under-estimate the amounts of water required for the four crops, compared to the estimates of the fixed allocatable input model. On-farm WUE is the highest for tomatoes (0.68), indicating that actual water use exceeds water requirements by about 32 per cent. The lowest WUE of 0.32 for sugar beet suggests that producers over-

irrigate this crop considerably. Sugar beet producers exceed water requirements of the crop by 68 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 can explain these low-ratio estimates of on-farm water-use efficiency for sugar beet.

Farmers in the study area over-irrigate wheat and potatoes by 63 per cent and 55 per cent respectively, compared to the required amount of water to produce the achieved yield levels. These estimates indicate that WUE for wheat is 0.37. For potatoes, the WUE is 0.45. These figures suggest that a big technology gap exists between the required irrigation practices for wheat and potatoes and the actual water application in the study area. This result has important policy implications, since most of the land is allocated for wheat and potato production, and because potatoes consume a large amount of water. Therefore, improved WUE for wheat and potatoes can contribute to the overall WUE in the study area. In this study, the overall WUE for wheat, potatoes, sugar beet and tomatoes is 0.40, suggesting a high potential for water savings once WUE is improved.

TABLE 12. ACTUAL AND REQUIRED AMOUNT OF WATER-USE BY CROP IN RABEA

Item	Wheat	Potatoes	Sugar beet	Tomatoes
Irrigated area (ha)	25.35	8.92	3.48	4.83
Yield (ton/ha)	2.184	16.311	14.091	12.761
Actual water used (m^3)	8 351.63	78 143.36	43 216.44	73 697.69
Required water level (m^3)				
Fixed allocatable input model	3 058.72	37 068.71	13 707.10	50 290.87
Variable input model	2 732.48	33 886.70	8 863.92	50 272.13
Satisficing model	2 550.41	33 887.52	8 863.54	50 274.24
WUE[a/]				
Fixed allocatable input model	0.37	0.47	0.32	0.68
Variable input model	0.33	0.43	0.21	0.68
Satisficing model	0.31	0.43	0.21	0.68
Average	0.34	0.45	0.32[b/]	0.68

* This figure also includes rainfall water quantity estimated at 2,927.8m^3.

a/ On-farm WUE is defined as the ratio of the required amount of water to the actual amount of water used (water applied + rainfall).

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ANNEXES

Appendix A

TABLE II. PERFORMANCE OF ESTIMATED MODELS IN PREDICTING ON-FARM WATER-USE FOR WHEAT IN RADWANIA

Type of prediction model of water use	Prediction accuracy measures		
	Mean absolute error (MAE)	Root mean square error (RMSE)	Mean absolute percentage error (MAPE)
In-sample predictions			
Fixed allocatable input model	1 260.87[b/]	1 191.06[b/]	0.391[b/]
Variable input model	2 163.83	2 053.04	0.750
Satisficing model	2 076.23	2 096.21	0.708
Out-of-sample predictions[a/]			
Draw 1			
Fixed allocatable input model	1 439.75[b/]	597.62[b/]	0.445[b/]
Variable input model	3 474.19	1 326.25	1.35
Satisficing model	2 889.60	1 126.38	1.14
Draw 2			
Fixed allocatable input model	1 290.45[b/]	826.74	0.911[b/]
Variable input model	2 755.26	979.43	1.34
Satisficing model	1 708.07	718.95[b/]	0.996
Draw 3			
Fixed allocatable input model	2 286.65[b/]	891.74[b/]	0.528[b/]
Variable input model	3 248.21	1 484.21	0.628
Satisficing model	2 707.28	1 388.21	0.563

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 parameter estimates are applied to the 20 per cent subset to make out-of-sample predictions and to apply the prediction accuracy measures. This procedure is repeated three times.

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

TABLE I2. PERFORMANCE OF ESTIMATED MODELS IN PREDICTING ON-FARM WATER-USE FOR BARLEY IN RADWANIA

Type of prediction model of water use	Prediction accuracy measures: Mean absolute error (MAE)	Root mean square error (RMSE)	Mean absolute percentage error (MAPE)
In-sample predictions			
Fixed allocatable input model	958.80	947.17[b/]	0.811[b/]
Variable input model	924.85[b/]	990.27	0.894
Satisficing model	1 045.76	1 103.64	0.811[b/]
Out-of-sample predictions[a/]			
Draw 1			
Fixed allocatable input model	1 596.51	645.62	0.623[b/]
Variable input model	1 334.71[b/]	572.54[b/]	0.755
Satisficing model	1 511.67	666.80	0.735
Draw 2			
Fixed allocatable input model	1 486.32	727.48	1.35
Variable input model	1 217.48	676.27	0.986[b/]
Satisficing model	1 004.85[b/]	544.96[b/]	1.343
Draw 3			
Fixed allocatable input model	1 357.03	551.81	0.467[b/]
Variable input model	1 172.16[b/]	514.12[b/]	0.498
Satisficing model	1 402.11	661.79	0.656

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 parameter estimates are applied to the 20 per cent subset to make out-of-sample predictions and to apply the prediction accuracy measures. This procedure is repeated three times.

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

TABLE 13. PERFORMANCE OF ESTIMATED MODELS IN PREDICTING ON-FARM WATER-USE FOR COTTON IN RADWANIA

Type of prediction model of water use	Prediction accuracy measures: Mean absolute error (MAE)	Root mean square error (RMSE)	Mean absolute percentage error (MAPE)
In-sample predictions			
Fixed allocatable input model	1 823.76[b/]	1 593.94[b/]	0.168[b/]
Variable input model	6 007.06	5 522.27	0.485
Satisficing model	7 577.48	6 687.58	0.768
Out-of-sample predictions[a/]			
Draw 1			
Fixed allocatable input model	2 226.32[b/]	1 094.72[b/]	0.317[b/]
Variable input model	1 141.76	4 915.73	2.17
Satisficing model	4 109.36	3 803.65	1.369
Draw 2			
Fixed allocatable input model	2 768.94[b/]	1 132.24[b/]	0.307[b/]
Variable input model	8 466.52	3 139.06	0.959
Satisficing model	8 974.31	3 539.62	0.799
Draw 3			
Fixed allocatable input model	2 930.58[b/]	1 044.24[b/]	0.162[b/]
Variable input model	7 550.59	3 542.56	0.338
Satisficing model	9 325.12	3 997.47	0.385

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 parameter estimates are applied to the 20 per cent subset to make out-of-sample predictions and to apply the prediction accuracy measures. This procedure is repeated three times.

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

Annex II

TABLE II1. PERFORMANCE OF ESTIMATED MODELS IN PREDICTING ON-FARM WATER-USE FOR WHEAT IN RABEA

Type of prediction model of water use	Prediction accuracy measures		
	Mean absolute error (MAE)	Root mean square error (RMSE)	Mean absolute percentage error (MAPE)
In-sample predictions			
Fixed allocatable input model	3 286.12	3 765.50[b]	1.360
Variable input model	3 008.20[b]	4 619.41	1.560
Satisficing model	3 126.98	4 679.47	1.165[b]
Out-of-sample predictions[a]			
Draw 1			
Fixed allocatable input model	4 213.82	2 036.98[b]	1.043
Variable input model	3 861.52[b]	2 243.51	0.770
Satisficing model	4 080.42	2 182.79	0.721[b]
Draw 2			
Fixed allocatable input model	3 904.71	1 642.28	1.722
Variable input model	2 176.64[b]	1 004.09[b]	1.362[b]
Satisficing model	3 082.09	1 291.74	1.826
Draw 3			
Fixed allocatable input model	4 547.19	2 777.10	2.419
Variable input model	2 543.98[b]	1 285.90	3.990
Satisficing model	2 934.31	1 263.99[b]	1.439[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 parameter estimates are applied to the 20 per cent subset to make out-of-sample predictions and to apply the prediction accuracy measures. This procedure is repeated three times.

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

TABLE II2. PERFORMANCE OF ESTIMATED MODELS IN PREDICTING ON-FARM WATER-USE FOR POTATOES IN RABEA

Type of prediction model of water use	Prediction accuracy measures		
	Mean absolute error (MAE)	Root mean square error (RMSE)	Mean absolute percentage error (MAPE)
In-sample predictions			
Fixed allocatable input model	6 170.86	8 341.24[b]	0.214[b]
Variable input model	5 844.88[b]	8 596.58	0.229
Satisficing model	5 939.38	8 806.14	0.214[b]
Out-of-sample predictions[a]			
Draw 1			
Fixed allocatable input model	8 713.80	5 357.17	0.264
Variable input model	7 884.72	5 044.73	0.261
Satisficing model	7 096.48[b]	4 530.61[b]	0.197[b]
Draw 2			
Fixed allocatable input model	7 816.77	1 670.30[b]	0.366[b]
Variable input model	6 703.09[b]	4 562.63	0.406
Satisficing model	7 108.09	4 532.11	0.398
Draw 3			
Fixed allocatable input model	9 725.49	5 940.63	0.597
Variable input model	8 140.99	5 316.53	0.563
Satisficing model	7 364.54[b]	5 127.65[b]	0.504[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 parameter estimates are applied to the 20 per cent subset to make out-of-sample predictions and to apply the prediction accuracy measures. This procedure is repeated three times.

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

TABLE II3. PERFORMANCE OF ESTIMATED MODELS IN PREDICTING ON-FARM WATER-USE FOR SUGAR BEET IN RABEA

Type of prediction model of water use	Prediction accuracy measures: Mean absolute error (MAE)	Root mean square error (RMSE)	Mean absolute percentage error (MAPE)
In-sample predictions			
Fixed allocatable input model	4 703.02	6 158.02[b/]	0.346[b/]
Variable input model	3 910.26[b/]	7 058.68	0.362
Satisficing model	4 813.20	8 041.80	0.385
Out-of-sample predictions[a/]			
Draw 1			
Fixed allocatable input model	3 586.60	1 570.21	N. A
Variable input model	4 098.18	7 061.67	0.365[b/]
Satisficing model	2 251.65[b/]	967.56[b/]	N. A
Draw 2			
Fixed allocatable input model	6 846.44	4 700.53[b/]	0.457[b/]
Variable input model	6 321.87[b/]	5 337.05	0.538
Satisficing model	7 922.15	5 827.47	0.661
Draw 3			
Fixed allocatable input model	7 953.66	5 725.30	0.905
Variable input model	6 728.41	5 879.42	0.772
Satisficing model	5 573.23[b/]	4 114.75[b/]	0.666[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 parameter estimates are applied to the 20 per cent subset to make out-of-sample predictions and to apply the prediction accuracy measures. This procedure is repeated three times.

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

TABLE II4. PERFORMANCE OF ESTIMATED MODELS IN PREDICTING ON-FARM WATER-USE FOR TOMATOES IN RABEA

Type of prediction model of water use	Prediction accuracy measures		
	Mean absolute error (MAE)	Root mean square error (RMSE)	Mean absolute percentage error (MAPE)
In-sample predictions			
Fixed allocatable input model	13 849.51	15 739.06 b/	0.326
Variable input model	13 271.13	20 106.01	0.315
Satisficing model	12 638.69 b/	21 477.86	0.245 b/
Out-of-sample predictions a/			
Draw 1			
Fixed allocatable input model	14 737.70	6 817.69	0.402
Variable input model	10 021.36	5 200.61	0.315
Satisficing model	8 728.91 b/	4 500.09 b/	0.223 b/
Draw 2			
Fixed allocatable input model	16 468.83 b/	18 161.08 b/	0.318 b/
Variable input model	17 279.22	19 281.97	0.361
Satisficing model	18 357.24	20 063.88	0.364
Draw 3			
Fixed allocatable input model	21 092.90	15 991.33	0.380
Variable input model	15 159.55	7 277.48	0.369
Satisficing model	10 658.26 b/	4 949.29 b/	0.256 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 parameter estimates are applied to the 20 per cent subset to make out-of-sample predictions and to apply the prediction accuracy measures. This procedure is repeated three times.

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

Annex III

ASSESSMENT OF WUE AT FARM LEVEL

ICARDA-ESCWA

Questionnaire No. .....

Village..
Sub-District..
District...
Reference ....
Farmer's name..
Rainfall zone ....
Farmer's age...
Years' experience in farming ....
Years' experience in irrigation..

Farmer's type:
- a. Part-time
- b. Full-time

Family size residing on the farm.............................. persons

Sources of income:
- Off-farm income .... %
- Farm income .... %
- Farm crop production .... %
- Farm livestock production .... %

Soil type:
- a. Sandy
- b. Medium
- c. Heavy

Soil salinity:
- a. Low
- b. Medium
- c. High

Soil depth:
- a. Deep
- b. Medium
- c. Shallow

1. What determines current farm cropping pattern?
   - a. Market conditions
   - b. Agricultural policies
   - c. Both
   - d. None of them

2. How cropping decisions are made?
   - a. Length of growing season
   - b. Labour requirement
   - c. Others...............................

3. Is the use of land restricted to certain crops only?
    a. Yes
    b. No

4. If yes, what crops and percentage of land in each group?

Crop	Percentage of land
Wheat	....
Corn	....
Cotton	....
Sugar beet	....
Potatoes	....
Vegetables	....
Other	....

5. How much does it cost you to use water .... (SL/ha/year)?

6. Is the amount of water available to your farm limited?
    a. Yes
    b. No

7. Location to water source:
    a. Head
    b. Medium
    c. Tail
    d. Well

8. Are there any limitations (restrictions) on water availability?
    - Quantity a. Yes b. No
    - Quality a. Yes b. No
    - Regulations a. Yes b. No
    - Others ....

9. Why do you irrigate?
    a. Agricultural policies in the form of credit and subsidized equipment
    b. Amount of rainfall is not sufficient for economic rainfed yield
    c. Shifting to new crops which require irrigation
    d. No rainfall
    e. Other (specify) ....

10. What determines the amount of water you apply to each group?
    a. Price of crop
    b. Cost of water
    c. Recommendations by extension
    d. Area planted in each crop
    e. Rules of thumb (specific)..

Wheat	Sunflower.....................................
Corn	Cucumbers ....
Potatoes....................................	Tomatoes......................................
Chickpeas.................................	Garlic ....
Cotton	Green peppers ....
Sugar beet	Other ....

11. Rainfall information

Season	Rain (mm)
Winter	....

Summer ....
Other ....

12. Price of fertilizer (SL/Kg):
    Ammonium nitrate (33)% ....
    Urea (46)% ....
    Phosphate (46)% ....
    Potassium (50)% ....
    Organic ....
    Others ....

13. What is the size of the farm?.................. ha

14. Land ownership
    Private ....%
    Rented ....%
    Shared ....%
    Other ....%

15. Water source available to the farm:
    a. Ground water
    b. Surface water
    c. Surface water using pump
    d. Other ....

Item/unit		Crop												
		Wheat	Corn	Potatoes	Chickpeas	Cotton	Sugar beet	Sunflower	Water melon	Fava beans	Tomatoes	Garlic	Green peppers	Barley
Planted Area (ha)														
Sowing Date														
Harvest Date														
Yield (kg/ha)	Grain													
	Straw													
Output price (SL/kg)	Grain													
	Straw													
Manure														
Phosphorous														
Nitrogen														
Potassium														
Insecticide														
Herbicide	B.L.													
	G.L.													
Others (specify)														
Insecticide														
Herbicide	B.L.													
	G.L.													
Others (specify)														

Note: B.L. = broad leaf
G.L. = grass leaf

Item/unit		Crop												
		Wheat	Corn	Potatoes	Chickpeas	Cotton	Sugar beet	Sunflower	Water melon	Fava beans	Tomatoes	Garlic	Green peppers	Barley
Seeds														
Var. 1	Name													
	Rate kg/ha													
	Price SL/ha													
Var. 2	Name													
	Rate kg/ha													
	Price SL/ha													
Var. 3	Name													
	Rate kg/ha													
	Price SL/ha													

Item/unit		Crop												
		Wheat	Corn	Potatoes	Chickpeas	Cotton	Sugar beet	Sunflower	Water melon	Fava beans	Tomatoes	Garlic	Green peppers	Barley
Machinery (Pre-harvest)	Use (hours/ha)													
	Price (SL/hour)													
Machinery (Harvest)	Use (hours/ha)													
	Price (SL/hour)													
Family labour (Man day/season)	No. Irrig.													
	No. others													
	Wage (Equ.)													
Hired labour (Man day/season)	No. Irrig.													
	No. others													
	Wage SL/day													

Item/unit	Crop												
	Wheat	Corn	Chickpeas	Potatoes	Cotton	Sugar beet	Sunflower	Water melon	Fava beans	Tomatoes	Garlic	Green peppers	Barley
1. Rainfed area													
2. Irrigated area													
Full irrigation													
- Surface water													
- Groundwater													
S. irrigation													
- Surface water													
- Groundwater													
S. irrigation													
- Surface													
- Sprinkler													
- Drip													
- Well used													

16. Irrigation costs:

Item	Wells				
	W1	W2	W3	W4	W5
Total cost of drilling - (SL)*					
Period of pumping/motor					
Average of pumping (hr/day)					
Cost of repair and maintenance (SL/year)					
Fuel cost during the year (SL/year)					

* Drilling, casing, pumping shaft, installation fee and pump shelter.

17. Quality of groundwater:

Item	Wells				
	W1	W2	W3	W4	W5
Fresh water					
Slightly salty					
Moderately salty					
Very salty					
Hot and sulfuric					

18. Groundwater and wells characterization:

Item	Wells				
	W1	W2	W3	W4	W5
Depth of well (m)					
Depth of water (m)					
Age (year)					
Diameter of the pump (inch)					
Share of each well in irrigation (percentage)					
Type of motor					
Mechanical					
Electrical					
Fuel price (SL/unit)					
Electricity					
Diesel (SL/Liter)					
Gasoline (SL/Liter-Gallon)					
Pumping pressure (PSI)					

19. Annual water budget (use):

Amount of irrigation/month/crop = no. of irr./month = duration of one irrigation/hrs. = discharge rate (m^3/hrs.)

Crop		Month (growing season)											
		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.
Wheat	no.												
	hrs.												
	m^3/hrs												
Barley	no.												
	hrs.												
	m^3/hrs												
Chickpeas	no.												
	hrs.												
	m^3/hrs												
Lentil	no.												
	hrs.												
	m^3/hrs												
Cotton	no.												
	hrs.												
	m^3/hrs												
Sugar beet	no.												
	hrs.												
	m^3/hrs												
Sunflower	no.												
	hrs.												
	m^3/hrs												
Corn (maize)	no.												
	hrs.												
	m^3/hrs												
Water melon	no.												
	hrs.												
	m^3/hrs												
Fava beans	no.												
	hrs.												
	m^3/hrs												
Tomatoes	no.												
	hrs.												
	m^3/hrs												
Potatoes	no.												
	hrs.												
	m^3/hrs												
Garlic	no.												
	hrs.												
	m^3/hrs												
Green Peppers	no.												
	hrs.												
	m^3/hrs												
Barley	no.												
	hrs.												
	m^3/hrs												

20. Water management:
    The farmer ceased irrigation long enough during the growing season
    a. Yes
    b. No

If yes, fill in the following:

Affected crop	Irrigation stopped

21. Water management practices used in the farm:
    Water application according to calendar schedule.
    a. Yes
    b. No

    Farmers rely on advanced management practices (e.g., soil moisture-sensing device).
    a. Yes
    b. No.
    c. Other (explain) ....

<u>Annex IV</u>

استبيان تقييم كفاءة استخدام المياه في المزرعة
ايكاردا - إسكوا

رقم الاستمارة: ....

القرية: .... الناحية: .... القضاء: .... المحافظة: ....

اسم المزارع: ....
المنطقة المطرية: ....
المعدل السنوي للأمطار: .... ملم
عمر المزارع: .... سنة
الخبرة في الزراعة: .... سنة
الخبرة باستخدام الري: .... سنة
نوع المزارع: أ- يعمل جزئياً في المزرعة ب- يعمل كلياً في المزرعة
عدد أفراد العائلة الساكنين في المزرعة: .... شخص

مصادر الدخل: الدخل من خارج المزرعة: .... ٪
الدخل المزرعي: .... ٪
مساهمة الانتاج النباتي: .... ٪
مساهمة الانتاج الحيواني: .... ٪

نوعية التربة: أ- رميلة ب- متوسطة ج- ثقيلة
ملوحة التربة: أ- واطئة ب- متوسطة ج- ثقيلة
عمق التربة: أ- عميقة ب- متوسطة ج- منخفضة

١- ما الذي يحدد التركيبة المحصولية الحالية في مزرعتك؟
أ- ظروف السوق ب- السياسات الزراعية
ج- الاثنان د- ولا واحد منهما

٢- كيف تتخذ قراراتك بشأن المحاصيل المزروعة؟
أ- طول موسم النمو ب- متطلبات العمل ج- أخرى (تذكر) ....

٣- هل ان استخدام الأرض محدد لمحاصيل معينة فقط؟

أ- نعم ب- كلا

٤- إذا كان الجواب نعم، ما هي المحاصيل المحدد زراعتها ونسبة الأرض المزروعة بكل منها؟

المحصول	نسبة الأرض
حنطة	٪ ....
ذرة	٪ ....
قطن	٪ ....
بنجر	٪ ....
بطاطس	٪ ....
محاصيل خضر (تُذكر)	٪ ....
محاصيل أخرى (تُذكر)	٪ ....

٥- ما هي كلفة استخدام مياه الري؟ .... دينار عراقي/هكتار/سنة

٦- هل ان كمية المياه المتوفرة لمزرعتك محدودة؟

أ- نعم ب- كلا

٧- موقع المزرعة بالنسبة لمصدر المياه:

أ- صدر ب- متوسط ج- أخير (بزايز) د- بئر

٨- هل هناك أي محددات (قيود) على استخدام المياه من حيث؟

- كمية المياه أ- نعم ب- كلا
- نوعية المياه أ- نعم ب- كلا
- تشريعات أ- نعم ب- كلا
- أخرى (تُذكر) .... أ- نعم ب- كلا

٩- لماذا تروي (تسقي) المحاصيل؟

أ- السياسات الزراعية على شكل قروض ومضخات مدعمة
ب- كمية الأمطار غير كافية للحصول على انتاجية من المحاصيل التقليدية
ج- التحول إلى زراعة محاصيل جديدة تتطلب زراعتها الري
ما هي هذه المحاصيل الجديدة؟
د- عدم سقوط الأمطار
هـ- أسباب أخرى (وضّح) ....

١٠- ما الذي يحدد كمية الماء المضافة لكل محصول؟

أ- سعر المحصول ب- كلفة المياه
ج- التوصيات الارشادية د- قواعد عامة (وضّح ذلك)

هـ- احتياجات النبات المائية

و- المساحة المزروعة بكل محصول

حنطة	....	زهرة شمس	....
ذرة	....	كوسا	....
بطاطا	....	طماطة	....
حمص	....	خيار	....
قطن	....	فلفل أخضر	....
بنجر	....	محاصيل أخرى	....

١١- معلومات الأمطار

الموسم والأشهر	كمية الأمطار (مل)
الشتاء	(..................)
الصيف	(..................)
المواسم الأخرى	(..................)

١٢- أسعار الأسمدة (دينار/كغم)

نترات الأمونيوم ٣٣ ٪ ....

سماد اليوريا ٤٦ ٪ ....

سماد الفوسفات ٤٦ ٪ ....

بوتاسيوم ٥٠ ٪ ....

الأسمدة العضوية ....

الأسمدة الأخرى ....

١٣- ما هو حجم المزرعة .... هكتار

أ- المساحة المزروعة .... هكتار

ب- المساحة المروية .... هكتار

١٤- نوع ملكية الأرض

أ- ملك .... ٪

ب- مؤجرة .... ٪

ج- محاصصة .... ٪

د- أخرى (تذكر) .... ٪

١٥- مصادر المياه المتوفرة في المزرعة

أ- مياه جوفية

ب- مياه سطحية

ج- مياه سطحية باستخدام مضخات

د- أخرى ....

مستويات استخدام موارد الانتاج

الفقرة/الوحدة		حنطة	ذرة	بطاطا	حمص	قطن	بنجر	زهرة الشمس	خيار/بطيخ	باقلاء	طماطة	فلفل أخضر	شعير
المساحة المزروعة (هكتار)													
ايجار الأرض (دينار/هكتار)													
تاريخ البذار													
تاريخ الحصاد													
الانتاجية (كغم/هكتار)	حبوب												
	تبن												
سعر الناتج (دينار/كغم)	حبوب												
	تبن												
الأسمدة المستخدمة (كغم/ هكتار)													
سماد عضوي													
الفوسفور													
النتروجين													
البوتاسيوم													
المبيدات المستخدمة (وحدة/هكتار)													
مبيد الحشرات													
مبيد أدغال	عريضة الأوراق												
	رفيعة الأوراق												
أخرى (وضح ذلك)													
أسعار المبيدات المستخدمة (دينار/كغم)													
مبيد الحشرات													
مبيد الأدغال	عريضة الأوراق												
	رفيعة الأوراق												
أخرى (وضح ذلك)													

ملاحظة: ١- تعاد تسمية المحاصيل أعلاه من قبل مالئ الاستمارة حسب التركيبة المحصولية لكل مزرعة.
٢- (١) هكتار = ٤ دونم عراقي.

الفقرة/الوحدة		المحاصيل											
		حنطة	ذرة	بطاطا	حمص	قطن	بنجر	زهرة الشمس	خيار/بطيخ	باقلاء	طماطة	فلفل أخضر	شعير
البذور	الاسم												
الصنف ١	الكمية المستخدمة (كغم/هكتار)												
	السعر (دينار/كغم)												
الصنف ٢	الاسم												
	الكمية المستخدمة (كغم/هكتار)												
	السعر (دينار/كغم)												
الصنف ٣	الاسم												
	الكمية المستخدمة (كغم/هكتار)												
	السعر (دينار/كغم)												
المكننة (قبل الحصاد)	الاستخدم (ساعة/هكتار)												
	السعر (دينار/ساعة)												
مكننة الحصاد	الاستخدام (ساعة/هكتار)												
	السعر (دينار/ساعة)												
العمل العائلي (يوم عمل/موسم زراعي)	عدد للعمليات الأخرى												
	الأجر (دينار/يوم)												
	عدد للري												
العمل المؤجر (يوم عمل/موسم زراعي)	عدد للعمليات الأخرى												
	الأجر (دينار/يوم)												
	عدد للري												

ملاحظة: كلفة الحصاد (الجني) لمحاصيل الخضر والمحاصيل الأخرى = عدد الجنيات x سعر العامل (دينار/يوم).

الفقرة/الوحدة	المحاصيل											
	حنطة	ذرة	بطاطا	حمص	قطن	بنجر	زهرة الشمس	خيار/بطيخ	باقلاء	طماطة	فلفل أخضر	شعير
١- المساحة المطرية (هكتار)												
٢- المساحة المروية (هكتار)												
* الري الكامل (هكتار)												
- مياه سطحية (هكتار)												
- مياه جوفية (هكتار)												
* ري تكميلي (هكتار)												
- مياه سطحية (هكتار)												
- مياه جوفية (هكتار)												
* تكنولوجيا الري التكميلي (هكتار)												
- سطحي												
- مرشات												
- تنقيط												
- استخدام الآبار												

١٦- تكاليف الري

الفقرة	البئر ١	البئر ٢	البئر ٣	البئر ٤	البئر ٥
	الآبار				
الكلفة الكلية للحفر (دينار)*					
فترة الضخ (يوم/ماطور/موسم)					
معدل عدد الريات (عدد/شهر)					
عدد ساعات الضخ اليومي (ساعة/يوم)					
تكاليف التصليح والصيانة (دينار/سنة)					
تكاليف الوقود السنوية (دينار/سنة)					

* (drilling, casing, pumping shaft, installation fee and pump shelter….)

١٧- نوعية المياه الجوفية

الفقرة	البئر ١	البئر ٢	البئر ٣	البئر ٤	البئر ٥
	الآبار				
مياه عذبة					
مياه قليلة الملوحة					
مياه معتدلة الملوحة					
مياه عالية الملوحة					
مياه حارة وكبريتية					

١٨- خواص المياه الجوفية والآبار

الفقرة	البئر ١	البئر ٢	البئر ٣	البئر ٤	البئر ٥
	الآبار				
عمق البئر (م)					
عمق مستوى الماء (م)					
عمر البئر (سنة)					
قطر المضخة (انش)					
مساهمة كل بئر في الري (٪)					
نوع المضخة					
ميكانيكية					
كهربائية					
سعر الوقود (دينار/وحدة)					
كهرباء (دينار/وحدة)					
ديزل (دينار/لتر)					
كازولين (دينار/لتر/غالون)					
ضغط الضخ (PSI)					

١٩- الاستخدام الشهري لمياه الري

كمية مياه الري لكل شهر لكل هكتار من كل محصول = عدد الريات في الشهر x عدد ساعات الرية الواحدة لكل محصول (ساعة) x كمية الماء المضافة في كل ساعة (م/ساعة ٣)

المحاصيل		الأشهر (موسم النمو)											
		ت٢	ك١	ك٢	شباط	آذار	نيسان	أيار	حزيران	تموز	آب	أيلول	ت١
حنطة	عدد												
	ساعة												
	م٣/س												
شعير	عدد												
	ساعة												
	م٣/س												
حمص	عدد												
	ساعة												
	م٣/س												
عدس	عدد												
	ساعة												
	م٣/س												
قطن	عدد												
	ساعة												
	م٣/س												
بنجر	عدد												
	ساعة												
	م٣/س												
زهرة الشمس	عدد												
	ساعة												
	م٣/س												
ذرة	عدد												
	ساعة												
	م٣/س												
خيار	عدد												
	ساعة												
	م٣/س												
باقلاء	عدد												
	ساعة												
	م٣/س												
طماطة	عدد												
	ساعة												
	م٣/س												
بطاطا	عدد												
	ساعة												
	م٣/س												
ثوم	عدد												
	ساعة												
	م٣/س												
فلفل أخضر	عدد												
	ساعة												
	م٣/س												

٢٠- إدارة المياه

هل تم قطع مياه الري لفترة طويلة وبما يؤثر على انتاجية المحاصيل خلال موسم النمو؟

أ- نعم ب- كلا

إذا كان الجواب نعم، أكمل الجدول التالي:

المحصول الذي قطعت عنه مياه الري	فترة انقطاع مياه الري (يوم)

٢١- طرق إدارة الري المستخدمة في المزرعة

تتم إضافة المياه باعتماد جدول زمني.

أ- نعم ب- كلا

إذا كان الجواب نعم، ماهي الجدولة المعتمدة؟

يعتمد المزارع على طرق متقدمة (مثل قياس رطوبة التربة)

أ- نعم ب- كلا ج- طرق أخرى (وضح ذلك)........................

٢٢- تكاليف الري الكلية للمزرعة (دينار)

التكاليف الثابتة (نظام الري، القنوات، المضخات، ... الخ) - انثارات .... (دينار/سنة)
التكاليف التشغيلية (العمل، الوقود، التصليحات، ...الخ) .... (دينار/سنة)

٢٣- كمية المياه الكلية المتوفرة للمزرعة

المصدر	عدد الأشهر	عدد الأيام/شهر	عدد الساعات/يوم	كمية المياه (م٣/ساعة/هكتار)
مياه سطحية				
مياه جوفية				

٢٤- أية معلومات أخرى عن المزرعة (وضح ذلك) ....