Economic and Social Commission for Western Asia	International Center for Agricultural Research in the Dry Areas
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ENHANCING AGRICULTURAL PRODUCTIVITY THROUGH ON-FARM WATER-USE EFFICIENCY: AN EMPIRICAL CASE STUDY OF WHEAT PRODUCTON IN IRAQ

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Executive summary

The dry areas of West Asia and North Africa (WANA) face severe challenges due to limited opportunities for the exploitation of new sources of water coupled with the rapidly growing demand for water resources. As a result, water resource management is becoming one of the most important economic and social issues of this century. Water allocation, water quality, growing and changing social demands for available water, changing technologies, water-use efficiency, and economic feasibility are issues of great interest to research institutions and decision makers at various levels. Given that irrigation accounts for 80-90 per cent of all water consumed in the WANA region, improving on-farm water-use efficiency can contribute directly to increased supply of water for other end users.

Available information indicates that scarce water resources of the region are poorly managed and inefficiently used. Low irrigation efficiency is associated with poor timing and lack of uniformity of water applications, leaving parts of the field over-or under-irrigated relative to crop needs. Moreover, 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. 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 for mono-crop systems, which do not precisely reflect the complex production decisions at the farm level under different environmental, technological, and economic conditions. More recently two empirical studies on economic assessment of on-farm water-use efficiency in agriculture were jointly conducted by ICARDA and ESCWA. These studies clearly demonstrate the low ratios of water-use efficiency in crop production implying the tendency of farmers to over-irrigate their crops. The methodology adopted by these two studies in assessing the status of on-farm water-use efficiency is proved to be a valid approach for conducting further empirical studies.

The main objective of this study is to assess the on-farm water-use efficiency of wheat production under specific farm conditions in northern Iraq. In 1991 a large supplemental irrigation project (the North Al-Jazeera Irrigation Project) was launched in order to serve approximately 60,000 hectares of arable land by using a linear-move sprinkler irrigation system. More recently, a new development project on “the Dissemination of Improved Irrigation Technologies” was introduced into the farming systems of Iraq, particularly in rainfed areas, to increase wheat production. The targeted goal has been to plant up to 0.5 million hectares of wheat under supplemental irrigation by the year 2007. Currently, there are about 3,500 new farms in Mosul Province under supplemental irrigation with an average size of holding of 25 hectares per farm. Wheat is the major winter crop covering 73 per cent of the project area. 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. The resulting indicators on on-farm water-use efficiency are very useful in guiding policies toward improving irrigation efficiency. Improving water-use efficiency is vital to sustain and improve wheat production in Iraq, a country, which has been classified as food deficit.

Efficiency is generally associated with a transformation of an input into an output. Both engineering and agronomic concepts have constituted the majority of the literature on water-use efficiency. The engineering focus defines the concept of irrigation efficiency as the amount of water from the main water source which can be effectively supplied to the root zone. The agronomic focus, however, illustrates the concept of crop water-use efficiency, defined as the fraction of water stored in the root zone that is transpired by the crop. This concept includes both crop water-use efficiency and crop water productivity. The combined agronomic and engineering focuses result in water-use efficiency, defined as the ratio of transpiration (mm) to total water supply (mm), and water productivity, defined as the ratio of yield (kg) to total water supply (mm).

These concepts reflect the technical measures of efficiency and thus are not sufficient to assess the economic level of water-use efficiency. The economically efficient amount of water-use depends on the relative prices of water and other inputs, the marginal products of the inputs, the prices of inputs and the amounts of other inputs, including rainfall. To address this complex situation at the farm level, the concept

of on-farm water-use efficiency is developed. On-farm water-use efficiency in agriculture is assessed by ICARDA and ESCWA using five case studies in the Syrian Arab Republic, Iraq, Jordan and Egypt. These case studies support the usefulness of this concept in assessing the efficiency of water-use under farmers' conditions and provide vital options for water savings. To further support the methodology of assessing on-farm water-use efficiency, this case study is implemented in Iraq using the farm survey data from a supplemental irrigation project. The data was collected from a cross-sectional survey of 284 farms in Ninavah province in Northern Iraq during the 2001-2002 season. The estimated indicators of on on-farm water-use efficiency will provide useful options and potential opportunities for water savings through its efficient use.

Comparison of farm yield data indicates that supplemental irrigation has more impact on bread varieties as compared to durum varieties in increasing wheat yield. Supplemental irrigation has increased yield of bread wheat varieties by more than 100 per cent, whereas the contribution to the yield of durum wheat varieties ranged between 58 and 81 per cent. In conclusion, supplemental irrigation has increased land productivity considerably. The impact of supplemental irrigation on water productivity is an issue of great interest to policy makers at various levels. Results show that supplemental irrigation has increased water productivity for all varieties. Water productivity increased the most (63 per cent) for IPA 99 variety. The impact of supplemental irrigation on water productivity of bread wheat varieties is higher than that of durum wheat varieties. Water productivity of bread wheat varieties was increased by 32 per cent as a result of using supplemental irrigation whereas water productivity of durum wheat varieties was increased by only 15 per cent due to the use of new irrigation technology. For all wheat varieties, the impact of supplemental irrigation is an increase in water productivity by 31 per cent. Thus, the use of supplemental irrigation has greatly increased land and water productivity.

Yield comparison of wheat producers under supplemental and rainfed conditions reveals that supplemental irrigation increases wheat productivity by 128 per cent as compared to rainfed farming. This is the total impact of supplemental irrigation on wheat productivity, which reflects the combined effect of other variables, as well. The estimated production function, however, gives a net impact of increasing wheat yield by 91 per cent as a result of using the supplemental irrigation technology. The net impact is mainly attributed to the use of supplemental irrigation. The difference of 37 per cent, between the total impact and the net impact, is attributed to other variables not used under rainfed conditions.

To assess the efficiency of on farm water-use, the three specified models of the fixed- allocatable input model, variable input model and the behavioral model are estimated using the ordinary least squares procedure. To validate the estimated models, three sets of out-of-sample forecasts are made. 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. Based on the result of the estimated coefficients and two of the comparisons of the prediction performance measures, it can be concluded that the fixed-allocatable input model is a better model to estimate on-farm water-use by wheat producers. The fixed-allocatable input model performs best in explaining short-run water-use, and its estimated coefficients provide further information, as follows:

(a) The estimated value of the coefficient of multiple determination implies that nearly 85 per cent of the variation in the amount of water applied to wheat is explained by the independent variables included in the estimated equation, which are wheat irrigated area, wheat output price, labor wage rate, total amount of water available to the farm, irrigation technology and water limitations. The estimated water demand equation for wheat under the fixed-allocatable input model is significant at the 1 per cent level of significance;

(b) Labor wage rate appears to be a strong determinant for short-run decisions on water-use for wheat. An increase in the labor wage rate by one Iraqi Dinar, holding other variables constant, will decrease water-use for wheat by 25.54 m^3. This result has important implications for wheat producers as the labor demand is highly inelastic under rainfed conditions, and thus a small increase in the demand for labor will increase labor wage rate considerably which in return will reduce the amount of water applied for wheat;

(c) Estimate of the water constraint variable (total amount of water available to the farm) indicates the allocation of a marginal increase in farm-level water availability for wheat producers. The individual estimated coefficient of the water constraint of 0.67 suggests that for a 1 m^3 increase in availability of water to the farm, 0.67 m^3 of it will be used mainly for wheat production. In other words, two-third of the incremental water is added to wheat production;

(d) Irrigation technology has an important and a significant impact on the amount of water-use in wheat production. The use of center-pivot sprinkler technology reduces the amount of water-use by 4934.53 m^3 per farm compared to the use of solid-set sprinkler technology. The estimated coefficient of the variable of the irrigation technology is negative and significant at the 1 per cent level of significance. Similarly, if farmers perceive water available to the farm as limited, they will reduce the use of water for wheat production by 824 m^3 per farm;

(e) Planted area under supplemental irrigation is a strong and highly significant determinant of the amount of water applied for wheat production. The estimated coefficient of irrigated area implies that increasing wheat area by one hectare will result in increasing the water-use by 745.74 m^3.

Estimates of on-farm water-use efficiency indicate that of the total wheat farmers, 80 per cent of them have on-farm water-use efficiency of less than one, indicating that these farmers over-irrigate their wheat crop. Meanwhile, the water-use efficiency of 20 per cent of the farmers is greater than one, implying that these farmers under-irrigate wheat crop by 10 per cent. The overall water-use efficiency for the whole sample is 0.77, which is less than one, indicating that the wheat producers over-irrigate their crop by 23 per cent. Among over-irrigating farmers, the water-use efficiency of 4 per cent of the farmers is estimated at 0.34, indicating that actual water-use exceeds required water-use by about 66 per cent. The water-use efficiency of 20 per cent of the farmers is 0.64, implying that this group over-irrigates wheat crop by 36 per cent. Meanwhile, 56 per cent of the farmers having water-use efficiency of 0.87 over irrigate wheat crop by 13 per cent under current production levels. Farmers over-irrigate wheat crop because of their own perceptions of water requirements and their expectations of rainfall and market conditions.

Farm size is an important factor in explaining the variation in on-farm water-use efficiency among wheat producers. More than 50 per cent of wheat producers are small size farm holders of less than 10 hectares with an average size holding of 6.7 hectares. The water-use efficiency of small size farmer holders is 0.77, implying that small farmers over-irrigate wheat production by 23 per cent. The water-use efficiency improves as the farm size increases. The water-use efficiency of medium farms (10.1-20 hectares) is 0.81. With the increase in farm size above 20 hectares the water-use efficiency decreases. The water-use efficiency of large farms is 0.72, indicating that large farms exceed water requirements by 28 per cent. Thus, small and medium farms are more efficient than large farms in using supplemental irrigation water in wheat production. This has important implications on the economies of size under supplemental irrigation.

The results obtained for the three models used in this study have important policy implications. The overall water-use efficiency for the sample farms is 77 per cent, indicating a potential for water-use efficiency by 23 per cent. The results by farm size, on the other hand, show that small, medium, and large farms have different potentials for improving their water-use efficiency by 23, 19 and 28 per cent respectively. However, each individual farm has a different potential for improving water-use efficiency ranging from a low of 13 per cent to a high of 66 per cent.

If policy makers encourage the design of appropriate technical as well as incentive packages, it would not be beyond their reach to capitalize on the potentials and improve water-use efficiency to the desired levels. By doing this, ample water will be available for productive use leading to increasing water productivity and improved agricultural productivity by producing more crop per drop.

Improvement in water management and irrigation as well as in technologies has the potential to optimize water-use efficiency at the farm levels. Sound extension strategies and the provision of pertinent advice to farmers will be instrumental (a) in optimizing water-use efficiency at the farm levels and (b) in reducing the adverse effects of salinization and water-logging on the productivity of land which are caused by over-irrigation. Thus, by obtaining optimal water-use efficiency, it is possible to increase wheat productivity in the study area while ensuring the sustainable use of resources, both water and land.

The methods of analysis used in this study are valid techniques for assessing on-farm water-use efficiency within the framework of multi-crop production systems. Results obtained are reliable and compare favorably with expert and technical recommendations. However, it is important to note that these results are only applicable to the study area and cannot be generalized at national and regional levels. The main difficulty encountered in such studies is the calculation of actual water-use, given the diversity at the farm levels with respect to source of water and irrigation technology.

Conducting of similar empirical studies using the same methods in different agro-ecological zones of Iraq are highly recommended in order to assess the current status of on-farm water-use efficiency for different crops and to determine the potential for improving water-use efficiency and to improve water and land productivity in Iraq, eventually producing more crop per drop.

When requested by an interested member state, ESCWA and ICARDA are capable of providing technical support in: (a) holding capacity building seminars on the methodologies of assessing on-farm water-use efficiency; (b) conducting farm surveys, data processing and analysis; and (c) drafting and publishing the empirical case studies on on-farm water-use efficiency.

I. INTRODUCTION

The West Asian and North African countries, as the rest of the world, face severe and growing challenges to both maintaining of water quality and meeting of 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 put increasing pressure on land and water quality. In all countries, water is available to users either at no cost or at a heavily subsidized price. Thus, neither water-users nor water-managers have incentives to conserve water; as a result, water is being over-used 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 to1, 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.

Water-use can be divided into three major categories: Domestic, industry and agriculture. Domestic use, in addition to drinking water, includes water-used for private homes, commercial establishments, public service, and municipal supplies. 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 indicate 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 advanced 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. Improving the efficiency of irrigation requires a better matching of water application to crop needs, in terms of both timing and quantity, thus crops will consume applied water more effectively, 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., 1985).

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-use efficiency and use of other inputs (Serageldin, 1998). Farmers, on their part, generally tend to over-irrigate as a result of their own 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 mono-crop systems, which do not precisely reflect the complex production decisions at the farm level under different environmental, technological and economic conditions.

In this study, the main objective is to assess the current status of on-farm water-use efficiency of wheat under specific farm conditions in Ninavah province, northern Iraq, where recently the use of supplemental irrigation has been expanded to increase wheat production in rain-fed areas. 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. The resulting indicators on on-farm water-use efficiency are very useful in guiding policies toward improving irrigation efficiency. Improving water-use efficiency to sustain and improve wheat production in Iraq is vital especially that the country has been classified as food deficit.

The methods used in this study is based on the methodology of the two empirical studies on economic assessment of on-farm water-use efficiency (ESCWA/ICARDA, 2000 and 2001), which proved to be a valid approach for conducting further empirical studies. These studies demonstrate the low ratios of water-use efficiency in crop production, implying the tendency of farmers to over-irrigate their crops.

II. WATER POLICIES IN WANA REGION

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, and the other Gulf States, as well as Yemen already exceed renewable water 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).

Alternatives to a new investment are conservation and improved management of existing supplies, both of which are cost effective. More problematic, however, is the 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; notwithstanding the fact that abandoning irrigation in arid areas destroys agricultural viability and has adverse multiplier and third-party effects. Increased efficiency should always be emphasized keeping in mind that only few governments are willing to commit themselves to a strategy of reducing irrigation areas or using the (costly) treated wastewater in irrigation – even if recognized as an inevitable alternative source of water for irrigation in the longer 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 behavior, 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 and sustainable use of both land and water resources. In both supply- and demand-management issues, augmentation of supplies (through reallocation and desalinization) is 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 advanced 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 other 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 meter per year. In Oman, over-exploitation of aquifers through the digging of thousands of diesel tube wells, 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).

In spite of the water scarcity challenges, most of the region does not treat water as the scarce resource. For instance, despite the prevalence of severe water scarcity in Jordan, water policies encourage the overuse of water while strict rationing is often required to allocate the resulting scarcities. Also, 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.

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

III. WATER-USE EFFICIENCY

A. WATER EFFICIENCY AND PRODUCTIVITY

Water scarcity is likely to be the single most important regional and global resource management challenge in the coming years. Prudent use of water is becoming an immediate necessity.

Water-use efficiency is an indicator commonly used to evaluate the performance of an irrigation system. 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).

Improving irrigation efficiency is a slow but difficult process that depends essentially on the local water scarcity situation. It may be expensive and it requires willingness, know-how and action at various levels.

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).

National water policies could encourage water savings in water-scarce areas by providing incentives and effectively enforcing penalties. When upstream managers cannot ensure conveyance efficiency, there may be no incentives for water-users to make efficiency gains. In the case of groundwater, this caveat may not apply since the incentive is generally internalized by the users, and in many cases groundwater-users show much greater efficiency than those depending on surface resources.

The water-use efficiency concept is not directly related to the amount of food that can be produced with an amount of available water.

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.

In this respect, water productivity, defined as the amount of food produced per unit volume of water-used, is more relevant. Because the water-used may have various components (evaporation, transpiration, gross inflow, net inflow, and others), it is essential to specify which components are included when calculating water productivity. The concept of water productivity, like the water-use efficiency, needs clear specification of the domain of interest.

Water productivity can be increased by increasing yield per unit of the land area, by using a better variety of agronomic practices, for instance, 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.

The terms water-use efficiency and water productivity should be used complementarily to assess the impact of water management strategies and practices used to produce more crops with less water. However, 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 vital to specify the water-use components that are taken into account when deriving water-use efficiency and productivity. Thus, it is proper 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.

Inadequate water resources make it imperative to evaluate the efficiency of water utilization to arrive at a socially protective type of irrigation. The water-use efficiency and productivity would differ according to different systems of irrigation, crop mix and environment, and are 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.

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.

In measuring water 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 water productivity:

(a) Pure physical productivity, defined as the quantity of the product divided by the quantity of the water diverted or depleted;

(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 context, many researchers frequently use the term 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 (SI). Yield is expressed as a mass (kg or ton), and the amount of water as a volume (m^3).

The water productivity 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 a perennial system in terms of situational efficiency. The yield rates of rice, for example, in the irrigation system were higher than those under the perennial system, although the water requirement was lower. The average water productivity 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 productivity. In the perennial system, the water productivity of rice was lower, but the crop was widely grown during the rainy season because of the agro-climate (Giriappa, 1984).

B. SUPPLEMENTAL IRRIGATION AND WATER PRODUCTIVITY

Supplemental irrigation (SI) can be defined as the addition to essentially rainfed crops of small amounts of water during times when rainfall fails to provide sufficient moisture for normal plant growth, in order to improve and stabilize yields.

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 to 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 to farmers. 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 Syria, 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.

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.

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 Full Irrigation (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 FI 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; thus, improving water productivity.

Comparing the water productivity of the SI of wheat with that of 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 meter of water-used in SI produced, on average, an extra 3 kg of wheat over rainfed yield, whereas a cubic meter used in FI produced about 0.5 kg/m^3. This large difference in the water productivity is attributed to the conjunctive use of rainfall and SI water. In Jordan, water productivity in rainfed wheat in Mushagar (300 mm annual rainfall) is 0.33 kg/m^3, when the cubic meter of rainfall is combined with a supplemental ½ m^3, the overall water productivity 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 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 favorable rainfall (in amount and distribution), this can be increased to 1 kg grain/m^3. However, water-used in SI can be much more productive. ICARDA research showed that a cubic meter of water applied at the right time (when the crop is suffering from moisture stress), combined with good management, could produce more than 2.5 kg of grain over the rain-fed production. This extremely high water productivity 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 tons/hectare using 800 mm of water. Thus, the water productivity 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 favorable.

C. ON-FARM WATER-USE EFFICIENCY

Efficiency is generally associated with a transformation of an input into an output (efficiency =output/input). Both engineering and agronomic focuses have dominated the literature on water-use efficiency. The engineering focus defines the concept of irrigation efficiency as the amount of water from the main water source, which can be effectively supplied to the root zone. This focus distinguishes between three types of efficiency; namely conveyance efficiency, farm efficiency and field efficiency (Schmidt, 2001). The agronomic focus, however, illustrates the concept of crop water-use efficiency, defined as the fraction of water stored in the root zone that is transpired by the crop. This concept includes both crop water-use efficiency and crop water productivity. The combined agronomic and engineering focus results in water-use efficiency, defined as the ratio of transpiration (mm) to total water supply (mm), and water productivity, defined as the ratio of yield (kg) to total water supply (mm).

These concepts reflect the technical measures of efficiency and thus are not sufficient to assess the economic level of water-use efficiency, as water is used in combination with a whole set of other inputs, such as land, fertilizers, labor, machinery, and management, to produce crops. Therefore, singling out any one input such as water to determine efficiency is not helpful if not misleading (ACIL Tasman, 2003). The economically efficient amount of water-use depends on the relative prices of water and other inputs, the marginal products of the inputs, the prices of inputs and the amounts of other inputs, including rainfall. The concept of on-farm water-use efficiency is developed to address this complex situation at the farm level (ESCWA/ICARDA, 2000 and 2001).

On-farm water-use efficiency is defined as the ratio of the required amount of water to produce a specific output level to the actual amount of water applied by farmers. Under this definition, on-farm water-use efficiency may take the value of less than one, greater than one or equal to one. If the value of on-farm water-use efficiency is less than one, it implies that farmers over-irrigate their crops. Whereas, a value of greater than one implies that farmers under-irrigate the crops. However, if the value of the calculated on-farm water-use efficiency is equal to unity, it means that farmers are fully efficient in using irrigation water because the required and applied amounts of water-use are equal.

On-farm water-use efficiency in agriculture is recently assessed using five case studies in Syria, Iraq, Jordan and Egypt (ESCWA/ICARDA 2000 and 2001). These case studies support the usefulness of this concept in assessing the efficiency of water-use under farmers' conditions and provide vital information for water savings. On-farm water-use efficiency in Radwania in Syria, for instance, is found to be 0.61 for wheat, 0.45 for barley and 0.75 for cotton. The estimates indicate that farmers over-irrigate wheat by 39 per cent, barley by 55 per cent and cotton by 25 per cent respectively. Other case studies provide similar information regarding the excessive use of irrigation water by crop producers. To further support the methodology of assessing on-farm water-use efficiency, this case study is conducted in Iraq using farm survey data from SI project. The results obtained on on-farm water-use efficiency will provide useful information on potential opportunities for water savings through its efficient use.

IV. METHODS FOR ASSESSING ON-FARM WATER-USE EFFICIENCY

On-farm water-use efficiency is defined as the ratio of the required amount of water to produce a specific output level to the actual amount of water applied by farmers. Based on this definition, on-farm water-use efficiency may take the value of less than one, greater than one or equal to one. If the value of on-farm water-use efficiency is less than one, it implies that farmers over-irrigate their crops. Whereas, a value of greater than one implies that farmers under-irrigate the crops. However, if the value of the calculated on-farm water-use efficiency is equal to unity, it means that farmers are fully efficient in using irrigation water because the required and applied amounts of water-use are equal.

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 was 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 are proposed for this study. These include a fixed-allocatable input model, a variable input model, and a satisficing model. In the long run, an input is considered to be a variable input, but in the short 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 labor 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 fixed-allocatable input model. Farm-level water-use serves as an exogenous variable in the fixed-allocatable 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 fixed-allocatable 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 input 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 Ninavah province of Iraq using data from a farm survey.

A. THE MODELS FOR ESTIMATING 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); 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):

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

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

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

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:

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

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 lentils. The water-use on wheat depends on acreage in potatoes and acreage in lentil, in addition to acreage in wheat.

3. *Behavioural model*

Under the behavioural (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. However, satisficing in the short run by following a rule-of-thumb or a distributor's recommendation may conserve on information requirements with little sacrifice in profit.

An alternative model may explain the producer decisions on water-use in the short run. A 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 using 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 analyzed 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 patterns 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. MODELS 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:

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

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

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:

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

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 fixed-allocatable input model of equation (3) is:

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

$$i = 1,\dots,m$$

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:

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

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:

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

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:

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

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:

$$\beta_j^i = \theta_j^i = \psi^i = 0 \qquad \begin{array}{c} i = 1,\dots,m \\ j=1,\dots,m \\ i \neq j \end{array} \qquad \text{(equation 15)}$$

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.

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:

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

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

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

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 surveys 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 questionnaire was developed and pre-tested in order to collect the required data for methodology testing and validation. 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, along with information on groundwater quality and well's characteristics, as well as water management practices used on the farm.

V. AN EMPIRICAL CASE STUDY OF WHEAT PRODUCTION IN IRAQ

A. WHEAT PRODUCTION IN IRAQ

Wheat is the first most important crop among all cereal crops. Data in table 1 indicates that total production of wheat peaked during the 1990's, reaching 1.2 million tons. During this period, wheat production under irrigated conditions reached its highest level of 742.4 thousand tons whereas the production of rainfed farming peaked during the 1970's, reaching 795.5 thousand tons. Similar pattern was experienced in planted area of wheat, where planted area of rainfed farming peaked to 1.284 million hectares during the 1970's, while the planted area of irrigated farming peaked to 748.4 thousands hectare during the 1990's. The total planted area of wheat in Iraq peaked during the 1970's, reaching 1.51 million hectares.

Wheat yield was the highest (0.794 ton/hectare) during the 1990's for national average. It was the highest (1.576 tons/hectare) during the 1970's for irrigated farming whereas wheat yield for rainfed farming peaked during the 1980's, reaching 0.614 ton/hectare. For the three decades, 1970-2000, yield of national average for wheat did not exceed 0.747 ton/hectare although the average yield of irrigated farming was 1.258 tons/hectare. This is mainly attributed to the low yield level (0.597 ton/hectare) of the rainfed farming which dominates most of the wheat plantations.

The contribution of rainfed farming to total wheat production was the highest during the 1970's and 1980's. Rainfed farming accounted for 85 per cent of each of the total area planted with wheat and 70-75 per cent of total wheat production during the two decades (table 2). The contribution of irrigated farming has increased since then, accounting for 47 per cent of the total wheat area and 63 per cent of the total wheat production during the 1990's.

On average, rainfed farming's contribution to total wheat production during the last three decades (1970-2000) was 58 per cent, also accounting for 74 per cent of the area planted with wheat. Wheat production actually experienced sharp seasonal fluctuations during the last three decades, mainly due to fluctuations in crop yield. Most of the fluctuations in total wheat production and in yield could be explained by the fluctuations in the production and in the yield of rainfed farming systems owing to their dependence on volatile weather conditions.

The changes in wheat production, area and yield over time are presented by trend analysis in table 3. The planted area experienced a downward trend for the whole country in general and for the agro-ecological zones in particular during the 1970's. The growth rates were –0.5 per cent, -3.0 per cent, and –1.0 per cent for rainfed, irrigated and the whole country, respectively. Similarly, yield and production demonstrated a downward trend during the same period. The yield and production of rainfed areas experienced the highest downward trending of –7 per cent each annually. This in return decreased wheat yield and production at the national level by -5.0 per cent and –6.0 per cent, respectively. The downward trend of planted area, yield and production continued throughout the 1980's and 1990's for the rainfed areas.

On the contrary, planted area, yield and production of wheat under irrigated farming experienced upward trend during the 1990's (8 per cent, 3 per cent and 10.5 per cent, respectively). This resulted in the positive growth rates in yield and production of wheat at the national level during the 1990's.

During the entire three decades (1970-2000), rainfed farming experienced a downward trending in the planted area, yield and production of wheat. On the other hand, during the same period, the irrigated areas experienced an upward trending in planted area and production of wheat (5 per cent and 4 per cent annually). At the national level, yield and production of wheat experienced positive growth rates of 0.3 per cent and 0.2 per cent, respectively whereas planted area experienced a negative growth of -0.5 per cent during the last three decades. The marginal upward trend in wheat production at the national level is mainly attributed to the expansion in the area planted with wheat under irrigated conditions.

TABLE 1. AREA, YIELD AND PRODUCTION OF WHEAT IN IRAQ, 1970-2000

Period/Item	Rainfed farming	Irrigated farming	Total for Iraq
1970-1979			
Area (000 hectares)	1284.4	216.8	1501.1
Yield (kg/hectare)	604	1576	742
Production (000 tons)	795.5	347.2	1142.7
1980-1989			
Area (000 hectares)	1052.5	179.3	1232
Yield (kg/hectare)	614	1088	701
Production (000 tons)	657.1	218.9	876
1990-2000			
Area (000 hectares)	748.4	667.4	1415.8
Yield (kg/hectare)	574	1120	794
Production (000 tons)	435.8	742.4	1178.2
1970-2000			
Area (000 hectares)	1019.4	364.6	1389.4
Yield (kg/hectare)	597	1258	747
Production (000 tons)	623.2	446	1069.2

Source: Ministry of Agriculture, Department of Agricultural Planning, various issues.

TABLE 2. CONTRIBUTION OF RAINFED AND IRRIGATED FARMING TO TOTAL WHEAT PRODUCTION IN IRAQ, 1970-2000

	Area (per cent)		Production (per cent)	
Period	Irrigated	Rainfed	Irrigated	Rainfed
1970-1979	15	85	30	70
1980-1989	15	85	25	75
1990-2000	47	53	63	37
1970-2000	26	74	42	58

Source: Calculated by the authors from data presented in table 1.

B. SUPPLEMENTAL IRRIGATION PROJECTS IN IRAQ

In 1991, a supplemental irrigation project (the North Al-Jazeera Irrigation Project) was launched in order to serve approximately 60,000 hectares of arable land, by using a linear-move sprinkler irrigation system. The North Jazeera Irrigation Project (Rabiah) is fed by the Tigris River via a large submerged pumping station located inside the reservoir of a large dam.

Winter crops occupy, under supplemental irrigation, about 80 per cent of the project's cultivable land. In the summer, however, the percentage cropped area is limited to only 30 per cent. Wheat is the major winter crop, covering 73 per cent of the project area. Other winter crops are barley, lentils, and potatoes, which cover 3, 1.5, and 2.5 per cent of the area, respectively. During the summer, tomato is the major crop, occupying 22 per cent of the project. Other summer crops include spring potatoes (5.5 per cent), sugar beet (1.0 per cent), and vegetables (1.5 per cent).

Recently, a new development project on "The Dissemination of Improved Irrigation Technologies" was introduced into the farming systems of Iraq, particularly in rainfed areas. The target has been to plant up to 0.5 million hectares of wheat under supplemental irrigation by the year 2007. Currently, there are about 3,500 new farms in the Mosul province under supplemental irrigation with an average size of holding of 25 hectares per farm.

TABLE 3. SOURCES OF GROWTH RATES IN WHEAT PRODUCTION IN IRAQ, 1970-2000 (PER CENT)

Period/Item	Rainfed area	Irrigated area	Total for Iraq
1970-1979			
Area	-0.5	-3.0	-1.0
Yield	-7.0	-1.0	-5.0
Production	-7.0	-4.0	-6.0
1980-1989			
Area	-5.0	4.0	-3.0
Yield	-2.0	-4.0	-0.4
Production	-7.0	3.0	-3.0
1990-2000			
Area	-7.0	8.0	-1.0
Yield	-4.0	3.0	2.0
Production	-11.5	10.5	0.4
1970-2000			
Area	-3.0	5.0	-0.5
Yield	-1.0	-1.0	0.3
Production	-4.0	4.0	0.2

Source: Calculated by the authors from data presented in table 1.

Note: These estimates were calculated from the specified components (items) on a linear time trend. The original data were transformed into logarithms. The average annual growth rate refers to the estimated coefficient of time in the corresponding regression equation.

C. DATA AND WHEAT YIELD OF THE SAMPLE FARMS

The data was collected from a cross-sectional survey of 284 farms in 20 districts in the Ninavah province in Northern Iraq during the 2001-2002 seasons. A stratified random sampling technique was used by containing farmers not overlapping with the farmers in other districts. Then, proportional allocation procedure was applied to determine the sample size for each district (Schaeffer, et al., 1979). Taking into consideration the type (center-pivot sprinkler system and solid-set sprinkler system) and origin (country where the irrigation technology manufactured and/or imported from) of irrigation technologies used by farmers, a representative sample of 284 farms were selected, all using supplemental irrigation in wheat production. Since some farmers grow more than one variety in their fields, each variety was taken as a separate observation, meaning that a farmer who plants two varieties is counted to be two observations. Accordingly, the total number of observations is 318. Among the sample farms, 148 farmers (46.5per cent of the sample) are using center-pivot sprinkler systems, which are mainly imported from Saudi Arabia, and 170 farmers (53.5 per cent of the sample) are using solid-set sprinkler system to irrigate wheat fields.

Yield data were recorded according to the type and origin of irrigation technology (table 4). Nearly 47 per cent of the farmers use center-pivot sprinkler systems, which produce an average yield of 3.08 tons/hectare. Meanwhile, over 53 per cent of the sample farms use solid-set sprinklers to irrigate wheat. Those farmers produce an average yield of 2.91 tons/hectare.

The yield levels of wheat under farmers' conditions is tabulated from the sample farms and presented in table 5. The most frequent yield level achieved among wheat producers was less than 3.0 tons/hectare. The yield of nearly 42 per cent of the producers was more than 3.0 tons/hectare, among which 20 per cent of the farmers achieved an average yield level of 4.8 tons/hectare. Likewise, 14 per cent of the producers achieved an average yield of 3.26 tons/hectare. About 30 per cent of the farmers produced in the lower tail of yield distribution of less than 2 tons/hectare. Meanwhile, some 28 per cent of the farmers produced within the yield interval of 2.001- 3.00 tons/hectare. The overall yield level for all producers was 2.9 tons/hectare, much above the historical yield level of less than one ton per hectare in the province.

TABLE 4. WHEAT YIELD ACCORDING TO THE TYPE AND ORIGIN OF IRRIGATION TECHNOLOGY

Type and origin	Farmers (%)	Yield (tons/hectare)
Center-pivot sprinklers		
Al-Khraif- Saudi Arabia	41.2	3.077
Asaidan- Saudi Arabia	5.3%	3.084
All Center-pivot	46.5	3.08
Solid-set sprinklers		
Algeria	23.9	2.97
Italy	5.0	2.89
Austria	0.6	3.4
Turkey	4.7	2.48
Egypt	11.3	2.81
France	3.8	2.75
Iraq	4.1	1.52
All solid-set	53.5	2.99
All types	100	2.91

Source: Calculated from farm survey data of the study.

TABLE 5. DISTRIBUTION OF SAMPLE FARMS ACCORDING TO YIELD LEVELS

Yield interval (tons/hectare)	Average yield (tons/hectare)	No. farmers	Percentage of farmers (%)
<= 1.0	0.87	6	2
1.001-1.50	1.21	32	10
1.501-2.00	1.81	57	18
2.001-2.500	2.35	36	11
2.5001-3.00	2.85	54	17
3.001-3.500	3.26	44	14
3.501-4.00	3.70	26	8
>4.00	4.78	63	20
Total	2.90	318	100

Source: Calculated from farm survey data of the study.

Variety is an important source of yield variation among wheat producers. Data in table 6 show that improved varieties (Waha, Um Rabia, IPA 99, Sham 3) gave higher yield levels than the local variety, Abu-Ghraib. This has an important implication for increasing the average yield level under supplemental irrigation as majority of farmers grew high-yielding improved wheat varieties. The other important consideration is that durum wheat varieties give higher yield level of 3.1 tons/hectare compared to that of bread-wheat varieties of 2.8 tons/hectare. The improved variety, Um Rabia, gave the highest yield level of 3.4 tons/hectare among all improved varieties. This variety is planted by nearly 13 per cent of the sample farmers.

D. IMPACT OF SUPPLEMENTAL IRRIGATION ON WHEAT YIELD AND WATER PRODUCTIVITY

Supplemental irrigation, like any other new technology, may change the optimal levels of inputs used, and thus the productivity. The profitability of adopting new irrigation technologies will depend on how large the productivity improvement is (Lin, 1994). Thus, information on the effect of new irrigation technologies on productivity is crucial for the potential diffusion of technology among farmers. A new technology will not be accepted by farmers unless it raises productivity. The data in table 7 examine the extent of productivity increase due to the introduction of improved irrigation technology. The results indicate that wheat yield under supplemental irrigation of 2.93 tons/hectare is higher than that under rainfed conditions of 1.28 tons/hectare. In other words**,** the total impact of supplemental irrigation is an increase of wheat yield by 128 per cent as compared to rainfed farming.

TABLE 6. YIELD OF SAMPLE FARMS ACCORDING TO VARIETIES

Variety	Type	Average yield (tons/hectare)	Farmers (per cent)
Waha	Durum Wheat	3.01	24.2
Abu-Ghraib	Bread Wheat	2.42	21.4
Um Rabia	Bread Wheat	3.40	12.6
IPA 99	Bread Wheat	3.05	7.9
Sham 3	Durum Wheat	2.84	5.4
Other varieties	Durum/Bread	2.94	28.6
All bread varieties		2.77	52.0
All durum varieties		3.08	48.0
All varieties		2.92	100

Source: Calculated from farm survey data of the study.

It is important to note that supplemental irrigation has more impact on increasing the wheat yield of bread varieties as compared to durum varieties. Supplemental irrigation has increased yield of bread wheat varieties by more than 100 per cent whereas the contribution to the yield of durum wheat varieties ranged between 58 and 81 per cent. This may be attributed to the biological characteristics of the varieties or the scheduling of irrigation water. In conclusion, supplemental irrigation has actually increased land productivity considerably.

TABLE 7. IMPACT OF SUPPLEMENTAL IRRIGATION ON WHEAT PRODUCTIVITY

Variety	Yield under supplemental irrigation (tons/hectare)	Yield under rainfed (tons/hectare)	Increase (per cent)
Waha	3.01	1.66	81
Abu-Ghraib	2.42	1.20	102
Um Rabia	3.38	1.64	106
IPA 99	3.05	1.27	140
Sham 3	2.84	1.80	58
Other varieties	2.94	1.60	84
All varieties	2.93	1.28	128

Source: Calculated from farm survey data of the study.

Of great interest to policy makers at various levels is the issue of the impact of supplemental irrigation on water productivity. The data in table 8 compare water productivity under supplemental irrigation and rainfed conditions. The results show that supplemental irrigation has increased water productivity for all varieties, except for Sham 3. Water productivity increased the most (63 per cent) for IPA 99 variety. The impact of supplemental irrigation on water productivity of bread wheat varieties is higher than that of durum wheat varieties. Water productivity of bread wheat varieties was increased by 32 per cent as a result of using supplemental irrigation whereas water productivity of durum wheat varieties was increased by only 15 per cent owing to the use of supplemental irrigation. For all wheat varieties, the impact of supplemental irrigation is an increase in water productivity by 31 per cent.

The use of supplemental irrigation has greatly increased land and water productivity; however, in the production of wheat under supplemental irrigation more inputs (such as fertilizers) are used as compared to rainfed conditions, and thus it is difficult to decide whether the land- and water- yield advantages are totally attributed to the use of supplemental irrigation and associated technologies.

TABLE 8. IMPACT OF SUPPLEMENTAL IRRIGATION ON WATER PRODUCTIVITY

Variety	Water Productivity (kg/m^3)		Increase (per cent)
	Rainfed	Supplemental Irrigation	
Waha	0.49	0.61	24
Abu-Ghraib	0.43	0.53	23
Um Rabia	0.50	0.62	24
IPA 99	0.41	0.67	63
Sham 3	0.55	0.49	-11
All durum varieties	0.52	0.60	15
All bread varieties	0.44	0.58	32
All varieties	0.45	0.59	31

Source: Calculated from farm survey data of the study.

Productivity (output per unit of input) is usually measured by index numbers. However, the index numbers impose restrictions on the form of the underlying production function, priori. The Laspeyres index, for example, assumes that the production function is linear, implying perfect substitution among all inputs in the production process. To avoid this restrictive assumption, Ball (1985) derived revised indices for productivity from a flexible multi output-multi input representation of the production function of the form translog transformation function. However, the translog function is constrained by constant returns to scale. This is a restrictive assumption, which lacks empirical evidence to be imposed as a priori on wheat production in northern Iraq. Moreover, the multi-colinearity problem among variable inputs is always evident in the translog function. As a result, it gives lower values for the estimates of t-test for many variables in the function.

These two difficulties may discourage the use of the index number approach for studying the impact of supplemental irrigation technology on total factor productivity. Instead, a frequently used method for estimation is the Cobb-Douglas function approach due to its ease of estimation and interpretation (Lin, 1994). An appropriate technique for assessing the impact of supplemental irrigation on productivity is the regression analysis. The impact of the supplemental irrigation on total factor productivity is estimated by adding a dummy variable to the function. The production function estimated here has the following form:

$$\text{Ln } Q = B_0 + B_1 \text{ Ln } X_1 + B_2 \text{ Ln } X_2 + B_3 \text{ Ln } X_3 + B_4 \text{ Ln } X_4 + B_5 \text{ Ln } X_5 + B_6 \text{ Ln } X_6 + B_7 D_1 + B_8 D_2 + B_9 D_3 + B_{10} D_4 + B_{11} D_5 + B_{12} D_6 + V$$

Where, Q is total wheat production for each farm (tons); Bi's are the parameters to be estimated.

X_1 is total planted area per farm (hectares)
X_2 is total amount of seed per farm (tons)
X_3 is total amount of pesticides per farm (tons)
X_4 is total amount of fertilizers per farm (tons)

X_5 is total Machinery per farm (hours)
X_6 is total labor per farm (hours)

D_1 is a dummy variable for Waha variety, taking a value of 1 for Waha and zero otherwise; D_2 is a dummy variable for IPA 99 variety, taking a value of 1 for IPA 99 and zero otherwise; D_3 is a dummy variable for Um Rabia variety, taking a value of 1 for Um Rabia and zero otherwise; D_4 is a dummy variable for Sham 3 variety, taking a value of 1 for Sham 3 and zero otherwise; D_5 is a dummy variable for other varieties, taking a value of 1 for other varieties and zero otherwise; D_6 is a dummy variable for supplemental irrigation, taking a value of 1 if the farmers applied water and zero otherwise

V is a residual term to capture the effect of other variables not directly included in the model.

The Abu-Ghraib variety is always taking a zero value as a base local variety, to measure the impact of improved varieties on wheat productivity under supplemental irrigation. The production function was estimated by using the OLS procedure. The estimated coefficients are presented in table 9.

TABLE 9. ESTIMATED COEFFICIENTS OF WHEAT PRODUCTION FUNCTION

Independent variables	Function (1): before correction	Function (2): after correction
Intercept	-1.625 (-1.89)	-0.867 (-2.66)**
Ln Land (hectares)	0.247 (1.28)	0.422 (2.53)**
Ln Seed (kg)	0.167 (0.94)	0.251 (1.96)*
Ln Pesticides (kg)	0.025 (1.62)	0.038 (2.77)**
Ln Fertilizers (kg)	0.035 (3.09)**	0.002 (0.26)
Ln Machinery (hr)	0.537 (4.54)**	0.299 (2.40)**
Ln Labor (hr)	-0.028 (-0.53)	0.029 (0.56)
Waha dummy variable (0,1)	0.189 (2.94)**	0.165 (2.86)**
IPA 99 dummy variable (0,1)	0.128 (1.45)	0.189 (2.56)**
Um Rabia dummy variable (0,1)	0.361 (4.85)**	0.241 (3.56)**
Sham dummy variable (0,1)	0.232 (2.43)**	0.143 (1.72)
Other varieties dummy (0,1)	0.185 (3.21)**	0.150 (3.04)**
SI dummy variable (0,1)	0.653 (11.64)**	0.646 (8.84)**
R-Square	0.83	0.85
Adjusted R-Square	0.83	0.85
D-W test	1.03	2.03
F-test	195.07**	233.05**

Note: Numbers in parentheses refer to the calculated t-test.
*, ** Significant at 5 per cent and 1 per cent levels of significance, respectively.
SI= Supplemental irrigation.

The value of the coefficient of multiple determination (R-Square) indicates that the explanatory variables included in the model explain 85 per cent of total variation in wheat production. The supplemental irrigation variable has more effect on wheat production, and its estimated coefficient is significant at 1 per cent level of significance. Other variables of significant influence on wheat production are planted area, seed, machinery and improved varieties.

Among the potential econometric problems of multicollinearity, heteroscedasticity, and autocorrelation, only the latter was found to be of harmful nature. Thus, the original data was corrected for the problem of autocorrelation by using the “generalized difference” approach and then by using the corrected data the production function was re-estimated. The approach involves the regressing of the dependent variable on the independent variables in the difference form, which is obtained by subtracting a coefficient of autocorrelation of the value of a variable in the previous time period from its value in the current time period (Gujarati, 1988).

The estimated coefficients of the dummy variables measure the shift in the intercept of the production function due to the corresponding improved varieties or supplemental irrigation.

The estimated coefficient of the supplemental irrigation dummy variable of 0.646 (function 2) indicates that wheat productivity under supplemental irrigation is 91 per cent higher than that of rainfed conditions. That is, given the same level of inputs, the yield advantage of the use of supplemental irrigation over rainfed farming is about 91 per cent. This is the magnitude of the upward shift in the wheat production function resulting from the use of supplemental irrigation. Similarly, the estimated coefficients of the dummy variables of improved variables measure the net impact on wheat yield as compared to the local variety, Abu-Ghraib.

The coefficient of Um Rabia dummy variable of 0.241, for example, implies that the yield advantage of Um Rabia variety over the local variety is 27 per cent under supplemental irrigation. In other words, under the same input levels, the improved variety Um Rabia increases wheat productivity by 27 per cent as compared to the local variety, Abu-Ghraib, supporting the conclusion that the use of improved varieties results in higher wheat productivity as compared to the local varieties under supplemental irrigation. Similar conclusions can be drawn from the estimated coefficients of the dummy variables of other improved varieties.

Yield comparison of wheat producers under supplemental irrigation and rainfed conditions reveals that supplemental irrigation increases wheat productivity by 128 per cent as compared to rainfed farming. This total impact of supplemental irrigation on wheat productivity reflects the combined effect of other variables, as well. The production function, however, gives a net impact of increasing wheat yield by 91 per cent as a result of using the supplemental irrigation technology. The net impact is totally attributed to the use of supplemental irrigation. The difference of 37 per cent, between the total impact and net impact, is attributed by other variables not used under rainfed conditions.

E. MODEL ESTIMATION AND EMPIRICAL RESULTS

All data collected from a farm survey, conducted in the Ninavah province in Iraq during the 2001-2002 season, include information on wheat production, input use, output and input price variables and water management practices. The survey also includes questions on crop-level acreage, irrigation technology, soil information, water sources, rainfall, annual water budget and on-farm irrigation practices. Collected information indicates that all farmers grow wheat as their only or principal crop for their livelihoods. Among the sample farms, only 3 producers grow barley, 12 farmers plant potato, 3 farmers produce sunflowers, and 4 producers grow sugar beet. Accordingly, water allocation equations were estimated only for wheat, as there was not enough number of observations to study water allocation decisions for other crops.

Several quantitative and qualitative independent variables are formed from the survey data. The quantitative variables include irrigated area planted in wheat (hectares), price of wheat (ID/kg), amount of total water available to the farm (m^3), amount of rainfall (mm), prices of variable inputs, such as labor wage (ID/hour), and water cost (ID/hectare/year). Water cost is calculated after taking into account all direct and indirect costs related to water application. These costs include fuel cost, repairs and maintenance, labor wages (both family and hired labor), annual depreciation. The annual depreciation is calculated using the fixed approach (of 10 years) on the costs of irrigation systems, ponds, well digging, pumping machines, transportation cost, and installation. An annual interest rate of 8 per cent is applied, as well.

The set of qualitative variables includes dummy variables on water limitation (taking a value of 1 if the amount of water available to the farm is limited, and zero otherwise), irrigation technology (taking a value of 1 if the irrigation technology is center-pivot sprinkler system and zero for solid-set sprinkler system), land tenure (taking a value of 1 if the land is privately owned and zero otherwise), and water source (taking a value of 1 if the water source is groundwater and zero otherwise).

Having specified and quantified related variables, the second step involved the estimation of models following methodology for on-farm water-use. The three specified models of the fixed-allocatable input model, variable input model and the behavioural model are estimated using the ordinary least squares procedure (ESCWA and ICARDA, 2000 and 2001). Three sets of out-of-sample forecasts are made. 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 procedure is repeated three times (Moore et al., 1994a and 1994b). The estimated models are presented in tables 10 to 12.

TABLE 10. ESTIMATES OF ON-FARM WATER-USE IN NINAVAH PROVINCE:
FIXED-ALLOCATABLE INPUT MODEL

Independent variables	Simulation 1	Simulation 2	Simulation 3	All sample simulation
Intercept	138.28 (0.04)	-864.48 (-0.19)	-1441.97 (-0.32)	-809.31 (-0.21)
Wheat irrigated area (hectares)	663.06 (7.26)**	690.50 (6.59)**	756.89 (7.14)**	745.74 (8.24)**
Price of wheat (ID/kg)	3.18 (0.15)	14.94 (0.59)	21.13 (0.82)	11.79 (0.53)
Total amount of water available to the farm (m3)	0.74 (24.25)**	0.67 (18.65)**	0.65 (20.53)**	0.67 (22.78)**
Irrigation technology (0,1)	-5618.46 (-3.03)**	-4016.79 (-1.94)*	-5152.35 (-2.52)**	-4934.53 (-2.73)**
Labor wage rate (ID/hr)	-26.57 (-4.55)**	-24.76 (-3.33)**	-31.24 (-4.36)**	-25.54 (-4.02)**
Water limitation (0,1)	-248.71 (-0.15)	-899.39 (-0.42)	-1163.83 (-0.56)	-824.14 (-0.46)
R-Square	0.88	0.83	0.85	0.85
Adjusted R-Square	0.88	0.83	0.84	0.85
F- Statistic	306.93**	200.58**	218.14**	292.22**

Note: Numbers in Parentheses refer to the calculated t-statistic.
*, **: Significant at 5% and 1% levels of significance, respectively.

The estimates provide some insights toward the selection of appropriate water-use model. The estimated water-use models are actually the derived factor demand functions for water. This has important implications on the expected signs of estimated coefficients of price variables in that the relationship between irrigation water and its price is negative. Whereas, the relationship is positive between the quantity of water demanded and the output price (which is the price of wheat in this case). Accordingly, the consistency of the signs of the estimated coefficients with the economic theory is a prerequisite condition for the model selection.

In the fixed-allocatable input model all estimated coefficients have the correct signs, supporting their plausibility and consistency with economic theory and a priori information. Irrigation technology, total quantity of water available to the farm, irrigated wheat area and labor wage rate appear to be a strong and significant determinants of farmers decisions on the amount of water applied to wheat.

Table 11. Estimates of on-farm water-use in Ninavah province: variable input model

Independent variables	Simulation 1	Simulation 2	Simulation 3	All sample simulation
Intercept	3572.02 (0.52)	3240.19 (0.51)	-1742.03 (-0.26)	2240.61 (0.37)
Wheat irrigated area (hectares)	994.44 (7.23)**	1083.91 (8.49)**	1260.09 (9.11)**	1039.55 (8.30)**
Price of wheat (ID/kg)	-3.79 (-0.09)	-8.73 (-0.24)	17.63 (0.46)	3.10 (0.09)
Irrigation technology (0,1)	19927.56 (7.09)**	18544.78 (7.01)**	14662.98 (5.22)**	18948.77 (7.45)**
Water cost (ID/hectare)	0.027 (2.26)*	0.03 (2.13)*	0.02 (2.16)*	0.03 (2.36)*
Water Source (0,1)	1732.97 (0.83)	588.73 (0.31)	2340.82 (1.11)	1567.30 (0.83)
R-Square	0.61	0.65	0.61	0.60
Adjusted R-Square	0.60	0.65	0.61	0.60
F- Statistic	73.53**	90.44**	76.32**	91.88**

Note: Numbers in Parentheses refer to the calculated t-statistic.
*, **: Significant at 5% and 1% levels of significance, respectively.

Table 12. Estimates of on-farm water-use in Ninavah province: behavioural model

Independent variables	Simulation 1	Simulation 2	Simulation 3	All sample simulation
Intercept	13576.41 (2.24)*	10960.79 (1.95)*	13585.41 (2.04)*	10464.51 (1.88)**
Wheat irrigated area (hectares)	1055.08 (7.83)**	1249.76 (9.76)**	875.23 (5.90)**	1047.66 (8.36)**
Irrigation technology (0,1)	16024.45 (6.03)**	16172.03 (6.74)**	20764.85 (7.19)**	17789.95 (7.40)**
Land tenure (0,1)	4911.96 (2.18)*	2721.48 (1.36)	6183.64 (2.62)**	4717.51 (2.37)**
Rainfall (mm)	-39.60 (1.85)*	-31.09 (-1.58)*	-38.11 (-1.65)*	-28.60 (-1.48)*
R-Square	0.61	0.67	0.59	0.60
Adjusted R-Square	0.60	0.66	0.58	0.60
F- Statistic	92.21**	122.25**	85.28**	115.02**

Note: Numbers in Parentheses refer to the calculated t-statistic.
*, **: Significant at 5% and 1% levels of significance, respectively.

Although wheat price has the correct positive sign, its effect on the amount of water applied is not significant. Similarly, water limitation has the correct negative sign, implying that as the amount of water available to the farm is limited, farmers reduce the amount of applied water to wheat. 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 in the water demand equation of wheat under the fixed-allocatable input model. This result suggests that producers perceive irrigation water as a fixed input in the short run.

In contrast, in the variable input model, water cost (as a proxy variable for water price or water valuation) is not negative for wheat demand equation for water. The water price (water cost) variable actually has the incorrect (positive) sign in the variable input model, indicating that after planting the crop, producers do not respond to water price in subsequent short-run decisions. This result suggests that the major impact on the amount of water applied to wheat under the variable input model is originated through irrigation technology and land allocation decisions, as both irrigation technology and wheat irrigated area appeared to be the only two determinants of farmers' decisions on the amount of water applied to wheat. Once cropland is allocated, the level of water price appears not to have a major quantitative impact on profit; otherwise, water price variable would be a significant determinant of short-run water-use. This conclusion is further supported by the fact that water in the study area is available to farmers free of charge, and thus water prices have no major influence on the amount of water allocated to wheat.

The behavioural model, on the other hand, provides good representation to the water-use decisions according to the estimated coefficients. For this model, irrigation technology, acreage allocation, land tenure and rainfall have the correct signs and significantly influence the producers' decisions on the amount of water applied to wheat. Farmers of privately owned land use more irrigation water for wheat compared to other types of land tenure. In line with common practices, farmers reduce the amount of water applied when the rainfall increases. In comparing the fixed-allocatable input model with the behavioural model, the former provides better goodness of fit (which is measured by the coefficient of determination) than the latter. The estimated coefficient of determination (R-Square) of the fixed-allocatable input model of 0.85 is much superior than that of the behavioural model of 0.60, justifying the selection of the fixed-allocatable input model.

In conclusion, the fixed-allocatable input model explains producer decisions on the short-run water-use better than the variable input model (Moore et al., 1994a and 1994b). This model handles more complex 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 farmers. Meanwhile, groundwater is subject to fixed pumping capacity in the short run. The three estimated models are compared with respect to the prediction accuracy measures and the results of comparisons further justify the choice of the fixed-allocatable input model.

F. MODEL VALIDATION

The three alternative models are compared in this section, using prediction accuracy measures as a means of model validation. Four sets of forecasts are made, including one in-sample prediction and three out-of-sample predictions. Out-of-sample forecasts for wheat water-use are made and compared with the actual on-farm water applications. Three measures of prediction accuracy are used to judge the performance of alternative models and thus provide evidence on the model choice. Hence, the Mean Absolute Error (MAE), the Root Mean Square Error (RMSE), and the Mean Absolute Percentage Error (MAPE) are calculated to compare the models of on-farm water-use for wheat.

A detailed presentation of the calculated measures is shown in table 13. Applying the three measures to each one of the one in-sample prediction and the three out-of-sample predictions generates twelve cases for evaluating the alternative models for wheat and provides evidence on a model choice. With the in-sample prediction, the fixed-allocatable input model out-performs the two alternative models (the variable input model and the behavioural model) according to each of the three measures of prediction accuracy. The results of out-of-sample predictions demonstrate a similar pattern of performance, under which the fixed-allocatable input model outperforms the other two according to the three measures of prediction performance, MAE, RMSE and MAPE.

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 those of the behavioural model for both in-sample and out-of-sample predictions. Accordingly, the 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 by wheat producers than the variable input model and the behavioural model.

TABLE 13. PERFORMANCE OF ESTIMATED MODELS IN PREDICTING ON-FARM WATER-USE IN NINAVAH PROVINCE

Type of models	Mean Absolute Error (MAE)	Root Mean Square Error (RMSE)	Mean Absolute Percentage Error (MAPE)
Fixed-allocatable input model			
In-sample predictions	5443.54*	8688.25*	0.419*
Out-of-sample predictions			
Simulation 1	6552.26	12143.18	0.585
Simulation 2	4383.40	7215.08	0.420
Simulation 3	5228.63	7322.61	0.285
Average (Simulations 1-3)	5388.09*	8893.62*	0.43*
Variable input model			
In-sample predictions	9381.34	14294.82	0.652
Out-of-sample predictions			
Simulation 1	10324.02	14289.17	0.656
Simulation 2	10906.98	18579.16	0.816
Simulation 3	9126.52	15345.21	0.425
Average (Simulations 1-3)	10119.17	16071.18	0.632
Behavioural model			
In-sample predictions	9622.36	14302.77	0.687
Out-of-sample predictions			
Simulation 1	10181.31	15991.29	0.475
Simulation 2	12417.71	19491.15	0.989
Simulation 3	8278.61	11714.26	0.610
Average (Simulations 1-3)	10292.54	15732.23	0.691

* Indicates the model that most accurately predicts short-run water-use for a given accuracy measure and experiment.

As a result of the estimated coefficients and the application of the prediction performance measures, it can be concluded that the fixed-allocatable input model is a better model to study on-farm water-use by wheat producers. As the fixed-allocatable input model performs best in explaining short-run water-use, it needs additional description. The estimates of table 10 reveal the following points:

(a) The value of the coefficient of multiple determination (R-Square) indicates that the model performs well in explaining crop-level water-use for a cross-sectional data. The estimated R-Square is 0.85, implying that nearly 85 per cent of the variation in the amount of water applied to wheat is explained by the independent variables included in the estimated equation. The estimated water demand equation for wheat under the fixed-allocatable input model is significant at the 1per cent level of significance;

(b) Labor wage rate appears to be a strong determinant for short-run decisions on water-use for wheat. An increase in the labor wage rate by one Iraqi Dinar, holding other variables constant, will decrease water-use for wheat by 25.54 m^3. This result has important implications for wheat producers as the labor demand is highly inelastic under rainfed conditions, and thus a small increase in the demand for labor will increase labor wage rate considerably which in return will reduce the amount of water applied for wheat;

(c) The estimate of the water constraint variable (total amount of water available to the farm) indicates the allocation of a marginal increase in farm-level water availability for wheat producers. The individual estimated coefficient of the water constraint of 0.67 shows that for a one m^3 increase in the availability of water to the farm, 0.67 m^3 of it will be used mainly for wheat production. This implies that almost two-third of the incremental water is added to wheat production;

(d) Irrigation technology has an important and a significant impact on the amount of water-use in wheat production. The use of center-pivot sprinkler technology reduces the amount of water-use by 4934.53 m^3 per farm compared to the use of solid-set sprinkler technology. The estimated coefficient of the variable of the irrigation technology is negative and significant at the 1 per cent level of significance. Similarly, if farmers perceive water available to the farm as limited, they will reduce the use of water for wheat production by 824 m^3 per farm;

(e) Planted area under supplemental irrigation is a strong and highly significant determinant of the amount of water applied for wheat production. The estimated coefficient of irrigated area implies that increasing wheat area by one hectare will result in increasing the water-use by 745.74 m^3.

G. ON-FARM WATER-USE EFFICIENCY

For the purpose of this study, on-farm 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 (including the amount of rainfall). The target production level for wheat is the yield of the sample farms. To obtain the required amount of water to produce the average yield levels, the estimated water demand equation with the fixed-allocatable input model is used. This is done by calculating the amount of water required for each individual farmer at the levels of the independent variables appearing in the demand equation. The calculated levels of required water are compared with the actual amount of water-used for each individual farmer.

The results are summarized in table 14. Of the total wheat farmers, 80 per cent of them have on-farm water-use efficiency of less than one, indicating that these farmers over-irrigate their wheat crop. Meanwhile, the water-use efficiency of 20 per cent of the farmers is greater than one, implying that these farmers under-irrigate wheat crop by 10 per cent. The overall water-use efficiency for the whole sample is 0.77, which is less than one, indicating that the wheat producers over-irrigate their crop by 23 per cent.

TABLE 14. ON-FARM WATER-USE EFFICIENCY IN WHEAT PRODUCTION IN NINAVAH PROVINCE

Level of WUE	Percentage of farmers (%)	Average WUE
<= 0.50	4	0.34
0.51-0.75	20	0.64
0.75-1.0	56	0.87
> 1.0	20	1.10
Total	100	0.77

Source: Farm survey data plus results of the fixed-allocatable input model.

TABLE 15. EFFECT OF FARM SIZE ON THE EFFICIENCY OF WATER-USE IN WHEAT PRODUCTION IN NINAVAH PROVINCE

Farm size (hectares)	Average farm size (hectares)	Farmers (%)	Average WUE
<= 10	6.7	51	0.77
10.1 - 20	15.5	25	0.81
> 20	29.1	24	0.72
Total	13.8	100	0.77

Source: Farm survey data plus results of the fixed-allocatable input model.

Among over-irrigating farmers, the water-use efficiency of 4 per cent of the farmers is estimated at 0.34, indicating that actual water-use exceeds required water-use by about 66 per cent. The water-use efficiency of 20 per cent of the farmers is 0.64, implying that this group over-irrigates its crop by 36 per cent. Meanwhile 56 per cent of the farmers having water-use efficiency of 0.87, actually over irrigate wheat crop by 13 per cent under current production levels. Farmers over-irrigate wheat crop because of their own perceptions of water requirements and their expectations of rainfall and market conditions.

Farm size is an important factor in explaining the variation in on-farm water-use efficiency among wheat producers. To demonstrate the impact of farm size on the efficiency of irrigation water-use, the results are re-tabulated in table 15. More than 50 per cent of wheat producers are small size farm holders of less than 10 hectares with an average size holding of 6.7 hectares. The water-use efficiency of small size farm holders is 0.77, implying that small farmers over-irrigate wheat production by 23 per cent. The water-use efficiency improves as the farm size increases. The water-use efficiency of medium farms (10.1 – 20 hectares) is 0.81. With the increase in farm size above 20 hectares the water-use efficiency decreases. The water-use efficiency of large farms is 0.72, indicating that large farms exceed water requirements by 28 per cent.

H. CONCLUSIONS AND RECOMMENDATIONS

The results obtained for the three models used in this study have important policy implications. The overall water-use efficiency for the sample farms is 77 per cent, indicating a potential for water-use efficiency by 23 per cent. The results by farm size, on the other hand, show that small, medium, and large farms have different potentials for improving their water-use efficiency by 23, 19 and 28 per cent respectively. However, each individual farm has a different potential for improving water-use efficiency ranging from a low of 13 per cent to a high of 66 per cent.

If policy makers encourage the design of appropriate technical as well as incentive packages, it would not be beyond their reach to capitalize on the potentials and improve water-use efficiency to the desired levels. By doing this, ample water will be available for productive use leading to increasing water productivity and improved agricultural productivity by producing more crop per drop.

Improvement in water management and irrigation as well as in technologies has the potential to optimize water-use efficiency as well as water productivity at the farm levels. Sound extension strategies and the provision of pertinent advice to farmers will be instrumental (a) in optimizing water-use efficiency as well as water productivity at the farm levels and (b) in reducing the adverse effects of salinization and water-logging on the productivity of land which are caused by over-irrigation. Thus, by obtaining optimal water-use efficiency, it is possible to increase wheat productivity in the study area while ensuring the sustainable use of resources, both water and land.

The methods of analysis used in this study are valid techniques for assessing on-farm water-use efficiency within the framework of multi-crop production systems. Results obtained are reliable and compare favorably with expert and technical recommendations. However, it is important to note that these results are only applicable to the study area and cannot be generalized at national and regional levels. The main difficulty encountered in such studies is the calculation of actual water-use, given the diversity at the farm levels with respect to source of water and irrigation technology.

Conducting of similar empirical studies using the same methods in different agro-ecological zones of Iraq are highly recommended in order to assess the current status of on-farm water-use efficiency for different crops and to determine the potential for improving water-use efficiency and to improve water and land productivity in Iraq, eventually producing more crop per drop.

When requested by any interested member state, ESCWA and ICARDA are capable of providing technical support in: (a) holding capacity building seminars on the methodologies of assessing on-farm water-use efficiency; (b) conducting farm surveys, data processing and analysis; and (c) drafting and publishing the empirical case studies on on-farm water-use efficiency.

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ملخص تنفيذي

تواجه المناطق الجافة لغرب آسيا وشمال أفريقيا تحديات خطيرة نتيجة لمحدودية فرص إيجاد مصادر مائية جديدة، يرافقها نمو متسارع في الطلب على المياه. وعليه، فان إدارة الموارد المائية أصبحت أحد أهم المواضيع الاقتصادية والاجتماعية لهذا القرن. وتبعا لذلك فأن توزيع المياه، نوعية المياه، نمو وتغير الطلب على المياه، التغيرات التكنولوجية، كفاءة استخدام المياه والجدوى الاقتصادية جميعها مواضيع هامة للمراكز البحثية وصانعي القرار على مختلف المستويات. وحيث ان الري يمثل ٨٠-٩٠ في المائة من إجمالي المياه المستهلكة في منطقة غرب آسيا وشمال أفريقيا، فأن تحسين كفاءة استخدام المياه في المزرعة سوف يؤدي الى زيادة عرض المياه للاستخدامات الأخرى.

تشير المعلومات المتاحة بأن موارد المياه النادرة أصلا في المنطقة تعاني من سوء إدارتها وضعف كفاءة استخدامها. ويرافق عدم جدولة مياه الري سوء توزيعها على الحقل انخفاض كفاءة الري، تاركا أجزاء من الحقل معرضة للكثير أو القليل من الماء مقارنة بحاجة المحصول. بالإضافة الى ذلك فأن مشغلي أنظمة الري لا يملكون أي حافز لتجهيز المزارعين بتوقيتات مثلى ودقيقة لجدولة الري لزيادة كفاءة استخدام المياه في المزرعة. كما أن المزارعين، من جانبهم، يميلون بشكل عام الى الهدر في استخدام المياه نتيجة لتصوراتهم حول احتياجات المحصول وتوقعاتهم لكمية الأمطار وقوى السوق. ومعظم البراهين المتوفرة في المنطقة حول كفاءة استخدام المياه مبنية بالأساس على التجارب البحثية لمحصول منفرد، وهذا لا يعكس بصورة دقيقة للقرارات الإنتاجية المعقدة تحت ظروف المزرعة لمختلف البيئات والتقنيات والظروف الاقتصادية. وقد تم مؤخرا إنجاز دراستين تطبيقيتين حول التقييم الاقتصادي لكفاءة استخدام المياه في المزرعة، من قبل المركز الدولي للبحوث الزراعية في المناطق الجافة "ايكاردا" واللجنة الاقتصادية الاجتماعية لغرب آسيا "الإسكوا". وهاتين الدراستين بينتا بوضوح النسب المنخفضة لكفاءة استخدام المياه في إنتاج المحاصيل، مشيرة بذلك الى ميل المزارعين للإفراط في ري محاصيلهم الزراعية. وقد تبين بأن المنهجية التي اعتمدت في تقييم حالة كفاءة استخدام مياه الري في المزرعة تصلح لإنجاز دراسات تطبيقية أخرى.

ان الهدف الرئيسي لهذه الدراسة هو تقييم كفاءة استخدام المياه لإنتاج القمح تحت ظروف المزارع في شمال العراق. في عام ١٩٩١ تم تنفيذ مشروع كبير للري التكميلي (مشروع ري الجزيرة الشمالي) من أجل تغطية حوالي ٦٠٠٠٠ (ستون ألف) هكتار من الأراضي الزراعية باستخدام أنظمة الري التكميلي المتحركة. وتم مؤخرا إدخال مشروع إنمائي (تنموي) جديد باسم "نشر تقنيات الري الحديثة" الى الزراعة العراقية وخاصة تحت الزراعة المطرية بهدف زيادة إنتاج القمح. ويستهدف هذا المشروع زراعة حوالي نصف مليون هكتار تحت الري التكميلي بحلول عام ٢٠٠٧. ويوجد حاليا في محافظة نينوى أكثر من ٣٥٠٠ مزرعة جديدة تحت الري التكميلي وبمعدل ٢٥ هكتار للمزرعة الواحدة. ويعتبر القمح المحصول الرئيسي الشتوي ويغطي أكثر من ٧٣ في المائة من مساحة المشروع. ولأغراض هذه الدراسة، فقد تم تعريف كفاءة استخدام المياه كونها تساوي نسبة الكمية المطلوبة من المياه لإنتاج مستوى معين من الناتج الى كمية المياه المستعملة فعلا (المضافة) من قبل المزارع. والمؤشرات المستخلصة حول كفاءة استخدام مياه الري في المزرعة ذات أهمية وفائدة كبيرة في توجيه السياسات المائية باتجاه تحسين كفاءة الري. ويعتبر تحسين كفاءة استخدام الري عامل حيوي لاستخدامه وتحسين إنتاج القمح في العراق الذي يعاني من فجوة غذائية كبيرة.

ان الكفاءة بشكل عام ترافق تحويل مورد ما الى ناتج. وان كلا من المفهوم الهندسي والزراعي يشكل الجزء الأكبر من الدراسات السابقة حول كفاءة واستخدام المياه. فالمفهوم الهندسي يعرف كفاءة الري على انها كمية المياه من مصدرها الرئيسي والتي بالإمكان تجهيزها في المنطقة الجذرية للنبات. بينما يعرف الزراعيون مفهوم كفاءة استخدام المياه للمحصول كونها جزء المياه المخزون في المنطقة الجذرية والمستخدم من قبل المحصول. وهذا المفهوم يتضمن كفاءة استخدام المياه للمحصول وإنتاجية المياه للمحصول. وان جمع المفهومين الهندسي والزراعي يعطي "كفاءة استخدام المياه" كونها النسبة بين الناتج (ملم) الى كمية المياه المجهزة (ملم)، بينما تعرف إنتاجية المياه كونها تساوي النسبة بين الإنتاجية (كغم) الى كمية المياه المجهزة (ملم).

وهذه المفاهيم تعكس المقاييس الفنية للكفاءة، وبذلك فانها غير كافية لتقييم المستوى الاقتصادي لكفاءة استخدام المياه. وان الكمية الكفوءة اقتصاديا من المياه تعتمد على الأسعار النسبية للمياه والموارد الأخرى، النواتج الحدية للموارد، أسعار وكميات الموارد الأخرى وكمية مياه الأمطار. ولتناول هذا الوضع المعقد على مستوى المزرعة، فانه تم اعتماد مفهوم "كفاءة استخدام المياه في المزرعة". وقد تم تقييم كفاءة استخدام المياه في الزراعة من قبل ايكاردا والإسكوا باستعمال خمسة دراسات تطبيقية في سوريا والعراق والأردن ومصر. وهذه الدراسات التطبيقية تدعم فائدة هذا المفهوم في تقييم كفاءة استخدام المياه تحت ظروف المزارع وتوفر خيارات حيوية للتوفير في المياه. واستمرار لهذا الجهد فقد تم تنفيذ هذه الدراسة في العراق باستخدام بيانات مسح ميداني لعينة من المزارعين في مشروع الري التكميلي. وقد شملت العينة استبيان ٢٨٤ مزارعا في محافظة نينوى خلال الموسم ٢٠٠٢/٢٠٠١. وتوفر المؤشرات المقدرة عن كفاءة استخدام المياه معلومات هامة حول فرص توفير المياه من خلال استخدامه الكفوء.

تشير مقارنة بيانات إنتاجية القمح لمزارعي العينة الى أن الري التكميلي له تأثير أكثر على زيادة إنتاجية أصناف القمح الطري مقارنة بأصناف القمح القاسي. حيث أدى الري التكميلي الى زيادة إنتاجية أصناف القمح الطري بأكثر من ١٠٠ في المائة، بينما ازدادت إنتاجية أصناف القمح القاسي بنسبة ٥٨-٨١ في المائة. وكخلاصة فان الري التكميلي أدى الى زيادة إنتاجية الأرض (وحدة المساحة) بشكل كبير جدا. كما أن أثر الري التكميلي على زيادة إنتاجية المياه يعتبر من المواضيع الهامة لصانعي القرار على مختلف المستويات. وقد أظهرت النتائج بأن الري التكميلي يؤدي الى زيادة إنتاجية المياه لكافة الأصناف. وقد ازدادت إنتاجية المياه لأصناف القمح الطري بنسبة ٣٢ في المائة كنتيجة لاستخدام الري التكميلي، بينما ازدادت إنتاجية المياه لأصناف القمح القاسي بنسبة ١٥ في المائة. ولجميع الأصناف فقد أدى الري التكميلي الى زيادة إنتاجية المياه لمحصول القمح بنسبة ٣١ في المائة.

مما تقدم نستنتج بأن الري التكميلي أدى الى زيادة إنتاجية الأرض والمياه بشكل كبير. وأظهرت مقارنة إنتاجية المزارعين تحت الري التكميلي والزراعة المطرية بأن استخدام الري التكميلي يؤدي الى زيادة إنتاجية القمح بنسبة ١٢٨ في المائة مقارنة بالزراعة المطرية. وهذا هو التأثير الكلي للري التكميلي على إنتاجية القمح، والذي يعكس التأثير المشترك لباقي العوامل، أيضا. وعليه فقد تم تقدير دالة إنتاج القمح لقياس التأثير الصافي للري التكميلي. حيث أشارت الدالة المقدرة الى أن التأثير الصافي هو زيادة إنتاجية القمح بنسبة ٩١ في المائة نتيجة لاستخدام تقنيات الري التكميلي والتأثير الصافي هذا يعود بالأساس الى استخدام الري التكميلي. وان الفرق بين التأثير الكلي والتأثير الصافي، والبالغ ٣٧ في المائة، يعود الى العوامل الأخرى التي لم تدخل إنتاج القمح تحت الزراعة المطرية ولكنها استخدمت تحت ظروف الري التكميلي.

ولدراسة كفاءة استخدام المياه في المزرعة فقد تم تقدير ثلاث نماذج هي نموذج المورد الثابت القابل للتوزيع، نموذج المورد المتغير، والنموذج السلوكي. وللتحقق من دقة النماذج المقدرة فقد تم احتساب ومقارنة بعض معايير قياس القوة التنبؤية، ومنها وبالإضافة الى المعلمات المقدرة فقد تمت المفاضلة بين النماذج الثلاث. وعليه يمكن الاستنتاج بأن نموذج المورد الثابت القابل للتوزيع هو أفضل نموذج لدراسة استعمال مياه الري في إنتاج القمح من قبل المزارعين. ومن هذا النموذج يمكن استخلاص المعلومات التالية:

(أ) تشير القيمة المقدرة لمعامل التحديد المعدل الى أن ٨٥ في المائة من التغاير في كمية المياه المضافة من قبل المزارعين لإنتاج القمح يعزى الى المتغيرات المستقلة الداخلة في الدالة وتشمل مساحة القمح، سعر القمح، معدل أجور العمل وكمية المياه الكلية المتاحة للمزرعة، تقنية الري ومدى توفر المياه للمزارع بصورة كافية. وكانت دالة الطلب على المياه المقدرة تحت نموذج المورد الثابت القابل للتوزيع معنوية بمستوى معنوية ١ في المائة؛

(ب) يعتبر العمل عامل محدد قوي لقرارات المزارع في الأجل القصير. فزيادة أجر العمل بمقدار دينار واحد، مع ثبات المتغيرات الأخرى، سوف يؤدي الى تقليل كمية المياه المضافة بمقدار ٢٥,٥٤ م^٣ للمزرعة الواحدة. ولهذه النتيجة تطبيقات هامة لمنتجي القمح لأن الطلب على العمل غير مرن تحت الظروف المطرية، وعليه فان زيادة صغيرة في الطلب على العمل سوف يؤدي الى رفع أجور العمل وبالتالي تقليل كمية المياه المضافة في إنتاج القمح؛

(ج) يشير متغير محدد المياه (كمية المياه الكلية المتاحة للمزرعة) الى كيفية توزيع المزارعين لأي زيادة محدودة (حدية) في كمية المياه المتاحة للمزرعة. ان المعلمة المقدرة لمحدد المياه والبالغة ٠,٦٧ تشير الى زيادة كمية المياه المتاحة بمقدار ١ م^٣ يؤدي الى استخدام ٠,٦٧ م^٣ منها لإنتاج القمح بالدرجة الأساس؛

(د) لتقنية الري أثر معنوي على كمية المياه المستخدمة في إنتاج القمح. حيث يؤدي استخدام المرشات المحورية الى تقليل كمية المياه بمقدار ٤٩٣٤,٥٣ م^٣ للمزرعة الواحدة مقارنة باستخدام المرشات الثابتة. وبالتالي اذا أدرك المزارعون ان كمية المياه المتاحة للمزرعة محدودة، فسوف يقللون من استعمال المياه في إنتاج القمح بـ ٨٢٤ م^٣ للمزرعة؛

(•) للمساحة المزرعة تحت الري التكميلي أثر قوي ومعنوي على كمية المياه المضافة في إنتاج القمح. فان المعلمة المقدرة لهذا المتغير تشير الى أن زيادة المساحة المزروعة بالقمح هكتار واحد سوف يؤدي الى زيادة استخدام المياه بمقدار ٧٤٥,٧٤ م^٣ كمعدل لكافة مزارعي العينة.

كما تشير تقديرات كفاءة استخدام المياه في المزرعة الى أن ٨٠ في المائة من منتجي القمح يهدرون استخدام الري. في حين أن كمية المياه المضافة من قبل ٢٠ في المائة من المزارعين هي أقل من الكمية المطلوبة بنسبة ١٠ في المائة. وكان معدل كفاءة استخدام المياه لعينة البحث حوالي ٧٧ في المائة، مما يعني بأن هناك هدر في استعمال مياه الري بنسبة ٢٣ في المائة. أي أن ٢٣ في المائة من كمية المياه المضافة تفوق الكمية المطلوبة لمستويات الإنتاج المتحققة لدى مزارعي العينة. ويعتبر حجم المزرعة أحد العوامل الهامة في تفسير الاختلاف في كفاءة استخدام المياه بين المزارعين اذ أن أكثر من ٥٠ في المائة من منتجي

القمح هم مزارعين صغار يبلغ معدل حجم مزارعهم حوالي ٦,٧ هكتار. وقد بلغت كفاءة استخدام مياه الري للمزارعين الصغار حوالي ٠,٧٧ أي أن هناك هدر باستخدام المياه بنسبة ٢٣ في المائة.

وتتحسن كفاءة استخدام المياه بازدياد حجم المزرعة، حيث بلغت كفاءة استخدام المياه للمزارعين ذوي الحيازات المتوسطة الحجم (١٠,١-٢٠ هكتار) حوالي ٠,٨١. وعند ازدياد حجم المزرعة الى أكبر من ٢٠ هكتار، فان كفاءة استخدام المياه تنخفض. حيث بلغت كفاءة استخدام المياه للمزارع الكبيرة حوالي ٠,٧٢. مشيرة بذلك بأن المزارع الكبيرة تفوق الاحتياجات المائية بنسبة ٢٨ في المائة. وعليه فان المزارعين الصغار والمتوسطين أكثر كفاءة في استخدام مياه الري التكميلي في إنتاج القمح. ولهذه النتائج تطبيقات هامة لاقتصاديات الحجم تحت ظروف الري التكميلي.

وللنتائج أعلاه تطبيقات هامة لأغراض السياسة الزراعية، حيث يوجد هناك إمكانية لتحسين كفاءة استخدام المياه بنسبة ٢٣ في المائة على مستوى العينة ككل. وتختلف إمكانية التوفير في المياه باختلاف حجم المزرعة وبواقع ٢٣ في المائة ، ١٩ في المائة و٢٨ في المائة للمزارع الصغيرة والمتوسطة والكبيرة، على التوالي. ولكل مزارع توجد هناك إمكانية لتحسين كفاءة استخدام المياه وبنسب تتراوح بين ١٣ في المائة و٦٦ في المائة. فاذا ما قام صانعي القرار بتشجيع استخدام حزمة تقنية متكاملة للري التكميلي من الجوانب الفنية والاقتصادية، فان بالامكان توفير كميات كبيرة من المياه للأغراض الإنتاجية. وهذا يقود الى زيادة إنتاجية المياه وتحسين الإنتاجية الزراعية من خلال إنتاج كمية أكبر من القمح بنفس كمية المياه أو تقليل كمية المياه المستخدمة لنفس كمية الإنتاج المنتجة فعلا.

ان التحسين في إدارة المياه والري واستخدام التقنيات له إمكانية في تحقيق المستويات المثلى لاستخدام المياه في المزرعة. وهنا تلعب السياسات الإرشادية وتوفير المعلومات والنصيحة للمزارعين دورا هاما في بلوغ المستويات المثلى لكفاءة استخدام المياه في المزرعة وتقليل التأثيرات العكسية للتملح وتغدق المياه على الإنتاجية، المتأتية من الهدر باستخدام المياه. وعليه، ومن خلال تحقيق المستويات المثلى لكفاءة استخدام المياه، فان بالإمكان زيادة إنتاجية القمح في منطقة الدراسة مع ضمان الاستخدام لموردي المياه والأرض.

وتعتبر المنهجية التي اعتمدت في هذه الدراسة طريقة ناجحة لدراسة وتقييم كفاءة استخدام المياه في المزرعة لأنظمة إنتاج المحاصيل المتعددة. وتأتي هذه النتائج متطابقة مع التوصيات الفنية وتقديرات الخبراء. ولكن من الأهمية الإشارة الى أن هذه النتائج تنطبق على منطقة الدراسة ولا يمكن تعميمها على المستويين الوطني والإقليمي. وان الصعوبة الرئيسية في مثل هذه الدراسات هو احتساب كمية المياه المستخدمة فعلا من قبل المزارعين بضوء اختلافهم من حيث مصدر المياه وتقنية الري المستخدمة والعوامل الأخرى.

ان إنجاز مثل هذه الدراسات التطبيقية في مناطق بيئية مختلفة من العراق باستخدام هذه المنهجية يعتبر من التوصيات الهامة لهذه الدراسة من أجل تقييم الواقع الحالي لكفاءة استخدام المياه لمختلف المحاصيل ولتحديد إمكانية تحسين كفاءة استخدام المياه وزيادة إنتاجية المياه والأرض في العراق، وبالتالي إنتاج ناتج أكثر بنفس كمية المياه.

وعند الطلب من أي من البلدان الأعضاء، فان اللجنة الاقتصادية والاجتماعية لغرب آسيا والمركز الدولي للبحوث الزراعية في المناطق الجافة مستعدان لتوفير الدعم الفني في: (أ) تنظيم حلقات دراسية لبناء القدرات الوطنية في منهجية تقييم كفاءة استخدام المياه في المزرعة؛ (ب) تنفيذ مسوحات ميدانية، ومعالجة البيانات وتحليلها؛ (ج) كتابة ونشر الدراسات التطبيقية الميدانية حول كفاءة استخدام المياه في المزرعة.