

Informing Policy Development for Sustainable and Productive Food Production Systems in Dry Areas

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Introduction

Despite remarkable growth in agriculture in the past 50 years, the world still faces a critical challenge: how to feed a population expected to reach nine billion by the year 2050. The goal for the agricultural sector is no longer simply to maximize productivity, but to optimize across a complex landscape of production, rural development, environmental, social justice and food consumption outcomes (Pretty et al., 2010). In dry areas, where water is the most limiting factor, achieving this goal will require coordinated action on several issues. First, to optimize the use of scarce water resources while continuing to increase food production. Second, to develop national, regional and international policies that support the development of more productive and sustainable food production systems. Third, to narrow the (widening) gap between potential and actual yields, i.e. what is possible using available technology versus what farmers are actually harvesting. Fourth, to diversify farming and systems, with intensive but sustainable production methods.

Policy makers are convinced that dryland agriculture – with generally low yields, large yield gaps and huge potential for improvement – holds the key to future food security. This was reflected in a statement by the President of India, Smt. Pratibha Patil, when she visited ICARDA headquarters in November 2010: “Dryland farming is of great importance for global food security as well as for a second Green Revolution in India.” This paper focuses on dryland agriculture, and specifically on water, the major limiting factor in dry areas

This paper examines a number of related issues. It begins with an overview of food security, water resources for agriculture, and the implications of climate change. It then reviews some empirical studies on water-saving technologies, sources of inefficiency in water use, and quantification of benefits. This is followed by a discussion on policy and related factors, including the processes and framework by which researchers can inform the development of agricultural policy. A section on conservation agriculture describes research results from ICARDA and the Australian experience. The concluding section revisits some policy aspects in light of the preceding discussion.

2. Food Security: Some Broad Issues

How can more food be produced sustainably? Opportunities for bringing more land under cultivation are extremely limited. In the future, production growth must come mainly from productivity growth. For example, it is estimated that 80% of the required increase in food production between 2015 and 2030 has to come from intensification (FAO, 2011). We must work to increase potential yield (maximum yield with the best varieties and agronomy, with constraints

removed) and simultaneously to close the yield gap (the difference between potential and actual yields).

2.1. Food prices and the poor

Higher and more volatile food prices are a major cause for concern, particularly in developing countries, where populations spend 50-80% of their income on food, compared to <15% of disposable income in developed countries (Austin, 2010). One study estimated that the 2008 spike in food prices significantly reduced the purchasing power of poor people in developing countries, e.g. by up to 32% in Arab countries (Shideed, 2008).

Higher prices will stimulate greater investments in food production, but smallholder farmers are often slow to respond to price incentives, because of various factors. Empirical studies in six countries showed that limited response by smallholders to the 2007-2008 increases in cereal prices, was due to water scarcity and institutional and policy factors such as unavailability of credit, inputs and information; export restrictions and price controls (Khouri et al., 2011).

There is a likelihood of more frequent commodity price spikes in the years ahead, due to increased volatility in commodity markets, more direct coupling of food and energy markets, and increased incidence of extreme weather events linked to climate change (Austin, 2010). Another factor is biofuels, whose production has trebled since 2000 and is projected to double again within the next decade. Liquid biofuels represent only 0.2% of energy consumption, but account for 7% of coarse grain use and 9% of vegetable oil consumption (Austin, 2010). Recent studies suggest that real prices of maize and oilseeds will increase by 26 % and 18% in 2020 as a result of biofuels production; and that at least one-third of agricultural land may be converted from food production to the production of crops used in ethanol production (Austin, 2010).

2.2. Water resources and climate change

Water is the single most binding constraint to agriculture in dry areas. Per capita water availability in West Asia and North Africa, for example, is less than 2000 m³. Large areas have annual rainfall below 100 mm per year. Extraction rates are mostly unsustainable; groundwater levels continue to fall, while salinization levels are increasing. Most countries in the region will drop below the internationally defined “water scarcity” level in the near future.

The era of abundant, cheap, and safe water is disappearing. In some developing countries two out of five women still walk long distances each day to collect water (Catley-Carlson, 2011). Because water is not valued, farmers and users tend to abuse and overuse this scarce resource. The second problem is that because water is not valued, people are reluctant to pay for it. As a result water is inefficiently used and thus is subject to huge losses in both domestic and agricultural sectors. Most irrigation systems are less than 50% efficient. Farmers who get water free or for little cost have no incentive to reduce their usage with water-saving technologies (Catley-Carlson, 2011).

In all regions, except Europe and North America, agriculture is by far the biggest user of water, accounting for about 69% of all global withdrawals (FAO, 2001). By implication, water-saving technologies for agriculture would have fundamental impacts on conservation of the global resource base.

Climate change will have significant effects on agriculture. The standard circulation models show that much of the world’s dry areas will be severely affected by climate change. Large parts of West Asia and North Africa will experience at least 20% decrease in rainfall, and up to 50% in many areas. Declines in rainfall will directly translate into reduced production, and necessitate changes in cropping patterns, and agricultural production.

Climate change will also increase risk, because extreme events (droughts, floods, temperature spikes) are predicted to increase in frequency and magnitude. Greater variability will compound the problems of dry areas, where variability is already high. Developing countries will

be hard hit, particularly countries in West Asia and North Africa, South Asia and Sub-Saharan Africa with extensive dry areas. These countries are highly dependent on agriculture, not only for food security but also for employment and economic growth. The International Food Policy Research Institute has projected that as a result of climate change, global wheat production would be reduced by 47%, rice by 27%, and maize by 13% in 2050 under irrigated conditions (Rosegrant, 2011).

In developing countries with large dryland areas, countries, there is usually a close correlation between GDP growth and rainfall, because of agriculture-dependent economies with limited diversification. The persistent association between rainfall and GDP growth in Ethiopia is a striking example of the vulnerability of rainfed agriculture-based economies to climate change (The World Bank, 2009).

3. Approaches to Ensuring Food Security

Most developing countries face formidable challenges in ensuring food security: rapid population growth, biophysical constraints, insufficient policy and institutional support, market factors, poor technology adoption, and others. Addressing these challenges will require coordinated efforts by different groups: researchers, policy makers, development organizations, etc. This section discusses a few of the many technology-related issues to be considered while developing food security initiatives.

There is a level of consensus among development organizations on the approaches needed to increase land and water productivity in order to ensure food security. The Asian Development Bank, for example, notes this can be achieved only through integrated system approach: investing in modern irrigation infrastructure and technologies; adopting enabling policies that enhance the adoption and impact of improved water management practices and price water resource at their opportunity cost; and strengthening institutions for more efficient and sustainable management of water (ADB, 2010).

3.1. Closing the yield gap

The yield gap is the difference between potential and actual yield achieved on-farm. Actual yield are of the order of 60% of potential, as documented in different farming systems: irrigated rice in south-east Asia, rainfed wheat in Central Asia, rainfed cereals in Argentina and Brazil (Godfray et al., 2010). Yield gaps are due to a number of factors that may be technical, economic (relating to markets or investment capacity), information-related etc. The yield gap is not static. Both potential and actual yields will change with time, as new technologies or new constraints develop.

Strategies designed to close the yield gap in the poorest countries face some particular challenges relating to small landholding size, the dominant role of women in the agricultural workforce, lack of secure land tenure, remote location etc. Closing the yield gap involves not just transferring known technologies and practices to farmers, but “putting in place the institutional structure -- especially well-functioning input and output markets, access to finance, and ways to manage risk -- that farmers need to adopt the technology” (Keating et al., 2010).

3.2. Sustainable intensification of production systems

The FAO defines sustainable intensification of production systems as “producing more from the same area of land while reducing negative environmental impacts and increasing contributions to natural capital and the flow of environmental services”. This approach is emerging as a major priority for policy makers, and international development partners. The Asian Development bank (ADB, 2010) identified three main constraints to agricultural growth: land and water shortages; lack of access to rural finance, infrastructure, technology, markets and distribution networks, and nonfarm income opportunities; and threat of climate change and price volatility. The ADB’s operational plan for Asia and the Pacific addresses each of these issues.

3.3. The concept of eco-efficiency

Producing more food per unit of land, water and other resources is essentially the concept of 'Eco-efficiency' which encompasses both the ecological and economic dimensions of sustainable agriculture (Keating et al., 2010). It opts for more agricultural output (both quantity and quality) with less input of land, water, nutrient, energy, labor or capital. This is a major challenge for agriculture in future in achieving such eco-efficiency while addressing the risk and variability. "The agricultural revolution over the next 40 years has to be the eco-efficiency revolution, with 50 to 100% increases in the efficiency with which resources of land, water, nutrients, and energy are used. Importantly, this greater output and efficiency has to be achieved without further greenhouse gas emissions while maintaining or restoring land, water, biodiversity, and agro-ecosystems" (Keating et al., 2010).

Agricultural research is the main source for developing the technologies and practices that can shift "eco-efficiency" while keeping risks low by shifting the efficiency frontier. Social and economic systems and institutions are the necessary conditions whereby improved technologies and practices can be embedded with constant or declining production risks. **Food security involves both closing the yield gap and breakthrough technologies and practices to raise yield potential and increase efficiency of resource use** (Keating et al., 2010).

3.4. Integrated approaches

Dryland farming systems are complex, with inter-dependent and interacting components – including crops, livestock, forestry and fish, with livelihoods supported by various, and seasonally changing, farm and off-farm sources of income. Past experience has shown that narrowly focused (e.g. commodity based) research is unlikely to develop successful technologies for these systems. A proposed new multi-partner program, led by ICARDA, will use an integrated, multi-disciplinary approach that fully takes these complexities into account.

The CGIAR Research Program on Dryland Systems (Integrated Agricultural Production Systems for the Poor and Vulnerable in Dry Areas) aims to develop technology, policy and institutional innovations to improve rural livelihoods. Research and capacity development activities encompass crop, livestock and natural resources technologies, markets, policy, and gender and equity issues. The proposed program will target five dryland regions: West African Sahel and dry savannas, East and Southern Africa, North Africa and West Asia, Central Asia, and South Asia. In each of these regions, research will be structured under four themes:

- Strengthening innovation systems, building stakeholder innovation capacity, and linking knowledge to policy action
- Reducing vulnerability and managing risk (technologies, institutional options)
- Sustainable intensification for more productive, profitable and diversified dryland agriculture with well-established linkages to markets
- Measuring impacts and cross-regional synthesis

The program design clearly identifies two types of farming systems that may require different technology 'mixes: vulnerable systems (e.g. subsistence farming with severe resource limitations) where the primary objective is to reduce risk and increase resilience; and better favored systems (smallholder systems with potential for intensification and market access) where the goal is to increase productivity.

The program brings together the full range of stakeholders: farming communities, national research and extension systems, policy makers, international and regional organizations, advanced research institutes, NGOs, the private sector, and development agencies. Research will be conducted at pilot sites in each target region, with emphasis on community participation in design, implementation and monitoring of interventions.

The aims are to prioritize key agricultural systems for impact, identify key researchable issues within target agro-ecosystems, increase the efficiency and sustainability of natural resource use, develop more resilient agricultural systems to manage risk and production variability, promote conservation and sustainable use of dryland agrobiodiversity, improve the productivity and profitability of agricultural systems through sustainable intensification, diversification, value-added products and market linkages, identify niches of importance to the most vulnerable livelihoods (even if they appear to have low marketing potential), address constraints faced by the most marginal farmers, and develop new partnerships and models of working together.

4. Water Saving Technologies

Water-efficient technologies such as improved irrigation methods are crucial for both rainfed and irrigated areas; this paper focuses mainly on rainfed areas. There is a wealth of literature on available, proven technologies, and on the sources of inefficiency in irrigation water use.

4.1. On-farm water use efficiency

Water-use efficiency can be measured in different ways such as irrigation efficiency (amount of water from the main water source which can be effectively supplied to the root zone), or crop water-use efficiency (the fraction of water transpired by the crop to that stored in the root zone). But technical measures of efficiency are not sufficient to assess the economic use of water. The economic efficiency of water use depends on the relative prices of water and other inputs, the marginal products and prices of the inputs, and the amounts of other inputs, including rainfall. At farm level, this is referred to as on-farm water-use efficiency (FWUE), defined for the purpose of this analysis as the ratio of the required amount of water for a target production level to the actual amount of water used. The resulting indicators of FWUE are very useful in guiding policies toward improving irrigation efficiency.

Irrigation accounts for 80-90% of water consumption in the WANA region. Thus, small improvements in FWUE can substantially improve water availability. 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 FWUE. Farmers generally over-irrigate as a result of their perceptions of water requirements and their expectations of rainfall and market values.

Six empirical studies on economic assessment of FWUE in agriculture, jointly conducted by ICARDA and the UN Economic and Social Commission for Central and West Africa, demonstrate the low ratios of water-use efficiency in crop production. Six case studies were conducted in the Syrian Arab Republic, Iraq (two studies), Jordan and Egypt (two studies).

To assess the efficiency of on-farm water use, three specified models, namely, the fixed-allocatable input model, variable input model and the behavioral mode (Just et al., 1983, 1990; Chambers and Just, 1989; Moore et al., 1994a,b). The models were used to determine the amount of water required by each crop in the six study areas. Results of the estimated coefficients and calculated indices of FWUE reveal the following (Shideed, et. al., 2005):

- When the amount of water required for the crops was compared with actual amount used, it was found that there was over-irrigation for all crops and in all the study areas. FWUE for wheat, for example, was found to be 0.61 in Radwan (Syria), 0.37 in Rabea (Iraq), 0.65 in Nubaria and Beni Sweif (Egypt), and 0.77 in Ninawah (Iraq). These estimates indicate that farmers over-irrigated wheat by 20–60%. It is, therefore, possible, without losing yield, to save an enormous amount of water which can be used to expand wheat area, or to produce other crops.

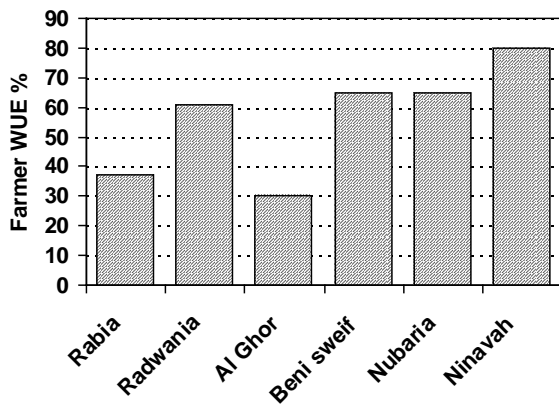


Figure 1. Wheat FWUE (%) in selected areas in West Asia and North Africa

- Estimates of FWUE under full irrigation provide important information on the efficiency of water use in producing competing crops. Cotton FWUE was estimated at 0.75 in Radwanian and Beni Sweif, reflecting relatively high water-use efficiency compared to other crops produced in these two areas. However, cotton producers exceeded crop requirements by nearly 25%, an amount that could be saved if farmers were provided with extension recommendations to rationalize the use of scarce water. Likewise, FWUE of two forage crops, bersem and corn, produced under full irrigation in Egypt was estimated at 0.72–0.76, suggesting high water-use efficiency in the production of these two crops. These estimates are higher than those of competing crops -- 0.55 for faba bean and 0.64 for sunflower -- produced under similar conditions in Egypt.
- The estimates of FWUE for cereal, industrial, and vegetable crops indicate a wide gap between required and actual water application, i.e. high potential for saving water. These results are consistent with the findings of a recent FAO study which concluded that water productivity seems to be lowest in water-scarce regions of agriculture-based economies (Bazza and Ahmed, FAO, 2002).
- Producers perceive water as a fixed input in the short run, but allocatable among competing crops on the farm. The analysis shows that increases in water availability are allocated most heavily to crops with relatively higher requirements, like cotton, tomato, potato, sugar beet, and bersem, rather than to crops with relatively low water requirements, such as wheat and barley
- Output prices and planted areas appear to be strong determinants of water allocation in the short-run among competing crops. After planting crops, producers do not respond to water prices in making subsequent short-run decisions. Since water prices in the study areas were highly subsidized, they did not have a major quantitative impact on water allocation. Land allocation, crop choice, irrigation technology and output prices are the main determinants of multi-crop water-use decisions. Previous studies show that water demand is inelastic at low price changes (Fraiture and Perry, 2002). Because water prices are very low in WANA, consumption of irrigation water can be reduced only by large increases in water charges – but this will greatly reduce farmer income in the short run.

4.2. Improving water use efficiency

The typical irrigation method at the field level in many countries is a surface gravity system, generally associated with low efficiency and high seepage and evaporation losses. For example, water use efficiency (the ratio of the amount of water actually utilized by the crop to the total water pumped) for irrigated agriculture in Syria is 40–60% (MunlaHasan, 2007). Traditional surface irrigation methods also lead to over-irrigation and/or uneven irrigation, especially when field drainage is poor.

A recent ICARDA study (Yigezu et al., 2011b) measured output oriented technical efficiency, irrigation water efficiency, and assess the reduction in water use inefficiency due to the adoption of modern irrigation methods (particularly sprinklers) for supplementary irrigation of spring wheat in Syria. It used market and non-market valuation methods to measure the economic and environmental impacts of the shift from traditional supplemental irrigation (TSI) to improved supplemental irrigation (ISI) of wheat farms in zones 1 and 2 of the Aleppo, Deraa and Al-Hassakah provinces in Syria.

At the low level of its current adoption on wheat farms in the three provinces (22.3%), ISI helps to conserve at least 120 million m³ of water per year. The combined impact of ISI with sprinkler technologies is estimated at US\$ 8.96 million per year. Introducing a water user charge of US\$ 0.20 for every cubic meter applied in excess of the recommended application rate of 1800 m³ can ensure adoption of ISI by all farmers leading to further conservation of at least 46 million m³ of water per year (Yigezu et al., 2011a). Such a policy not only promotes groundwater conservation but also increases the productive value of water and farm profits.

4.3. Benefits of supplemental irrigation

Supplemental irrigation (SI) is an important technology for boosting food production and food security. Supplemental irrigation is understood by most farmers as the use of irrigation in addition to rainwater – regardless of the amount applied. In its true essence, SI involves the application of irrigation only when rainfall is inadequate, with the amount and timing carefully scheduled to ensure that a minimum amount of water is available during critical stages of crop growth (Oweis, 1997). SI in low rainfall areas not only increases yield relative to purely rainfed production, but also substantially improves the productivities of both irrigation and rainwater (Oweis and Hachum, 2004). To avoid confusion, we distinguish between improved supplemental irrigation (ISI), in which the recommended water application rates are used and traditional supplemental irrigation (TSI) where farmers use excessive irrigation rather than the recommended levels.¹

Several studies have been conducted to estimate the impacts of SI. For example, El-Shater (2009), Bader (2010), Shideed et al. (2005), Adary et al. (2002) and Salkini and Ansell (1992) reported almost two-fold increases in wheat yield with the use of SI and related technologies relative to solely rainfed crops. Water use efficiency measurements in West Asia and North Africa revealed that wheat yield under rainfed conditions ranges from 0.35 to 1.0 kg per m³ of water (Oweis and Hachum, 2009). In comparison, ISI with appropriate management and optimal irrigation produces an additional 2.0 to 3.5 kg of grain per m³ of ISI, compared to solely rainfed wheat (Ilbeyi et al., 2006).

A recent case study (Yigezu et al., 2011a) surveyed 513 farms in two areas (Zones 1 and 2) in Aleppo, Deraa and Al-Hassakeh governorates in Syria, which together produce 61% of the country's wheat. Table 1 shows the profile of the sample farm households. Some of the findings are described below.

¹ Scheduling of SI is determined for each year using the water balance method. For instance, in zones 1 and 2 of Syria, which are the study areas for this research, optimum yields were obtained with SI of 600 to 1800 m³/ha. Hence, in this analysis, we used the higher end (1800 m³) as the upper limit for the amount of water applied under ISI

Table 1: Profile of the sample farm households in terms of irrigation method and water use

	Zone 1	Zone2	Total
Traditional irrigation			
Households using the practice (%)	34	70	53
Average water used m ³ per ha	2554	2744	2686
Average yield (mg/ha)	5384	4892	5040
Sprinkler irrigation			
Households using the practice (%)	66	30	47
Average water used m ³	1852	1910	1869
Average yield (kg/ha)	5840	5460	5733

Note: Some farmers who use surface irrigation methods are applying less than 1800m³/ha while some farmers who use sprinklers apply excessive irrigation water (>1800m³/ha).

Water was valued at the value marginal product. The values of marginal products at the profit maximizing levels of inputs should be equal to factor price. The marginal value product of water for sample farms is estimated at US\$ 0.13.

The marginal product of water varies depending on the type (TSI or ISI) and method (surface or sprinkler) of irrigation. Generally, ISI and sprinklers lead to higher marginal products (MP) of water than TSI and surface canals, respectively.

ISI consumes less irrigation water than TSI, and also saves fuel and other costs associated with pumping groundwater. Most of the pumps in Syria use diesel fuel. Adoption of ISI saves an estimated 49.8 million liters of diesel per year, worth about US\$ 20 million in the three provinces.

The net effect of the shift from TSI with canals to ISI using sprinklers for the individual adopter is a US\$ 235.5/ha increase in annual profit. The total profit gained by all farmers adopting ISI with sprinklers (18% of total farms) in the three provinces is estimated at US\$ 4.7 million per year. The adoption of ISI at the current adoption level of 22% in the three provinces has led to a total annual increase in farm profits of US\$ 9.0 in 2010. In terms of economic and social costs and benefits, even if the conserved water is used wastefully for TSI with open surface canal, the introduction of ISI in the three provinces still has a clear overall positive impact.

Despite the obvious benefits of ISI, TSI is still practiced by 78% of wheat farms with an average irrigation water application rate of 2600 m³/ha. What can the government do to encourage adoption? One possibility is to introduce water user charges. Under the existing conditions where farmers do not pay any water user charges, the profit maximizing application rate for surface canal users is 2375 m³/ha which is 12% lower than the current average (2686 m³/ha). This shows that these farmers are applying unnecessarily too much irrigation. Water user charges of US\$ 0.11 or higher per m³ would force surface canal users to reduce their application rate to the recommended level (1800 m³ of irrigation water). However, at this water user charge, the profit maximizing rate of irrigation water application for sprinkler users is 2075 m³/ha which is still higher than the recommended level. The minimum water user charge that would force sprinkler users to reduce their application rate to the recommended level is US\$ 0.20/m³. Hence, if the government were to impose this level of water user charge for every cubic meter applied in excess of the recommended 1800 m³/ha, all farmers in Zones 1 and 2 of Syria will be compelled to apply the recommended level regardless of their irrigation technology.

Given the rapid depletion (2- 6 m per year in some areas), conservation of groundwater is a priority for the Syrian government. Substantial amounts of groundwater could be conserved by introducing user charges for every cubic meter of irrigation water applied in excess of 1800 m³/ha (the upper limit of the recommended application range). Such a policy would also increase total farm profits by US\$ 16.14 million per year. The total impact of introducing the optimal water user charge of US\$ 0.20/m³ ranges between US\$ 36-90 million per year. However, introduction

of water user charges in Syria, and other dryland countries, could be very sensitive as nearly one-third of wheat production area in the country depends on supplemental irrigation.

4.4. Technical and irrigation efficiencies

Traditional surface irrigation methods, involving canals and field furrows, lead to over-irrigation and/or uneven irrigation, especially in the absence of land leveling and good drainage. A stochastic frontier production and efficiency model was estimated using a sample of 385 farms to analyze the technical, irrigation water, and irrigation water technical cost efficiencies among wheat farms in zone 1 and zone 2 of Aleppo Governorate in Syria.

The estimated output oriented technical efficiency measures show high efficiency differential among the farms ranging from 47% to 98% with a mean value of 78% (Table 2). By more efficient utilization of inputs, with current technology, the average farmer can increase yield by 22%. Generally, irrigation water efficiency turns out to be lower than technical efficiency but has very high variability across farms. The mean irrigation water efficiency of 69% shows that everything else constant, a farmer with the average irrigation water efficiency can reduce the amount of water by 31% with no loss of yield, only by adjusting the input mix (Yigezu et al., 2011b).

Table 2. Estimates of technical, irrigation and cost efficiencies under supplemental irrigation of wheat farms in Syria, 2010

Irrigation method	N	Technical efficiency (%)	Irrigation water efficiency (%)	Irrigation water technical cost efficiency (%)
Surface	186	70	66	89
Improved	142	89	75	91
Total Farms	328	78	69.9	89.9

The mean irrigation water technical cost efficiency is estimated at 89.9% indicating that by making more efficient utilization of irrigation water, the average farmer can reduce total cost by 10.2%. Even though the total cost reduction is not small in absolute value, it is small relative to the amount of irrigation water reduction that can be achieved (31%). This is because currently, there are no charges for pumping water from wells, so irrigation water and associated costs (including labor) account for only 35% of total cost of production.

Irrigation method is the most important variable explaining inefficiency in wheat production in the study area. Sample farms show substantial adoption rate (57%) of the sprinkler irrigation technology. After controlling for all other possible determinants of inefficiency in the stochastic frontier and inefficiency model, the efficiency differential between adopters and non-adopter can be attributed to the sprinkler technology. Farmers who use sprinklers, on the average, have 19% and 9% higher output oriented and irrigation water use efficiencies, respectively, than those using traditional surface irrigation method. However, even among the farmers who use the improved technology (sprinklers), there is still 25% gap in irrigation water efficiency which needs to be closed.

4.5. Water saving potential in irrigated systems

In irrigated agriculture, water savings can be generated by a combination of improved delivery systems and increasing on-farm water use efficiency. Studies in the Euphrates basin, for example, highlight the enormous potential, through improved irrigation technologies such as sprinkler and drip irrigation, and by improved management of existing irrigation systems and practices (SIWI, 2011). For example, improved management of current crops can increase WUE by 15-20%. Improved irrigation systems can increase WUE by 10-30% depending on the type of system.

Better delivery systems at farm level can give increases of 20%. Better delivery systems at community or regional level can give increases of 30%.

5. Informing Policy Development

Food security concerns have led to extensive policy debate, which has highlighted several issues (Solh, 2011). First, current agricultural policies in developing dryland countries are inadequate in general, and particularly ineffective in protecting the fragile natural resource base. Second, land degradation and water scarcity are occurring rapidly, both in marginal environments and in irrigated areas. Third, it is extremely hard to protect and conserve communally owned natural resources such as rangeland and water. Technology alone is not sufficient but must be supported by policy, community-led action and continuous monitoring. This underscores the crucial role of researchers in informing policy development. However, it must be noted that direct use of research results to fundamentally change policy is rare. Rather, the primary pathways by which decisions are shifted are often indirect, and involve improving general understanding of the context in which decisions are taken through “conceptual influence”. As a result, such influence is primarily indirect, and may involve a large number of intermediate adoption and diffusion events before new understanding contributes to a shift in policy (CGIAR, 2006).

Political-economic factors can be crucial, particularly for management of natural resources. Policy reform on natural resources will not happen unless researchers have fully taken these factors into account. Of course, providing policy makers with new research information is necessary, but not sufficient to foster adoption of such recommendations by politicians (Zilberman and Waibel, 2007).

In measuring the contribution of research to changes in policy, establishing causality from research to implementation of the policy is critical (Norton and Alwang, 1998). To establish policy influence, Ryan (1999) and Shideed et al. (2008) interviewed partners, stakeholders, and policy makers about their perception of how policy changes had taken place and the role of different institutions and information in the change.

Research that successfully influences policy can generate large impacts (e.g. Ryan, 1999, 2002). For example, ICARDA’s research on barley fertilization in rainfed areas in Syria led to a fundamental change in government policy on fertilizer allocation. Although some other policy distortions remained, the returns to research on barley fertilization were still substantial and consistent with an estimated rate of return to investments in research and dissemination of 70%, and a benefit-cost ratio of 35-41 (Ahmed et al., 2010; Shideed et al., 2008)

The Syria case also provided important lessons. Policy makers may only partially adopt research results or recommendations. It is vital that national partner institutions are involved in any policy-oriented research. Building mechanisms for leveraging policy influence in project design and implementation also helps address policy makers’ concerns, and increase the chances of success. Thus, understanding the impact pathway and identifying key partners along the pathway is a prerequisite for successful research-for-development.

6. Farmland Acquisition

There is an increasing trend of large-scale land acquisitions, where higher-income but natural resource-poor countries invest in agriculture in developing countries, producing food for export to the investing country. A detailed analysis is outside the scope of this paper; but the issue is raised here for two reasons: it represents a large and largely unstudied change in traditional farming systems, and there are major concerns as well as major opportunities relating to resource conservation and introduction of conservation agriculture and other innovations. A recent study (World Bank, 2011) highlighted, among others, the following issues:

- 1) None of the sub-Saharan African countries of most interest to investors is achieving more than 30% of potential yield on currently cultivated area. Thus, increasing productivity on existing farmland would have a much bigger impact than simply expanding the land area at current yields.
- 2) There is considerable scope for South-South exchange of good practice. When done right, large-scale farming can provide opportunities for poor countries with large agricultural sectors and ample endowments of land – but secure land rights and improved land governance are needed.
- 3) Given the large difference in labor intensity across crops, the social and equity implications of cropland expansion will depend on the type of crop grown and the way production is organized. Recent development in technology -- such as zero-tillage, pest resistant varieties, and information technology -- made it easier to manage large farms.
- 4) International organizations can support countries to maximize opportunities and minimize risks from large-scale land acquisition in four ways: assist countries to integrate analysis on large-scale land acquisition into national strategies; provide financial and technical support for capacity development; support the development of responsible agro-investments principles; and help establish and maintain mechanisms to disseminate information and good practice on management of land acquisitions.

7. Conservation Agriculture

Innovations such as conservation agriculture are helping to address the challenge of productivity growth in the face of resource scarcity. While conservation agriculture has been widely adopted in some regions (e.g. USA, Australia, Latin America) and some crops, adoption has been slow in many developing countries – and particularly in West Asia and North Africa, where land and water resources are particularly scarce. This section discusses some of the theoretical aspects, and highlights the lessons learnt from the Australian success, and some of the results achieved by ICARDA and its partners.

7.1. Efficiency frontiers for conservation agriculture

The return-risk framework suggests that “efficiency frontiers” exist at which the return from existing technology is maximized for different risk levels. The curves in Figure 2 describe such frontiers: the lower, solid line represents the frontier for currently adopted technologies and practices; the higher, dashed line represents the frontier for “yet-to-be” adopted technologies which create new opportunities and return-risk dimensions. Using this framework, pathways for technology intervention can include (Carberry et al., 2010; Keating et al. 2010):

- Moving from B to D by adopting current best practices to remove system inefficiencies with no increased exposure to risk
- Moving along the efficiency frontier using existing technologies (D to A) but with an associated increase in inputs and risk
- Adopting breakthrough practices or technologies to move to a new efficiency frontier (dashed line) that enables
 - Maintaining output through increased efficiency of resources use (reduced level of resources use) while reducing exposure to risk (D to C)
 - Increasing output with the same exposure to risk (D to F) or (same level of resources)

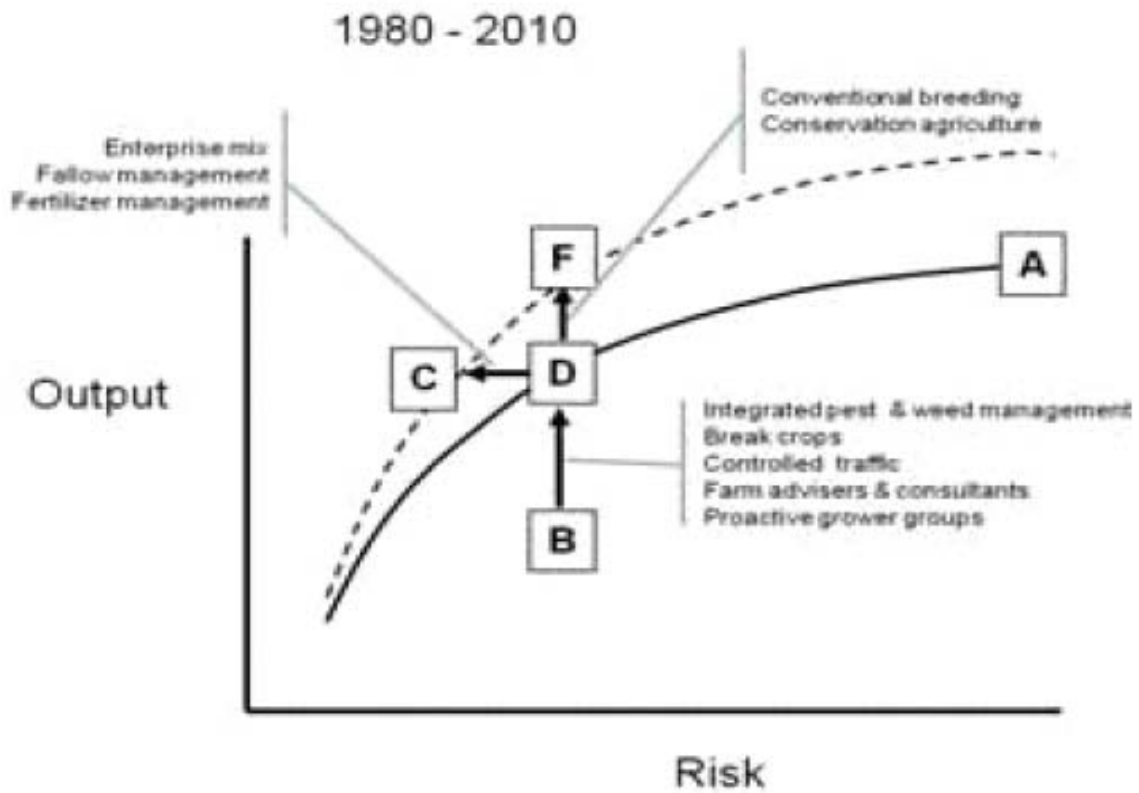


Figure 2. Conceptual framework for efficiency frontiers of conservation agriculture (after Carberry et al., 2010 and Keating et al., 2010)

In reality, most farmers choose acceptable risk investments which return closer to 60-80% of the potential (point D). To increase returns with little added risk, the only real option for these producers is to move from the current efficiency frontier (solid line) by adopting breakthrough technologies (D to F).

Figure 2 illustrates how Australian farmers have adopted technology and information systems over the past 30 years to improve their economic performance and deal with the high risk of farming in a variable climate.

The widespread adoption of conservation agriculture in Australia is a significant management practice which has raised cropping productivity over the past 30 years. Conservation tillage practices improve rainfall infiltration and increase soil water storage, which commonly results in increased water use efficiency of crops in Australian dryland farming (Carberry et al., 2010).

As water supplies for irrigation become less secure under climate change, conventional irrigated agricultural systems may be replaced by dryland agronomic practices with supplementary irrigation to increase the efficiency of water use. Opportunities to modify government policies that impede efficiency gains could be addressed. New technology packages would include conservation agriculture techniques, together with other resource-efficient technologies such as supplemental irrigation.

In practice, productivity increases can be realized through combinations of these strategies as managers respond to market signals, availability (and affordability) of technologies and immediate drivers such as drought (and price volatility as well as policy changes).

An investment approach to create new return-risk frontiers is to obtain productivity gains through innovation (research, development and adoption of new technologies). Productivity can be increased through three intervention pathways:

- Develop and implement technologies or interventions that remove system inefficiencies, i.e. move from point B to point D in Fig. 2
- Invest in breakthrough technologies that increase the efficiency of resource use whilst reducing risk (point D to point C, Fig. 2)
- Invest in breakthrough technologies that offer greater returns for the same level of risk (point D to point F).

The efficiency frontier framework can also be applied to other technologies. Keating et al. (2010) apply the framework of Figure 2 to the case of water use efficiency (WUE) for grain production, defined as the ratio between grain yield and evapotranspiration. Empirical studies demonstrate opportunities to improve WUE using two pathways of the return-risk framework, by closing the yield gap and move crop yield up onto the efficiency frontier (point B to D) by better controlling biotic stresses. The second pathway is to move along the efficiency frontier and increase WUE with a yield-maximizing strategy (point A). This would require farmers to increase their investment risk either by increasing inputs or the chance of crop failure (Keating, et al., 2010).

The only pathways for farmers to increase production are either to move along the efficiency frontier (and so increase their investment risk) or to adopt new technologies that generate a new efficiency frontier (Keating, et al., 2010).

7.2. Relevance of Australian experience in conservation agriculture to developing countries

Despite its variable climate and fragile environment, Australian dryland farming systems have outperformed the agricultural sectors in most other countries over the past 30 years. Much of productivity growth in Australian dryland farming is attributed to conservation agriculture.

International agricultural research centers like ICARDA are helping dry-area developing countries to develop relevant technologies locally and facilitate the introduction of technologies developed under similar conditions in other countries. The AusAID/ACIAR- supported project on

conservation is a successful example: the zero-tillage system is being promoted, with adoption growing rapidly.

Cereal and legume yields in dryland cropping in West Asia and North Africa are low given rainfall and attainable water use efficiencies. In contrast, many farmers in Australia approach attainable yields using conservation cropping. An Australian-funded project in West Asia, managed by ICARDA, has achieved impressive results in developing and promoting conservation cropping in Iraq and Syria, where ZT has been little known or adopted. The program helped introduce ZT in the 2006-2007 season. In the 2010-2011 season, about 50 farmers used ZT on 6000 ha in Nineveh province in Iraq and 400 farmers on 15000 ha in Syria, as shown in Fig. 3 (Piggin et al., 2011). A key constraint to adoption was overcome with development of locally-manufactured or modified ZT seeders, which were effective and affordable. Local farmers encouraged to try ZT were impressed with increased yields and cost savings. Farmers have been purchasing/modifying their own seeders and taking up ZT, and adoption is expected to continue to increase in both countries, and to expand to other countries in the region.

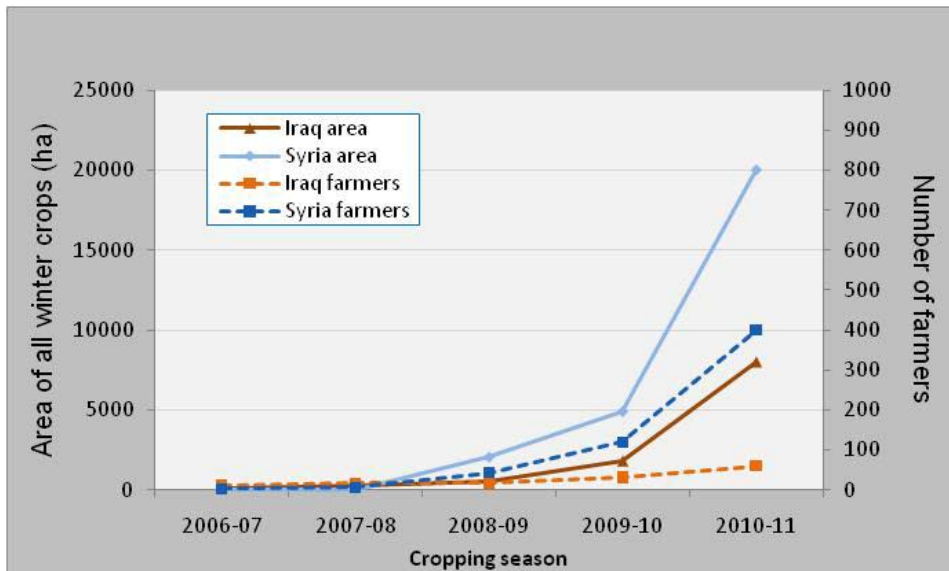


Figure 3. Adoption growth of zero tillage in Iraq and Syria, 2006-11 (source: ACIAR-AusAID Iraq Project, Colin Piggin, May 2011).

8. The Next Green Revolution

The dramatic increases in food production during the 1st Green Revolution demanded increased resources, particularly water, fertilizers, energy and land to a lesser extent. As argued by Austin (2010), those resources are no longer available to drive another “broad-scale green revolution”. Land degradation is increasingly severe, surface and groundwater resources are at or beyond sustainable utilization limits. Clearly, future food production growth must be driven by productivity growth.

Austin (2010) further argued that the next revolution must increase yields without increasing inputs of water, fertilizer, pesticide or energy. Instead, it must increase “knowledge-intensity”. In contrast to the “first Green Revolution’s seed-fertilizer-water package, the next must deal with sustainability and environmental friendliness- toward agro-ecology, agro-forestry, and conservation agriculture”.

“Intellectual inputs will be needed to underpin a series of “mini-green revolutions” in agricultural productivity; localized to countries and areas within nations, centered across similar agro-ecological zones and regions. The key characteristics of each of these mini-revolutions will be leveraging those intellectual inputs against the unique dynamics of biophysical, policy, market and investment environments”.

Historically, agricultural science has delivered component technologies aimed at increasing farm-level productivity. The future will be more complex, and individual technologies are unlikely to drive innovation. Responses must be designed within increasingly complex market and institutional arrangements, and integrated value chains. The next revolutions will entail ecological sustainable and integrated innovations such as integrated pest management, precision farming, minimum tillage, and integrated fertility management. Food security cannot be achieved without addressing underlying social inequities, poverty/hunger, vulnerability, equity and sustainability.

The inter-dependence between food and health security will become increasingly apparent, with increasing prevalence of nutritionally related diseases and other transmissible agents. The nutrition dimension of food security has evolved from an early focus on protein deficiencies, then to calorific intake and most recently to micronutrient deficiencies. The next Green Revolution must go beyond cereals, and diversify to include high value crops.

9. The Need for Research Investment

Research has played a major role improving food security through higher output and especially higher productivity, and thus increasing agricultural production growth. Most of the growth has been achieved through productivity increase. Science and technological innovation are critical for various reasons, as summarized by Austin (2010, quoting The World Bank World Development Report, as reported by Austin, 2010): to meet growing demand; to maintain market competitiveness; to address poverty and to tailor technologies to growing heterogeneity among farmers and gender groups; and for adapting to and mitigating environmental externalities such as climate change.

Despite the very high returns to investment, estimated at 65%, agricultural research-for-development has experienced significant under-investment (Austin, 2010). International investments in the CGIAR, for example, have stagnated during the past decade. The CGIAR’s Strategy and Results Framework (2011) notes that:

“To achieve a food-secure world by 2025, an annual increase in agricultural productivity of 0.5% across all regions until that year is required... This equates to a massive expansion of investment in agricultural research for development... from US\$ 5.1 billion per year today to US\$ 16.4 billion per year by 2025.... This includes the investment needed in national as well as international public sector research. Investment in international public goods research is currently about 10% of total public R&D spending (slightly over US\$ 500 million in 2009)... Extrapolating to 2025, a CGIAR budget of US\$ 1.6 billion (10% of US\$ 16.4 billion) by 2025 is required.”

One of the causes of the slowdown in productivity growth was a fall in the growth of public research investments. Increased investment is needed to stimulate sustainable growth in agriculture, which is the engine for the economic growth and poverty reduction, as well as a major job market.

Carberry et al. (2010) note that although Australian Research, Development & Extension (RD&E) has been a significant contributor to productivity growth over the past 30 years, productivity growth appears to have slowed in the last 10 years. This is partly explained by declining growth in public investment in RD&E, among other factors. Meeting the global challenge to increase food production by 70% by 2050 depends largely on increasing investments

in RD&E, promoting risk management systems, improving farmers' skill and human capital, and developing policies that encourage efficiency gains.

Science is essential, but not sufficient to ensure productivity growth and food security. Broader socio-economic and environmental factors are influential (Fig. 4). Multi-disciplinary research, together with supportive policies, is required to develop and promote innovation, and ultimately to apply innovation to ensure food security while protecting natural resources.

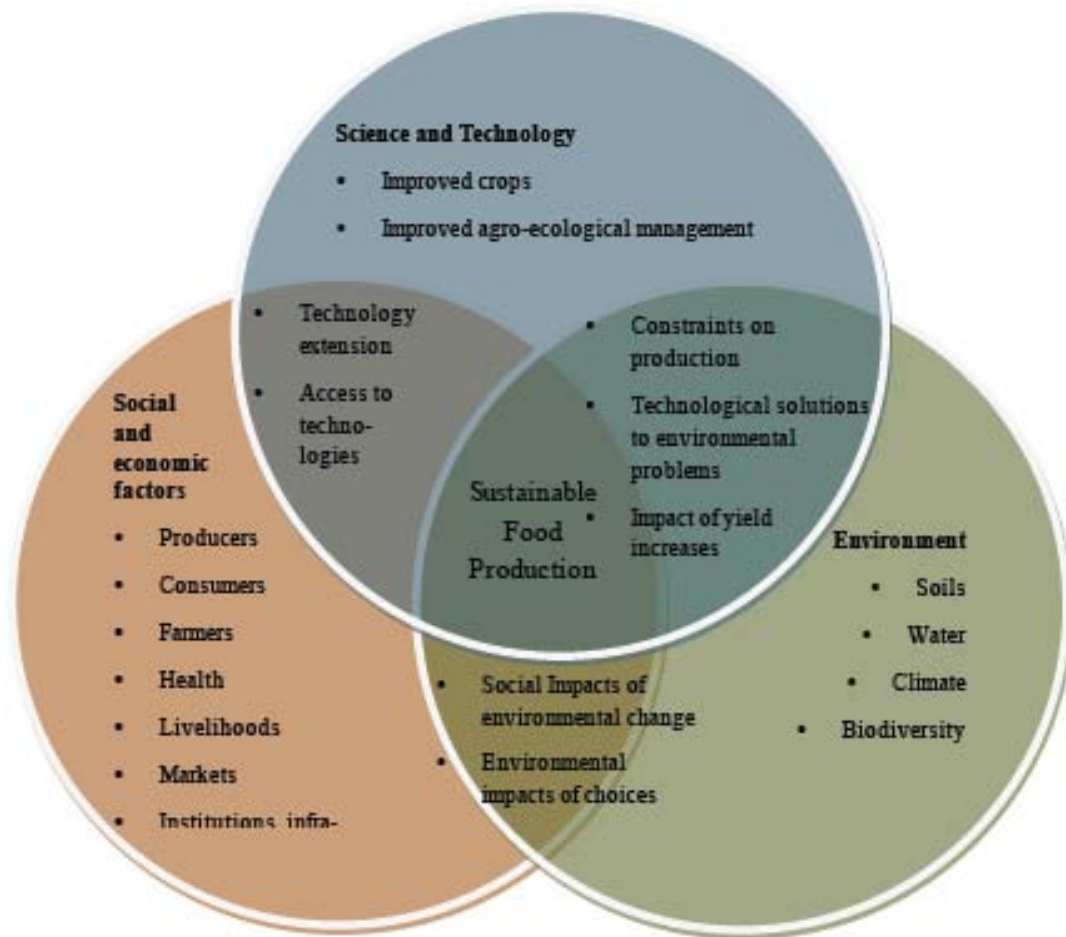


Figure 4. Role of science and technology in sustainable food production systems (after Austin, 2010)

10. Policy and Research Implications

The preceding discussion illustrates the huge potential of technological innovation to improve food security, but also the need for supportive policies and institutions to encourage farmers to adopt these innovations. The challenge for researchers is to inform the development of enabling national and international policies that support sustainable land use and efficient agricultural production. The lack of information flow between scientists, practitioners and policy makers is known to exacerbate the difficulties, despite increased emphasis on evidence-based policy (Pretty et al., 2010). This section highlights some key issues in the research-policy interface, focusing on water resources.

To ensure food and water security in dry areas, four key areas must be addressed: investment deficits in agricultural research and development, widening yield gap coupled with slowdown in productivity growth, water scarcity, and knowledge gaps. Risk is a critical factor influencing adoption and thus it needs explicit attention in the diagnosis and intervention measures (Keating et al., 2010).

New technologies may improve yield and product quality, but may not necessarily improve input use efficiency. For example, the introduction of supplemental irrigation into traditionally rainfed agriculture has increased yields and reduced yield variability. However, the benefits will be fully realized only when farmers have adequate technical know-how about the SI technology. Without this, water savings may be far less than what can be achieved.

Irrigation method is the most important variable in explaining the variation in efficiency in both technical and irrigation water efficiencies. A shift from traditional surface irrigation to modern irrigation methods, particularly sprinklers, leads to higher output oriented technical efficiency and irrigation water technical efficiency. However, even among farmers who use modern irrigation methods, there is still about 25% water use inefficiency that can be eliminated by building farmer knowledge. Similarly, ICARDA's empirical studies in Syria show that irrigation water efficiency differential between the most efficient and most inefficient farm is in excess of 60% with the average farmer lagging behind the most efficient farmer by 28%. This indicates more wasteful use of irrigation water than other inputs – and the scope for saving irrigation water without reducing wheat production. These findings illustrate the need for extension interventions – with strong policy support -- to enable farmers to make best use of new technologies.

Participatory, community-led approaches are critical, particularly for land and water management technologies. This approach has been successfully used by ICARDA and its partners in different countries. For example, the IFAD-supported Badia Rangelands Development Project in Syria is a participatory rangelands management project that has introduced the concept of grazing cost recovery by the end- users (IFAD, 2010).

Different strategies are required to tackle the waste in food production and consumption, estimated at 30-40% in both developed and developing countries. In developing countries public investment in transport infrastructure would reduce spoilage while better functioning markets and the availability of capital would increase the efficiency of the food chain, for example, by allowing the introduction of cold storage (Godfray et al., 2010).

Financial analyses show that the rates of return for farmers to invest in some soil-conserving technologies, in marginal dry areas, are often not high enough to trigger technology adoption. Development investments are necessary to provide farmers with incentives stimulate adoption. Such incentives can be justified because the economic rate of return to investment is satisfactory if these costs are accounted for. In addition, there are important environmental benefits -- in the form of reducing soil erosion, maintaining soil fertility, and conserving soil moisture -- that can be generated from public investments in dry areas. Successful, sustainable natural resources management requires approaches that go beyond the conventional and biophysical aspects and that capture the holistic nature of the problem by integrating economic,

environmental and social aspects (Shideed et al., 2007). Land tenure, for example, is an important factor affecting the adoption of soil-conserving technologies. The long-term environmental benefits of conservation cropping may be irrelevant to farmers whose planning horizon is limited by insecure land tenure.

Research findings are available on many of the key issues, although important knowledge gaps still exist. The studies described in this paper show that policies create most of the conditions that lead to greater resource-use efficiency level. Examples include farm size, water allocation and costs, cropping patterns, inputs, and crop pricing. Water allocation among crops, techniques and growing seasons should consider the level of efficiency which may be attained under each option. Well designed, implemented policies are the key to efficient use of scarce resources, growth in farm income and protection of the environment.

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