Food Security (2018) 10:589–601
https://doi.org/10.1007/s12571-018-0794-3

ORIGINAL PAPER

Economic and food security benefits associated with raised-bed wheat production in Egypt

Jeffrey Alwang[1] · Samy Sabry[2] · Kamel Shideed[3] · Atef Swelam[4] · Habib Halila[5]

Received: 22 September 2017 / Accepted: 13 April 2018 / Published online: 9 May 2018

Abstract
Countries in the West Asia and North Africa (WANA) region are dependent on imports of wheat to meet their food security needs. Mechanized raised-bed wheat production is an effective means of increasing productivity and saving scarce water, but the technology needs substantial adaptation to local conditions. This paper estimates the economic benefits from a long-term adaptive research project designed to adapt and promote mechanical raised-bed wheat production in Egypt. The technology itself is associated with a 25% increase in productivity due to higher yields, 50% lower seed costs, a 25% reduction in water use, and lower labor costs. The mechanical raised-bed program is now a component of Egypt's national wheat campaign and it is estimated that by 2023 approximately 800,000 ha of wheat will be planted with the technology. This paper estimates that over a 15 year project horizon, the benefits will exceed US$ 4 billion, with most of the benefits accruing to more than one million Egyptian wheat producers. Other benefits include reduced wheat imports (by more than 50% by 2025), reduced dependence on international commodity markets and increased productivity on more than 200,000 ha of water-starved lands.

Keywords Wheat productivity · Food security · Research for development · Technical change · Benefits

1 Introduction

Countries in the West Asia and North Africa (WANA) region are dependent on imports to meet food security needs (Shideed et al. 2010). Wheat is the most important consumer staple; WANA regional annual cereal imports now exceed 60 million tonnes (t), with wheat accounting for more than 50% of the total (AOAD 2009; Ibrahim et al. 2012). Concerns about dependence on import markets have driven WANA governments to enact policies to stimulate domestic wheat production (Shideed et al. 2010). Increased production will lower imports, save foreign exchange, and, especially since the global food price spike in 2007, when governments encountered difficulty in sourcing wheat on international markets, enhance national food security. In Egypt, bread shortages led to long queues at supply points, and subsequent food riots in the early months of 2008 shook the government to its foundations (Peeters and Albers 2013; Veninga and Ihle 2018).

Water availability is the most binding constraint to increased cereal production in WANA and irrigation water is increasingly scarce as urbanization and industrialization compete with agriculture for water use (El Kharraz et al. 2012; Ibrahim et al. 2012; Oweis et al. 2000). Agriculture accounts for approximately 86% of Egyptian water use (FAO 2017) and the government is seeking technologies to increase water use efficiencies (El Kharraz et al. 2012; Ibrahim et al. 2012). Mechanized raised-bed (MRB) wheat production is an effective means of increasing water use efficiency and productivity, and its wide-scale dissemination can enhance food security by intensifying wheat production in water-scarce environments (Majeed et al. 2015; Sayre and Moreno Ramos 1997).

The MRB wheat production system, originally developed in the USA and modified in Mexico, has to be adapted to local

✉ Jeffrey Alwang
alwangj@vt.edu

[1] Virginia Polytechnic Institute and State University, Blacksburg, VA, USA

[2] Agricultural Research Center, Cairo, Egypt

[3] International Center for Agricultural Research in the Dry Areas, Amman, Jordan

[4] International Center for Agricultural Research in the Dry Areas, Cairo, Egypt

[5] International Center for Agricultural Research in the Dry Areas, Tunis, Tunisia

conditions (Sayre et al. 2005; Roth et al. 2005). Adaptation is a long-term endeavor requiring institutional continuity for testing and fine-tuning over many production cycles (see Sayre et al. 2005 and the many case studies presented in Roth et al. 2005). The adaptive research necessary to bring such technologies to scale is facilitated by multi-year commitments from national agricultural research systems (NARS), their domestic partners, and international agricultural research centers (IARCs). The WANA MRB wheat production system, which was adapted and tested in Egypt and is now being spread to other WANA countries, involved a partnership between a Consultative Group for International Agricultural Research (CGIAR) center — the International Center for Agricultural Research in the Dry Areas (ICARDA), and national partners. Information on the economic impacts of widespread dissemination of the MRB wheat technology in WANA is not available.

The objectives of this paper are to: (i) assess the impacts of mechanical raised bed (MRB) wheat production under irrigated conditions in Egypt; (ii) document and analyze the costs of achieving national food security by reducing reliance on international markets; and (iii) analyze the effort under the lens of comparative advantage — what unique attributes are needed to enable such a research for development program to achieve impact at scale?

The paper is organized as follows. It begins with an overview of the WANA MRB wheat research program and how the sequence of research for development projects contributed to the development and diffusion of MRB technologies. Next, the technology and its components are described. It is clear that the MRB wheat production system is not "off-the-shelf" and ready to go. While the technology has been applied in many contexts, the package has to be fine-tuned based on agro-ecological, manufacturing, and institutional conditions (see case studies presented in Roth et al. 2005). The paper then presents a conceptual framework showing the linkages between agricultural research and its impact on consumers and producers. The conceptual framework is applied using data from Egypt to quantify benefits. A discussion of results and our conclusions follow.

2 Background

Wheat has been planted on raised soil beds in developed countries since at least the 1960s, and in the early 1970s, the International Maize and Wheat Improvement Center (CIMMYT) began experimenting with the technique in Mexico (Roth et al. 2005; Sayre and Moreno Ramos 1997). Following field trials to investigate seeding rates, fertilization and use of other inputs, CIMMYT and its Mexican partners began in 1978 to transfer raised-bed wheat to farmers in the Yaqui Valley, Mexico (Sayre et al. 2005). Technology uptake was almost universal in the Valley; in 1981 about 6% of Yaqui farmers were producing wheat on raised beds, but by 1996 more than 90% were using the system (Sayre et al. 2005). The package included judicious use of pre-planting irrigation and mechanical cultivation for weed control. It reduced herbicide applications, water use, and seeding rates by up to 50% (Sayre and Moreno Ramos 1997).

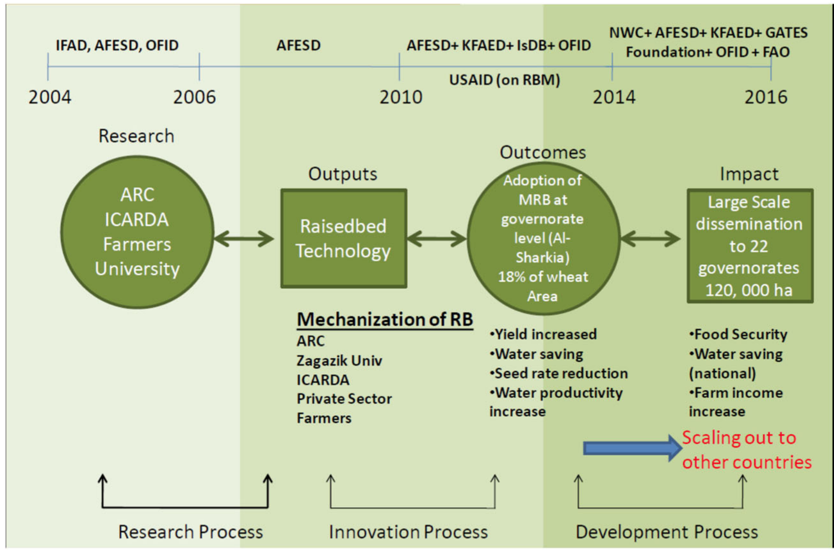
Researchers found that farmers appreciated weed control with fewer herbicide applications and the fact that the same bed can be used in multiple cropping cycles with minimum alterations to the bed, saving production costs (Sayre and Moreno Ramos 1997). During field testing, yields were 14% higher but profits were 217% higher on raised beds compared with flat-plant basin irrigation, showing the importance of cost reduction to system profitability (Sayre and Moreno Ramos 1997). CIMMYT researchers speculated that raised bed production has wide applicability in developing countries where irrigated wheat is grown, and the technology has spread to India, Pakistan, and other Asian countries (Roth et al. 2005). In these countries, evidence shows that water use efficiency is generally enhanced by the MRB technology (Roth et al. 2005), but the technology has not spread appreciably into WANA, where water is a constraining element in wheat production systems (Karrou et al. 2012). Part of the problem, and similar to the experience in South Asia, has been that the technology needs adaptation to local conditions. Successful adaptation requires identification of a specific wheat variety, adjusting bed dimensions to local conditions, creation and calibration of a mechanical bed-formation and planting machine, adjustment of irrigation regimes to local conditions, and further fine-tuning of the agronomic package (Sayre et al. 2005).

2.1 The technology and its development

Work toward adapting raised-bed wheat to conditions in WANA began during the first phase of the Water Benchmarks of CWANA project[1] (Fig. 1), which introduced planting wheat in wide furrows and on raised beds to save irrigation water (ICARDA 2008). Raised beds are widely used in Egypt to grow irrigated vegetables, and the transfer of the raised bed technology to wheat production in geographically similar areas (almost all production in Egypt is found in the Nile Delta) was a natural step. During the first phase of the CWANA project, machinery for bed preparation and seeding was not available, and beds and furrows were constructed

[1] Water Benchmarks of CWANA Phase I (Community-Based Optimization of the Management of Scarce Water Resources in Agriculture in West Asia and North Africa) began activities in 2004 and ended in 2008. It was funded by the Arab Fund for Economic and Social Development (AFESD), the International Fund for Agricultural Development (IFAD) and the OPEC Fund for International Development (OFID). The project included activities on sites throughout WANA.

Fig. 1 Research impact pathway for raised soil bed technology in Egypt



manually. The project's applied research component focused on fine-tuning the agronomic management, evaluation of water use efficiency, and analysis of economic and financial returns to raised-beds (ICARDA 2008, 2014). Analysis showed that high labor costs associated with manual preparation of the beds were an obstacle to widespread uptake. In phase two,[2] a prototype mechanical planter adapted to conditions in the Delta was designed and tested. The prototype was modified following field tests, but the MRB technology was not suitable for release until the agronomic package was fine-tuned to optimize bed height and width, seeding patterns, and other management components (Figs. 2 and 3).

The global commodity price spikes in 2007–8 (Veninga and Ihle 2018) increased interest in promoting wheat self-sufficiency in many countries (World Bank, FAO and IFAD 2009). Increased production has direct effects on three of the four pillars of food security: increased availability and access to food, and due to production under irrigated conditions, greater stability in food markets (FAO 2015). The Enhancing Food Security in the Arab Countries (EFSAC) project was an action-orientated follow-up to the Water Benchmarks Projects (Fig. 1). Its main components are dissemination at scale of proven production technologies and adaptive research to fine-tune in-pipeline technologies and demonstrate their potential under farmer conditions (ICARDA 2014, 2016). This project and its follow-up[3] continued adapting the MRB package to local needs.

Under EFSAC, MRB wheat technology was disseminated in Al Sharkia governorate, the largest wheat-producing area in Egypt. Subsequently, activities expanded to Al-Dakahlia governorate, the 3rd-largest wheat-producer. The technology is now being spread to 22 governorates as part of the National Wheat Campaign (NWC).

2.1.1 The mechanized raised-bed wheat package

Wheat production on MRBs involves a package of technology. Field trials to validate raised-beds included tied-packages of improved seeds, recommended seeding rates, sowing dates, planting parameters, fertilizer application, water

Fig. 2 Raised-bed fields prior to plant emergence in Egypt

[2] Water Benchmarks of CWANA Phase II, a follow up to the Phase I was funded by AFESD and ran from 2009 to 2013.

[3] Enhancing Food Security in the Arab Countries, Phase I, ran from 2010 to 2014, and was funded by AFESD, the Kuwait Fund for Arab Economic Development (KFAED), the Islamic Development Bank and OFID. Phase II began in 2014, with the Bill and Melinda Gates Foundation added to the list of donors.

Fig. 3 Raised-bed wheat field in Egypt

application regimes and other management components (ICARDA 2014, 2016). Long-term evaluation of the system yielded a defined package comprising an improved wheat variety,[4] seeded at a rate of 108 kg/ha, sowing dates within the 15–30 November window, bed preparation and planting with the mechanized plow/seeder, and nitrogen fertilizer applied at 168 kg N/ha. Estimates of differences in productivity and cost between the raised-bed package and current practices (flat basin irrigation) are available from field trial data (ICARDA 2014). Other components, such as growing berseem (Al Fahl) following rice and before wheat (Saleh and Ahmed 2016), can be separated from the wheat-specific technology.

A key element of the MRB package is mechanization, as rising labor costs and inefficient seeding make manual bed preparation unattractive to farmers. The raised-bed seeder, adapted to local conditions, costs approximately US$ 5000, with an estimated life of 10 years. The seeder is drawn by a 60-HP or larger tractor, and can prepare a 1 feddan (= 0.42 ha) raised bed in approximately 35 min. In Egypt, as of mid-2016, roughly 60 of these machines were operating, purchased as a part of the EFSAC project.[5] Experts in Egypt expect that eventually raised-bed preparation will be a service provided, as most mechanical plowing now conducted in Egypt is, by machinery owner-operators (Sabry 2016, personal communication, October 2016). Currently, beds are prepared using project equipment and costs are subsidized. Participants pay 120 E£[6] per feddan for bed preparation; ARC technicians and ICARDA scientists estimate that mechanical bed-preparation costs would range from 150 to 200 E£ per feddan in the absence of the project subsidy. Fields have to be well-plowed prior to formation of the raised bed; mechanical bed preparation does not save plowing costs, nor is it a form of reduced tillage conservation agriculture (Figs. 2 and 3).

2.1.2 Water savings

Water savings is an important feature of the raised-bed technology, but evidence shows that water use depends on soil and other conditions in the area (Kukal et al. 2010). Field trials in Egypt indicate that MRB wheat production reduces irrigation water use by about 25% compared to farmer practices which involve flooding the entire field (ICARDA 2014, 2016). This reduced irrigation saves costs of pumping water for farmers (a direct benefit through cost-savings),[7] but a larger benefit is increased water availability to farmers at the tail end of the irrigation canals. Irrigation water in the Delta is a rotation-based system where each mesqa[8] receives water in winter for approximately five continuous days and then faces ten days without access to water (Ghazouani et al. 2014; Gouda 2016). Farmers at the head of the mesqa normally pump water vigorously and flood their fields as a precautionary measure when it becomes available. This practice leaves shortages further down the canals leading to practices such as reuse of drainage water (Ghazouani et al. 2014). There is evidence of social conflicts related to water use and these conflicts grow as water becomes more scarce (Ghazouani et al. 2014).

Raised-bed planting initiatives have targeted farmers at the heads of mesqas in the expectation that raised-bed farmers would pump less water allowing increased availability further down the canal. According to project documentation, this availability has emerged although its extent depends on conditions in the mother canal and impacts of increased water have yet to be quantified (ICARDA 2014). Differences in water availability in canals due to raised beds can be quantified by measuring the water level at the head, middle and tail in two canals (with and without MRBs) and comparing levels across the canals. Alternatively, farmers at the tail ends could be surveyed to examine yield changes and cropping mixes before and after introduction of the raised beds. At a

[4] The recommended variety depends on agro-ecological conditions and seed availability. Newly released improved wheat cultivars are part of the package: Sids 12, Misr 1 and Misr 2 at project inception, with Gemmiza 11 starting in 2011, Sids 13 starting in 2012 and Shandawel 1 starting in 2013.

[5] Additional machines were purchased by EFSAC for use in, Iraq and Tunisia. Each country requires modification of the Egypt-specific design and ICARDA engineers are providing necessary support for such modifications.

[6] 1 E£ = USD 0.060 at the time of writing.

[7] Irrigation distribution systems in Egypt deliver water 50 to 60 cm below field surfaces and farmers pump water to lift it from delivery canals (Wahby et al. 1984). Pumping costs include diesel fuel, time cost and equipment depreciation: farmers are not charged for water use. Egypt's cereal sector is heavily dependent on fuel: an estimated 11.1% of production value is attributable to fuel costs (Al-Riffai et al. 2016).

[8] The mesqa is the lowest level of irrigation canal in Egypt; each mesqa feeds between 10 and 40 farms.

minimum, additional water availability will increase productivity in mesqa tail ends and lower reuse of drainage water (improving overall water quality); it could also affect cropping choices (El-Shinnawi et al. 1980; Ghazouani et al. 2014). A non-monetary benefit of further diffusion of MRB would be reduced social conflict over water use.

An additional benefit of lower water use is reduced stress on field drainage and associated losses due to waterlogging. Reduced through-put in the irrigation system will lead to external (to the farm) benefits of improved water quality (Ghazouani et al. 2014). The raised bed technology lowers the amount of water used on the farm, leading to fewer fertilizer applications to the field because of less fertilizer leaching from the root zones. With over-irrigation, nutrient-rich leached water enters the drainage water, which becomes the water source for neighboring farms. Raised-bed planting reduces pesticide applications due to reduction in fungal and other diseases due to better radiation interception, accumulative temperature and lower humidity in the canopy. These benefits are difficult to quantify, but should be considered, and the benefit estimate from our model, because it does not include longer-term environmental benefits associated with MRB, will underestimate the true benefits of the technology.

2.1.3 The research for development partnership

The Water Benchmarks and ESFAC projects are partnerships involving ICARDA and national actors. By design, most national agricultural institutions such as the Agricultural Research Center (ARC) of Egypt use commodity-orientated approaches. While such approaches help gain political support from commodity groups and consumers of strategic crops such as wheat, it leaves national systems ill-structured to employ multi-disciplinary approaches. The MRB technology is not new, but the full package is new and its development required inputs from multiple disciplines, including social and environmental scientists. In contrast to national actors, ICARDA's integrated research projects work in a systems framework, and the analytical components of technology packages such as MRB often extend beyond field and farm levels, to examine social acceptability, policy constraints, impacts on water use and broader implications of development actions (Ghazouani et al. 2014; ICARDA 2014, 2016). Limited capabilities of NARS to perform in a multi-disciplinary environment help justify the IARC participation. In addition, the MRB package has implications for multiple crops and a commodity focus on wheat alone would have made it difficult for ARC to pursue the research. Finally, the time frame for full development, testing and implementation (Fig. 1) would have made it difficult for a NARS partner to stay engaged without ICARDA acting as a catalyst.

An integrated, region-wide research for development approach allowed horizontal movement within Egypt and facilitated transfer of raised-bed technologies to other countries. During Phase II of the CWANA Water Benchmarks Project, the MRB technology was tested in sites in Iraq and Sudan (2010–2012); this testing led to further experimental work for expansion to Morocco and Sudan under the EFSAC Phase I and Iraq and Tunisia in Phase II. Horizontal expansion requires adaptation to local conditions. In addition to agronomic fine-tuning, the raised-bed planting machine requires design changes to ensure compatibility with local conditions. Full implementation of the expansion requires participation of scientists from multiple disciplines and a systems approach to research from the experiment station to farmer fields and over entire agro-ecologies.

Expansion of MRB to areas and countries was aided by use of geo-informatics to create suitability maps for the MENA region (Ziadat et al. 2014). These maps identify areas (based on agro-ecological and climatic conditions) where the technologies have potential. Generation of suitability maps is itself a research undertaking requiring coordination of data gathered from field experiments and other sources. The institutional umbrella created by partnerships between IARCs and NARS facilitated research and upscaling to bring the technology to scale.

EFSAC is one of the components of the Egyptian National Wheat Campaign (NWC), coordinated by the Ministry of Science and Technology. The successful early experience in Al Sharkia governorate led to incorporation of the MRB technology into the national campaign. As a result of this incorporation, wheat experts estimate that by 2023, more than 800,000 ha of wheat will be produced using mechanized raised beds (Fig. 4). According to the ICARDA suitability analysis, about 79% of the non-sandy irrigated lands in Egypt are suitable for the raised-bed technology (Ziadat et al. 2014, p. 65).[9]

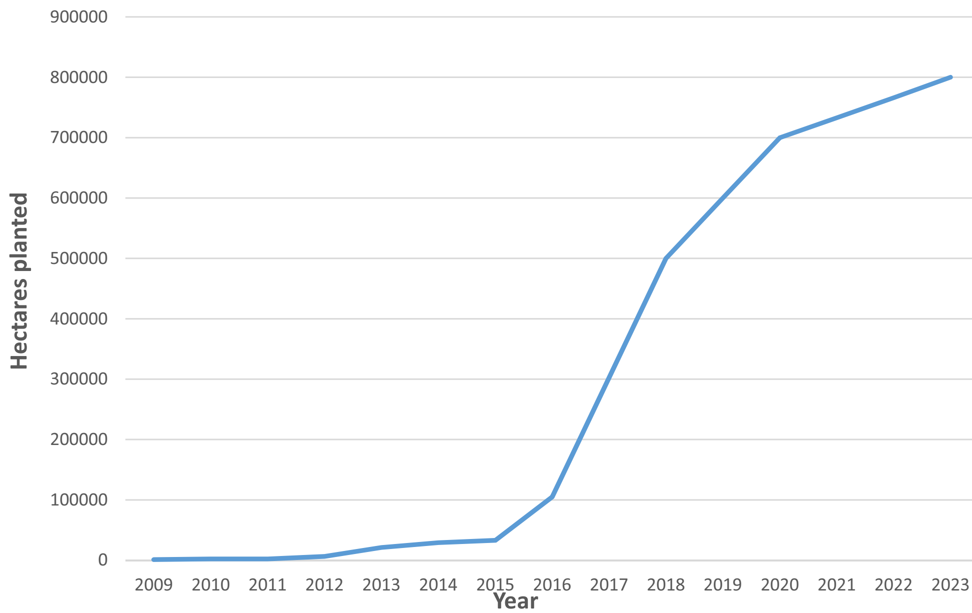
3 Methods

3.1 Conceptual framework

Economic impacts of new technologies are manifested through direct and indirect effects (deJanvry and Sadoulet 2002; Zeng et al. 2015). Direct benefits of new technologies are felt on the farms of adopters and come from reduced per-unit costs of production. Such reductions can result from lower costs of operation or increased yields, or both. When many farmers adopt, farm-level effects are

[9] More than 850,000 ha (about 29% of wheat area) are in the highest suitability class; 660,000 are suitable at level 2 and 823,000 ha are suitable at level 3. About 21% of wheat area is not suited for the technology.

Fig. 4 The raised-bed adoption profile in Egypt. Source: EFSAC project documentation (through 2016); forecasted for 2016–2023 based on piecewise sigmoid (2023 estimate from Dr. Samy Sabry, Egyptian National Wheat Coordinator, confirmed in interviews with other policy makers)



aggregated to the market level and are reflected as a rightward shift in market supply. This shift creates indirect benefits to consumers, because a supply shift against an inelastic demand lowers consumer prices. Lower prices adversely affect producers, and the net effect depends on whether producers adopt the lower-cost technology and other conditions such as their cost of production. If the market price declines by more than producer productivity grows, adopting producers will be hurt by the price effect. Non-adopting producers are also hurt as the market price falls.

Other market-related factors that may need to be accounted for include changes in input markets, such as labor and machinery. If the research-induced supply shift in the primary (wheat) market leads to price changes in other markets, these changes should be accounted for as the partial equilibrium approach assumes that prices are fixed in other markets. In addition, the framework described here only accounts for market-mediated impacts. As noted, MRB wheat farming reduces water use and improves water quality. These environmental benefits are not included in our measure of market-mediated impacts, so our results reflect a conservative estimate of net benefits from the technology.

Measurement of impacts in a partial equilibrium surplus framework requires three broad steps: (i) compute the per-unit cost change for adopters of the technology; (ii) aggregate cost changes for all adopters (and over time) to get market supply shift; and (iii) use a market model to compute changes in benefits to producers and consumers (Alston et al. 1995). The distribution of benefits among certain classes of producers and consumers can be disaggregated by using information on adoption patterns, input purchases, market participation and consumption patterns (Zeng et al. 2015).

Per-unit differences in the cost of production should be measured with respect to a counterfactual — what the cost of production would have been in the absence of the technology. These can be estimated econometrically using suitable data with observations on adopters and non-adopters,[10] using farm-level budget data from field trials, and by questioning producers and even scientists about the cost of production, and others (Alpuerto et al. 2009; Rudi et al. 2010). Ample evidence is available for the costs of production under MRB technology from more than six years of trials on farmer fields (ICARDA 2008, 2014, 2016). In these trials, the counterfactual is the experimental control — wheat yields and production costs for neighboring farmers who grew wheat using traditional methods. Interviews with project leadership indicated that some selection bias was present — farmers were selected to participate because they were more entrepreneurial and progressive compared to non-participating farmers. The presence of selectivity means that estimates of productivity gains for these progressive farmers may overstate the gains to the average adopter of the technology.

In an ex-ante context, technology adoption rates are forecasted into the future and the rate of adoption, together with the per-unit (e.g. per kg) cost savings, determine the aggregate direct benefits by year. These parameters also determine the annual shift in market supply of the commodity in question used to measure annual benefits to market participants.

[10] A growing literature uses treatment effect approaches to measure this cost-shift; much of this literature focuses on challenges to identification of a treatment effect when using observational data (Matuschke et al. 2007; Minten and Barrett 2008).

Conditions in the market also affect benefits. Producer and consumer prices for wheat in Egypt are set by government, and fixed producer prices in recent years have exceeded world (import) prices (Siam and Croppenstedt 2007; McGill et al. 2015). As a result of the fixed prices, technology-induced supply shifts have no effect on consumer prices. Increased domestic production is stimulated by the high price policy and government budget expenditures grow as domestic production crowds out cheaper imports. However, consumer prices are unaffected because they are set independently of producer and import prices (McGill et al. 2015). Ignoring the subsidy to consumers and government outlays, benefits in an open economy model with fixed prices are shown in Fig. 5.

In a partial equilibrium framework, adoption of MRB wheat technology shifts market supply rightward from S_0- > S_1. If demand were inelastic (downward sloping), the price would fall as supply shifts. Since Egyptian wheat policy fixes producer prices at P_P, the producer price is unaffected by the supply shift. Prior to introduction of the technology, producer surplus is reflected by the area $P_P aI_0$. As adoption occurs and quantity supplied to the market shifts from Q_0 to Q_1, producer surplus shifts to $P_P bI_1$, a net difference attributable to the technology of abI_1I_0. This area can be computed as (Zeng et al. 2015):

$$\Delta PS = \Delta TS = (K - Z)P_P Q_0(1 + 0.5Z\eta) \quad (1)$$

$$= lim_{\eta \to \infty}\left(K - \frac{K\varepsilon}{\varepsilon + \eta}\right)P_P Q_0\left(1 + .05\frac{K\varepsilon}{\varepsilon + \eta}\eta\right) \quad (2)$$

$$= P_P Q_0 K(1 + 0.5K\varepsilon) \quad (3)$$

where $K = (I_0 - I_1)/P_w$ and ε is the elasticity of supply. Z in Eq. 1 is equal to $K\varepsilon/(\varepsilon + \eta)$ where η is the absolute value of the own-price elasticity of demand. Because price does not change (η is infinite), Z can be ignored while computing the surplus change in the open economy model. The surplus change in Eq. 3 can easily be computed using a spreadsheet. Note that the supply shift has two additional effects: it reduces imports of wheat, and it raises to the government the overall cost of the program (because the cost of domestically procured wheat is higher than the price on international markets).

3.2 Egypt's wheat markets

Wheat is produced in Egypt as a winter crop by some 4.3 million farmers on 1.45 million ha, all of which are irrigated. Wheat accounts for about 9 % of the total value of agricultural production. Despite the scale of production, the country is dependent on wheat imports (Table 1) and through consumer and producer price policies, the Egyptian government is an important player in import and domestic markets (McGill et al. 2015). Several papers have analyzed the cost to the government and implications for agricultural productivity of wheat policy. Most conclude that these costs are relatively high (Ahmed et al. 2001; Kherallah et al. 2000). Historically the Egyptian government has been willing to bear this cost partly due to concerns about being overly dependent on foreign wheat supplies and unwillingness to cede to international actors and markets influence over national food security (Siam and Croppenstedt 2007; McGill et al. 2015). In fact, Siam and

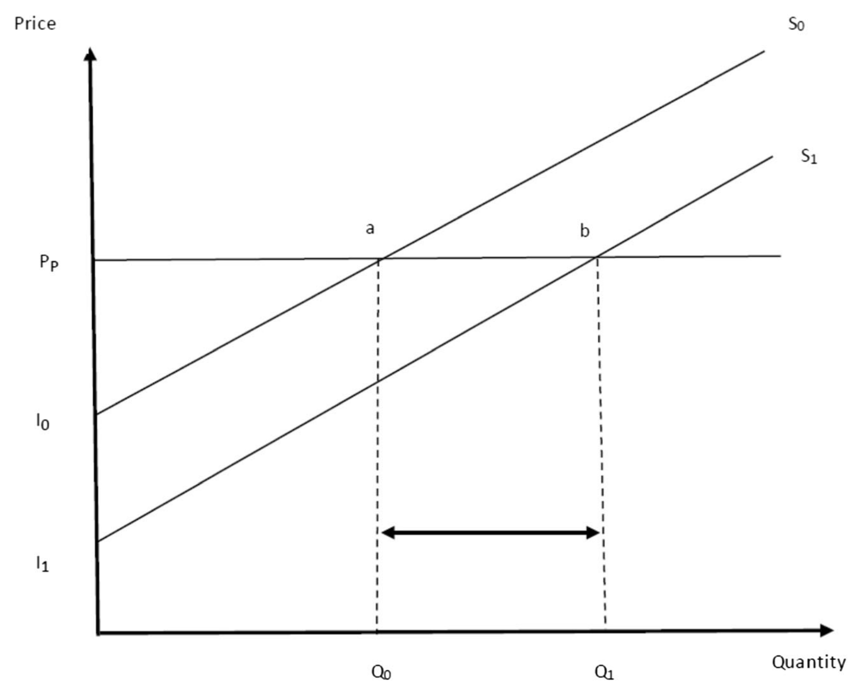


Fig. 5 Surplus change from supply shift in small open economy case. Note: The gain in producer surplus is represented by the area I_0abI_1. This results from the rightward shift in market supply (S_0- > S_1), and the increase in quantity supplied from Q_0 to Q_1. The supply shift is induced by the diffusion of the technology, and the size of the shift depends on adoption and unit cost savings as described in the text

Table 1 Egyptian wheat data, by year (million tonnes, t)

	2008/9	2009/10	2011/12	2012/13	2013/14	3-year average
Production	7.97	8.52	8.37	8.79	8.80	8.70
Imports	9.93	10.05	11.50	8.10	10.50	10.00
Domestic utilization	16.50	16.97	18.17	18.69	19.05	18.60
Feed	0.70	0.80	1.50	1.60	1.90	1.70
Food	14.80	15.17	15.57	15.89	16.15	15.90
Producer price (US$/t)	290.9	322.8	395.3	416.4	376.5	
Import price (US$/t)	241.2	245.2	326.4	322.8	264.0	

Source: McGill et al. 2015; price data are from FAOSTAT

Croppenstedt (2007) found that wheat market liberalization would imply substantial costs for producers and consumers and reliance on global markets will not enhance food security. Improved wheat yields lessens dependence on world markets and, as such, provide a buffer to international price fluctuations. While national food security is enhanced by productivity increases, additional policy measures such as the use of buffer stocks will complement these increases (Siam and Croppenstedt 2007).

3.3 Data

The data to calibrate the economic surplus model include information on costs of production (compared to the counterfactual), historical and forecasted MRB technology adoption rates, information on producer prices, and quantities of wheat produced, consumed and imported. Data come from a variety of sources, including field trial data, interviews with technicians and experts, and secondary sources. Information on costs of production on control farms compared to raised-bed farms (with the full package) were obtained from project documentation (ICARDA 2014, 2016).

Numerous reports of the Water Benchmarks and EFSAC projects provide estimates of cost savings and yield gains associated with MRB production (ICARDA 2014, 2016).[11] Sources of cost savings include lower seed costs (50% lower based on project documentation); water savings (a 25% reduction in water cost); lower labor costs (for field preparation and seeding; additional labor is needed in harvest and threshing due to the increased yield); and increased machinery cost (estimated to be 150 E£ per feddan). Under both MRB and conventional planting, two passes of a plow are necessary prior to planting. The net reduction in production costs is estimated to be 25% of total cost of production. While crop yields vary by trial and year, project documents and interviews with scientists indicate that a 25% gain in yield is a best estimate.

Estimates of adoption of the MRB technology are accurate, since all the raised bed machines being used to plant wheat in Egypt were purchased by the EFSAC project. Reported wheat land planted to MRB (in ha) from project documentation and a forecast based on expert opinion are shown in Fig. 4. Estimates of national wheat production come from McGill et al. (2015), a large-scale comprehensive study of the Egyptian wheat sector. Price data come from project documentation: the 2016 producer price for wheat was US$ 314 per t. The elasticity of supply was assumed to be 0.38, using a summary of estimates of own-price elasticity of wheat supply in Egypt (USAID 2006).[12] The additional production associated with adoption of raised-bed wheat production is associated with increases in employment associated with sales, use and maintenance of the plow; added production also raises employment in wheat processing. Information on employment generation from these sources came from various sources. Finally, information on increased production due to added water availability (associated with less water use on the raised bed plots) comes from various sources.

Research costs were estimated based on project documentation. ICARDA management estimated the proportion of each project's resources by year going to raised-bed related research and outreach. These estimates were multiplied by the total annual project budget to arrive at annual raised-bed costs (Table 2).

[11] The counterfactual is cost of production and yields in control farms — neighboring farmers who allowed their costs and yields to be measured. An assumption of the estimate of project benefits is that per land-area gains will be replicated as the package is scaled up. The experience in Al Sharkia indicates that newly incorporated farmers are receiving similar benefits compared to demonstration farmers selected for early participation (Saleh and Ahmed 2016).

[12] Absent good information, best practice is to assume a unitary own-price elasticity of supply (Alston et al. 1995), but due to wide donor interest in Egyptian wheat policy, a number of estimates exist. USAID (2006) summarizes more than seven studies and, while the estimates vary by study, the average elasticity of supply was 0.37. Kherallah et al. (1999) use a supply elasticity of 0.3.

Table 2 Project expenditures in Egypt on raised-bed research, different projects, by year. All amounts are in US$ (2009)

Year	Project			Total
	CWANA Benchmarks	AFSC I	WLI Egypt	
2009	17,125			17,125
2010	4281	20,660		24,941
2011	4281	20,660	5750	30,691
2012	4281	20,660	5750	30,691
2013	4281	20,660	5750	30,691
2014		20,660	5750	26,410
2015			5750	5750
2016			5750	5750
2017			5750	5750

Source: Based on information from ICARDA's management system assuming that 25% of the overall funds sent to Egypt were devoted to raised-bed research

4 Results

4.1 Economic surplus results

Estimates of producer surplus changes due to adoption of the raised bed technology were computed using Eq. 3. The yearly changes, based on actual and forecasted adoption rates, are discounted back to 2009, the first year MRBs were used on demonstration plots in Al Sharkia governorate. Adoption by year comes from project documents for 2009–2016 and national wheat campaign estimates of adoption through 2023 (Sabry 2016, personal communication).

When discounted at a 5% annual rate and under assumptions discussed above, the 15-year project horizon yields producer benefits of US$ 4.5 billion.[13] As wheat producers in Egypt tend to farm modest land areas, these benefits will be shared by more than one million farmers as of 2023 (the number of benefiters grows in proportion to the adoption rate). When research costs are included, returns to the research investments are computed to be US$ 4.3 billion. While the rate of return to the research for development program is very high, the research costs do not include all the early development costs incurred by CIMMYT in the 1970s and later.

Several scenarios were used to examine the sensitivity of the findings to model assumptions. We varied the elasticity of supply, used pessimistic and optimistic assumptions about yield and cost changes, and examined how the benefits would be distributed if Egyptian wheat producers received the world price instead of the favorable support provided by the Egyptian government (Table 3). Clearly results are sensitive to underlying model assumptions, and the discounted benefits vary between US$ 2.0 billion and US$ 6.4 billion over the 15-year period studied. The elasticity of supply is obviously an important parameter, and the value of 0.75 is used as an absolute upper bound. Supply of wheat is constrained by area in the Nile Valley and given the favorable policy environment that has predominated, it is doubtful that the extensive margin will grow much further. Any increases in wheat production will have to come through production intensification and the lower elasticity estimate (0.37) is probably the best.

The "world price" scenario in Table 3 shows that if wheat policy were reformed so that Egyptian producers were to receive the world price rather than the domestic price, which is more than 50% higher than the world price, discounted benefits over the time horizon from the raised-bed program would be cut by about half (from US$ 4.5 billion to US$ 2.8 billion). Wheat farmers are encouraged by the policy mechanism to increase their wheat productivity, so the price policy promotes adoption of the raised-bed technology. However, about a half of the substantial benefits from the raised-bed program are not due to the subsidized producer price; the technology has strong positive benefits even when market distortions are eliminated. Note that by lowering producer prices, adoption targets might not be achieved and producers may shift land out of wheat production; in such cases, the rightward supply shift would be attenuated. An intermediate price scenario is also shown in Table 3, where it is assumed that the producer support price is half-way between the current domestic price to producers and the world price (US$ 250/t); under this scenario, the discounted net present value is US$ 3.6 billion.

It is important to note that this policy has its costs and the Egyptian people, through taxation, are paying for it. Numerous studies have examined the implications of Egyptian wheat policy for consumers, producers and overall welfare gains and losses (Kherallah et al. 1999; Siam and Croppenstedt 2007; USAID 2006). An assessment of these factors is beyond the scope of the current study, but reduced benefits from adoption of raised-bed wheat is one implication of policy reform. Even with policy reform, the raised-bed program has huge estimated benefits. Increased productivity also has two additional benefits not considered in static analysis of policies: (i) it reduces imports, freeing up foreign exchange for more pressing needs; and (ii) it reduces reliance on uncertain international commodity markets and, by doing so, promotes national food security (FAO 2015). A recent analysis using the IFPRI IMPACT model shows that raised bed adoption of similar magnitudes as assumed here will reduce wheat imports from approximately eight million metric t to less than four million t annually by 2025, even with expected growth in domestic demand. This reduction will save more than US$ one billion annually by 2025 (Frija et al. 2016). In addition to these benefits, non-market environmental benefits due to less water use and

[13] When the baseline model is run from 2009 to 2017, where we have good information about adoption and impacts on participating farmers, the net present value of benefits (in 2009 dollars) is US$ 576,000. As the NWC up-scales diffusion, benefits grow rapidly.

Table 3 Present value (PV) results from alternative scenarios and sensitivity analysis

Scenario	Assumptions	PV (2009) (billion US$)
Baseline	$\varepsilon = .37$, $\Delta y = 25\%$, $\Delta cost = -25\%$, price = 314	4.5
Elastic supply	$\varepsilon = .75$, $\Delta y = 25\%$, $\Delta cost = -25\%$, price = 314	2.8
Low yield, low cost change	$\varepsilon = .37$, $\Delta y = 10\%$, $\Delta cost = -15\%$, price = 314	2.0
High yield, high cost change	$\varepsilon = 1$, $\Delta y = 35\%$, $\Delta cost = -35\%$, price = 314	6.4
Intermediate price	$\varepsilon = 1$, $\Delta y = 35\%$, $\Delta cost = -35\%$, price = 250	3.6
World price	$\varepsilon = .37$, $\Delta y = 25\%$, $\Delta cost = -25\%$, price = 195	2.8

Present value is not estimated net of research costs to show returns to wheat farmers

productivity benefits to producers at the end of the irrigation canals are not included in our calculus. These benefits, which are difficult to quantify, are likely to be substantial.

4.2 Additional benefits

In addition to economic surplus (a widely accepted measure of welfare change), policy makers might be interested in additional employment generated from an expansion of MRB wheat production. The most obvious employment generation is in the machinery sector where added demand for raised bed machines will generate employment in their manufacture and maintenance. Wheat experts note that the most prominent barrier to expanded area under raised-beds is access to the bed-preparation/planting machine (ICARDA 2016). Based on a total projected area of 800,000 ha by 2023, an estimated 4800 of these machines will be needed (each machine can prepare approximately 300 feddan per season).

In general, machinery and equipment production in Egypt is not labor intensive; according to the most recent social accounting matrix (SAM) for the country, labor represents about 4.2% of the total value of production in the manufacturing sector (al-Riffai et al. 2016).[14] Assuming, optimistically due to the specialization of the manufacture of raised-bed machinery, that 15% of the value of production goes to labor, construction of each piece of raised-bed machinery would generate about US$ 750 worth of direct employment. The manufacture of 4800 machines would generate at least 120,000 person-days of employment (at a wage of US$ 30 per day). If a full-time job assumes employment for 220 days, the raised-bed machinery production will lead to approximately 550 full-time jobs (for a single year). Maintenance will also generate employment; it is estimated that a single machine will occupy two workers for ten days each, or 20 days per machine (Frija 2016). Maintenance will produce about 440 full-time jobs, which will be permanent employment.

[14] Al-Riffai et al. (2016) do not distinguish between urban and rural manufacturing and specialized heavy equipment manufacturing is likely to be far more labor intensive than most manufacturing. Their SAM, although highly disaggregated, does not contain the detail necessary to examine employment in plow/planter production.

4.2.1 Additional production due to increased water supply

Benefits from expanded production on down-canal farms would emerge, but the data needed to compute these estimates do not exist. It is known that additional water availability will lead to increased production on down-canal lands. Project documentation shows that raised-bed wheat farmers use approximately 4007 m^3/ha of water compared to 5314 m^3/ha on control farms (ICARDA 2014). Assuming these savings are representative of average savings across the 800,000 ha of potential area under MRB, full expansion of the system will save 1.05 billion m^3 of irrigation water annually.

4.2.2 Spillovers to other countries

As noted, the EFSAC project is piloting MRB methods in countries interested in this technology. As a part of its Morocco Green program, the Moroccan government is interested in improving water use efficiency while sustainably intensifying wheat production. It is estimated that, pending fine-tuning, the technology will be moved immediately to Tadla area, where some 30,000 ha of irrigated wheat are grown. In Tunisia, experimentation is ongoing and it is expected that if the adaptive research is successful, the area under raised-bed technologies will be 30,000 ha out of the total irrigated wheat area of 40,000 ha in Sidi Bouzid.

5 Discussion

Achieving national food security implies tradeoffs between alternative policies. Trade optimists point toward efficiency gains from allowing comparative advantage to dictate domestic food production priorities and using international commodity markets to achieve food security. However, food-insecure countries are now more reluctant to rely on international markets for food security. In fact, analysis prior to the 2007–8 international price spike showed that WANA countries, particularly Egypt, were more food insecure than their income and other conditions indicated. Over-reliance on international markets left them more vulnerable than they would otherwise be (Diaz-Bonilla et al. 2000). In the face of unreliable international markets, the Egyptian government has re-doubled efforts to promote domestic production and MRB wheat production, in addition to raising productivity, saves water and labor, two increasingly scarce inputs. While the global experience with MRB wheat production is mixed (Roth et al. 2005; Sayre and Moreno Ramos 1997), the evidence from field trials in Egypt show the technology to be effective at raising yields by more than 25%, saving water and saving labor-related costs of production (ICARDA 2014, 2016). These yield gains are higher than estimates from Mexico (Sayre and Moreno Ramos 1997) and indicate impressive efficiency gains from the technology.

As the various projects have introduced the MRB technology to new areas in Egypt, wheat farmers have adopted it quickly and there is no evidence of subsequent dis-adoption. The largest obstacle to obtaining the 800,000 ha target with MRB is the lack of machinery, but when the forecast expansion occurs, there will be an additional one billion m^3 of water available for alternative uses per year, enough to farm more than 210,000 additional ha.

Policies to promote wheat productivity directly benefit relatively poor wheat producers and contribute to national food security by increasing wheat availability and access, two important determinants of food security (FAO 2015). MRB production on 800,000 ha will lead directly to an increase in domestic wheat availability of about 1.2 million t, more than 6% of current usage and representing about 12% of current wheat imports. Access to food is enhanced by MRB production as incomes of wheat producers grow by approximately US$ 728 million per year by 2020.

WANA governments intervene in domestic markets and promote wheat production as a hedge against international market volatility. While measurement of the efficiency cost of this hedge is beyond the scope of this study, we show that substantial benefits from use of MRB supplement the program's contribution to food security. Gains to national food security should be considered during assessment of the costs and distributional effects of national wheat policy (Ahmed et al. 2001; Kherallah et al. 2000; Siam and Croppenstedt 2007). While valuation of food security benefits is complicated, ignoring them while evaluating policy underestimates the benefits from an otherwise complex set of policies.

All examples of successful implementation of MRB wheat production in developing countries found in the literature involved longer-term partnerships between NARS and international actors (Sayre and Moreno Ramos 1997; Roth et al. 2005). The conditions that make such partnerships critical to success are not unique to Egypt or WANA-region NARS. These conditions include the long time profile of the necessary research, its multi-disciplinary nature, and the need for research teams to work in a systems approach. Anderson et al. (2013) note that positive organizational changes in NARS require shifting from production of research outputs to fostering innovation to achieve broad social goals, and increased focus on holistic (i.e. system-orientated) research. Others have noted that reductionism is part of the culture of many NARS (Anderson et al. 2013; Vanloqueren and Baret 2009). In this context, it is argued that regional partnerships will help promote systems thinking and will generate economies of scale in collaborative research for development (GFAR 2011).

6 Conclusions

The raised-bed wheat program, an applied research initiative spanning four donor-funded projects, has the potential to transform the Egyptian wheat sector. At a relatively modest research cost, 15-year benefits, even under least optimistic assumptions, exceed multiple billions of dollars. The national wheat campaign of Egypt was restructured under the project's influence and the raised-bed technical package is now a centerpiece of that campaign. Raised soil beds will likely form the core of water savings for wheat production across the WANA region. The process by which the technology package was refined and promoted in Egypt was strengthened by the partnership between ARC and other national and international actors.

The research for development partnership was made possible by long-term engagement of national and international institutions. While Egyptian scientists are capable of developing each of the component technologies on their own, the multi-disciplinary, system's approach promoted by the international research center merged the separate parts into a cohesive package. The long arc of donor funding solidified the package and brought it to fruition.

Compliance with ethical standards

Conflict of interest None of the authors has a potential conflict of interest with respect to the research reported in this paper.

References

Ahmed, A. U., Bouis, H. E., Gutner, T., & Löfgren, H. (2001). *The Egyptian Food Subsidy System: Structure, Performance, and Options for Reform*. Research Report 119, Washington, D.C.: International Food Policy Research Institute.

Alpuerto, V.-L. E. B., Norton, G. W., Alwang, J., & Ismail, A. M. (2009). Economic impact analysis of marker-assisted breeding for tolerance to salinity and phosphorous deficiency in rice. *Review of Agricultural Economics, 31*, 779–792.

Al-Riffai, P., Moussa, S., Khalil, A., Hussein, F., Serag, E., Hassan, N., Fathy, A., Sameih, A., ElSarawy, M., Farouk, E., Souliman, S., & Abdel-Ghafour, A. (2016). *A disaggregated social accounting matrix 2010/2011 for policy analysis in Egypt*. Egypt SSP Working Paper 02. Cairo: Central Agency for Public Mobilization and Statistics and International Food Policy Research Institute.

Alston, J. M., Norton, G. W., & Pardey, P. G. (1995). *Science under Scarcity: Principles and Practice for Agricultural Research and Priority Setting*. Ithaca: Cornell University Press.

Anderson, J., Roseboom, J., & Weidemann Associates, Inc. (2013). *Towards USAID re-engaging in supporting national agricultural*

research systems in the developing world. Washington, D.C: USAID & Weidemann Associates.
Arab Organization for Agricultural Development (AOAD). (2009). *Situations of food security in the Arab countries*. Khartoum: AOAD.
deJanvry, A., & Sadoulet, E. (2002). World poverty and the role of agricultural technology: Direct and indirect effects. *Journal of Development Studies, 38*, 1–26.
Diaz-Bonilla, E., Thomas, M., Robinson, S., Cattaneo, A. (2000). Food security and trade negotiations in the World Trade Organization: A cluster analysis of country groups. TMD Discussion Paper No. 59. Washington, DC: International Food Policy Research Institution.
El Kharraz, J., El-Sadek, A., Ghaffour, N., & Mino, E. (2012). Water scarcity and drought in WANA countries. *Procedia Engineering, 33*, 14–29.
El-Shinnawi, S. A. A., Skold, M. D., & Nasr, M. L. (1980) *Economic costs of water shortages along branch canals*. Cairo: Egypt Water Use and Management Project Technical Report 9.
Food and Agricultural Organization of the United Nations (FAO) (2015). Egypt: Wheat sector review. Rome: Food and Agricultural Organization of the United Nations.
Food and Agricultural Organization of the United Nations (FAO)—Aquastat Query. (2017). http://www.fao.org/nr/water/aquastat/countries_regions/Profile_segments/EGY-WU_eng.stm
Frija, A., Aw-Hassan, A., Mason D'Croz, D., & Assefa, S. G. (2016). *Wheat self-sufficiency in Sub-Sahara Africa: Foresight modeling of improved wheat management and area expansion scenarios in selected countries*. Amman: ICARDA working paper.
GFAR. (2011). *The GCARD Road Map: Transforming Agricultural Research for Development Systems for Global Impact*. Rome: GFAR Secretariat, FAO.
Ghazouani, W., Molle, F., Swelam, A., Rap, E., & Abdo, A. (2014). *Understanding farmers' adaptation to water scarcity: A case study from the Western Nile Delta*. Colombo: International Water Management Institute Research Report 160.
Gouda, D. M. (2016). *Social Capital and Local Water Management in Egypt*. Oxford: Oxford University Press.
Ibrahim, M., Lal, R., Bary, E. A., & Swelam, A. (2012). Water Resources and Agronomic Productivity in the West Asia and North Africa Region. Ch. 7. In R. Lal & B. A. Stewart (Eds.), *Soil and Water Agronomic Productivity.* New York: CRC Press.
ICARDA. (2008). *Options for Coping with Increased Water Scarcity in Agriculture in West Asia and North Africa (CWANA Water Benchmarks Final Report)*. Aleppo: ICARDA.
ICARDA. (2014). *Enhancing Food Security in Arab Countries. First Phase, Final Report*. Amman: ICARDA.
ICARDA. (2016). *Enhancing Food Security in Arab Countries. Second Phase Progress Report*. Amman: ICARDA.
Karrou, M., Oweis, T., Benli, B., & Swelam, A. (2012). *Improving Water and Land Productivities in Irrigated Systems*. ICARDA, ISBN: 92–9127–259-0.
Kherallah, M., Minot, N., & Gruhn, P. (1999). *Adjustment of wheat production to market reform in Egypt*. Market and Structural Studies Division Discussion Paper No. 32, Washington, D.C.: International Food Policy Research Institute.
Kherallah, M., Löfgren, H., Gruhn, P., & Reeder, M. M. (2000). *Wheat Policy Reform in Egypt: Adjustment of Local Markets and Options for Future Reforms*. Research Report 115, Washington, D.C.: International Food Policy Research Institute.
Kukal, S. S., Sudhir-Yadav, Humphreys, E., Amanpreet-Kaur, Yadvinder-Singh, Thaman, S., Singh, B., & Timsina, J. (2010). Factors affecting irrigation water savings in raised beds in rice and wheat. *Field Crops Research, 118*, 43–50.
Majeed, A., Muhmood, A., Naiz, A., Javid, S., Ahmed, Z. A., Shah, S. S. H., & Shah, A. H. (2015). Bed planting of wheat (Triticum aestivum L.) improves nitrogen use efficiency and grain yield compared to flat planting. *The Crop Journal, 3*(2), 118–124.
Matuschke, I., Mishra, R., & Qaim, M. (2007). Adoption and impact of hybrid wheat in India. *World Development, 35*, 1422–1435.
McGill, J., Prikhodko, D., Sterk, B., & Talks, P. (2015). *Egypt: Wheat sector review.* Rome: Food and Agricultural Organization of the United Nations.
Minten, B., & Barrett, C. B. (2008). Agricultural technology, productivity, and poverty in Madagascar. *World Development, 36*, 797–782.
Oweis, T., Zhang, H., & Pala, M. (2000). Water use efficiency of rainfed and irrigated bread wheat in a Mediterranean environment. *Agronomy Journal, 92*, 231–238.
Peeters, M., & Albers, R. (2013). Food prices, government subsidies and fiscal balances in south Mediterranean countries. *Development Policy Review, 31*(3), 273–290.
Roth, C. H., Fischer, R. A., & Meisner, C. A. (eds) (2005). *Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico. Proceedings of a workshop held in Griffith, NSW, Australia, 1–3 March 2005*. Canberra: ACIAR Proceedings No. 121.
Rudi, N., Norton, G. W., Alwang, J., & Asumugha, G. (2010). Economic impact analysis of marker assisted breeding for resistance to pests and post harvest deterioration in cassava. *African Journal of Agricultural and Resource Economics, 4*(2), 110–122.
Sabry, S. (2016) Personal communication.
Saleh, E. M. A., & Ahmed, H. H. (2016). *Enhancing Food Security in Arab Countries, Phase II/Egypt. Results of the Socio-economic Study at Al Dakahlia Governorate. Mimeo, 18 pp*. Cairo: ARC.
Sayre, K. D., & Moreno Ramos, O. H. (1997). *Applications of Raised-Bed Planting Systems to Wheat*. Wheat Special Report No. 31. Mexico: CIMMYT.
Sayre, K., Limon, A., & Govaerts, B. (2005). Experiences with permanent bed planting systems CIMMYT, Mexico. In C. H. Roth, R. A. Fischer, & C. A. Meisner (Eds.), *Evaluation and performance of permanent raised bed cropping systems in Asia, Australia and Mexico*. Proceedings of a workshop held in Griffith, NSW, Australia, 1–3 March 2005. Canberra: ACIAR Proceedings 121.
Shideed, K., Shomo, F., & Aw-Hassan, A. (2010). Population growth and trends in food production and consumption in the CWANA region. Ch. 69. In P. Pingali & R. E. Evenson (Eds.), *Handbook of Agricultural Economics, Volume 4*. Amsterdam: North-Holland.
Siam, G. M., & Croppenstedt, A. (2007). *An assessment of the impact of wheat market liberalization in Egypt: A multi-market model approach*. ESA Working Paper No. 07–15. Rome: FAO.
USAID. (2006). *Impact on Egypt's Economic of Eliminating Domestic Support for Commodities: Literature Review of Supply and Demand Elasticity.* Cairo: Nathan Associates.
Vanloqueren, G., & Baret, P. V. (2009). How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations. *Research Policy, 39*, 971–983.
Veninga, W., & Ihle, R. (2018). Import vulnerability in the Middle East: effects of the Arab spring on Egyptian wheat trade. *Food Security, 10*(1), 183–194.
Wahby, H., Quenemoen, M., & Helal, M. (1984). *A Procedure for Evaluating the Cost of Lifting Water for Irrigation in Egypt*. Egypt Water Use and Management Project technical report 7. Cairo: USAID. http://pdf.usaid.gov/pdf_docs/PNAAT150.pdf.
World Bank, FAO & IFAD. (2009). *Improving Food Security in Arab Countries*. Washington, DC: World Bank https://openknowledge.worldbank.org/handle/10986/23966. License: CC BY 3.0 IGO.
Zeng, D., Alwang, J., Norton, G. W., Shiferaw, B., Jaleta, M., & Yirga, C. (2015). Ex-post impacts of improved maize varieties on poverty in rural Ethiopia. *Agricultural Economics, 46*, 515–526.
Ziadat, F., Mazahreh, S., Haddad, M., Benabdelouahab, T., Attaher, S., Karrou, M., Oweis, T., & Kandakji, T. (2014). *Similarity and Suitability Analysis to Assist the Out-Scaling of Sustainable Water and Land Management Practices in West Asia and North Africa*. Research Report 11. Beirut: ICARDA.

Jeffrey Alwang is an applied agricultural economist with more than 30 years of experience. He received his PhD in 1989 from Cornell University, USA and has been employed as a professor in the Department of Agricultural and Applied Economics at Virgina Tech since then. His research focus is in poverty and vulnerability analysis, assessment of impacts of agricultural technologies, and agricultural policy analysis. Jeffrey has served in advisory context to several CGIAR centers, including IFPRI, ILRI, CIP, CIAT, ICARDA and CIFOR. He has also consulted for the World Bank, FAO, USAID and others.

Dr. Sami Sabry is Emeritus Research Professor, Wheat Research Department, Field Crops Research Institute (FCR), Agricultural Research Center (ARC), Egypt. He is also National Coordinator for the EFSAC "Enhancing Food Security in Arab Countries" project in Egypt and Former Director of the Field Crops Research Institute (FCRI) Agricultural Research Center (ARC), Egypt.

Kamel Shideed is currently ICARDA's Assistant Director General for International Cooperation and Communications, a post he has held since 2009. Prior to that and starting in 2005 he was the Director of ICARDA's Social, Economic and Policy Research Program after serving at ICARDA as a senior Natural Resources Economist since 2004. Before joining ICARDA, Kamel was Professor and Head of Planning and Economic Analysis at the Agricultural Research System and the University of Baghdad in Iraq. He has a wide range of experience including international agricultural research-for-development, resource mobilization and donor's relations, and partnerships. He has an active network with partners in many developed and developing countries, particularly in West Asia, North Africa, the Nile Valley and Sub-Saharan Africa, South Asia, and the Central Asia and Caucasus regions. Kamel received a PhD from Mississippi State University, USA in 1984 in Agricultural Economics. He has authored and co-authored over 130 publications.

Atef Swelam Spanning over 15 years, **Dr. Atef Swelam**'s experience in irrigation and water management has focused on the sustainable intensification and diversification of small-scale farming systems. From irrigation management to climate resilience, his research and field work have been targeted towards open-source and innovative solutions to improve the livelihood of poor communities. His research covers various fields including irrigation, drainage and salt-affected soil management, as well as the socio-economic dynamics surrounding water use. He has channeled his expertise in agricultural water management to uncover innovative and easily applicable solutions to increase biophysical and economical farming system productivity. He currently works as a Senior Scientist at the International Center for Agricultural Research in the Dry Areas (ICARDA). Prior joining ICARDA, Atef was associate professor of water management at the University of Zagazig, Egypt.

Habib Halila received a Master of Science in soil sciences and irrigation from Utah State University, USA in 1972 and a Doctor of Philosophy (PhD) in Biology/Plant Pathology from the University of London, UK in 1974. He was Principal Agronomist, Ministry of Agriculture, Tunisia and Chief and Founder of the National Laboratory of Food Legumes Research at the National Institute for Agricultural Research in Tunisia. Since 1997 he served as ICARDA Regional Coordinator of the West Asia Regional Program based in Amman, Jordan, and covering Cyprus, Lebanon, Jordan, Iraq, Syria and Turkey. Then, beginning in 2001 he was ICARDA Regional Coordinator of the Nile Valley and Red Sea Regional Program based in Cairo, Egypt and covering Egypt, Sudan, Ethiopia, Eritrea and Yemen. From 2005 to 2009 he was the FAO Representative in Morocco and is currently ICARDA Coordinator of the project, Enhancing Food Security in Arab Countries.