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Enhancing Food Security in Arab Countries Project:
Adoption and Impacts of Project Interventions and Returns on Investment in Egypt, Jordan, Morocco, Sudan, and Tunisia

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WORKING PAPER **15**

ISSN 2709-7757
9 772709 775008 01524

Suggested citation

Yigezu, Y.A., El-shater, T., Sweidan, R., Saleh, E.A., Maaroufi, H., Ibrahim, A.M.M., and Boughlala, M. 2024. Enhancing Food Security in Arab Countries Project: Adoption and Impacts of Project Interventions and Returns on Investment in Egypt, Jordan, Morocco, Sudan, and Tunisia. ICARDA (International Center for Agricultural Research in the Dry Areas) Working Paper #15. Beirut, Lebanon.

About ICARDA

Established in 1977, the International Center for Agricultural Research in the Dry Areas (ICARDA) is a non-profit international organization undertaking people-centered research-for-development to provide innovative, science-based solutions to improve the livelihoods of communities across the non-tropical dry areas. In partnership with research institutions, governments, NGOs and the private sector, our work advances scientific knowledge, shapes practices, and informs policy.

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Acknowledgment

Financial supports for this research were obtained from the project on Enhancing Food Security in Arab Countries (EFSAC) - funded by the Arab Fund for Economic and Social Development (AFESD), Kuwait Fund for Arab Economic Development (KFAED), the Bill & Melinda Gates Foundation (BMGF), the OPEC Fund for International Development (OFID), the Islamic Development Bank (IsDB) and the CGIAR Program on Wheat (CRP-WHEAT). The funders of this research had no bearing on any of the analyses and results of this study. The authors would also like to thank Drs. Habib Halila and Seid Kemal the outgoing and incoming coordinators of the project and Drs. Sami Sabry, Yahya Bani Khalaf, Mohamed Boutfirass, Amani Idris, and Ibtihel Sbai, who are the national coordinators of the project in Egypt, Jordan, Morocco, Sudan, and Tunisia for their unreserved support in the production of this working paper. Last but not least, we would like to thank all the enumerators and the kind farmers in all five countries who volunteered to provide the needed data for this study.

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List of Acronyms

2SLS	Two-stages least square
ANA	Agricultural Nutrient Assistant
ARC	Agricultural Research Center (Egypt)
DAP	Di ammonium phosphate
EFSAC	Enhancing Food Security in Arab Countries
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
FY	Fiscal year
GDP	Gross domestic product
IFAD	International Fund for Agricultural Development
INRA	National Institute of Agricultural Research
IV	Instrumental variables
MAD	Moroccan Dirham
MVP	Multivariate probit
MVT	Multivariate tobit
NARC	National Agricultural Research Center (Jordan)
ONICL	Office National Inter-professional of Cereals and Legumes
PSM	Propensity score matching
ROI	Returns on investment
SARD-SC	Support to Agricultural Research for the Development of Strategic Crops in Africa
SMS	Short Messaging Service
SSR	Self-sufficiency ratio
WANA	West Asia and North Africa

A) Project overview, data, and methods

1. Introduction

The 2008 global food crisis alerted the world, and especially import-dependent countries such as many countries in the Arab world, to the vulnerability of food supplies and prices to global environmental risks. While global food supplies have stabilized, weather and climate change risks, national and regional conflicts, trade embargos, and competition for resources continue to pose risks to food prices and food availability now and in the future. Most Arab countries cannot meet their food demands from domestic production and depend on food imports in varying degrees – making them the most import-dependent countries in the world. Arab countries import at least 50 percent of the food calories they consume (FAOSTAT, 2018). Projections of the region's food balance indicate that dependence on imports will increase by 60 percent over the next 20 years (IFAD, 2009), making countries vulnerable to both price hikes and shortages in food supply in the international market, and put pressure on countries' economies, as foreign exchange is diverted to financing food imports. Given the expectations that the Arab region will remain a food deficit region and thus dependent on international markets to feed its growing population, it is essential that new strategies for enhancing food security be developed and implemented.

No other crop better embodies the concerns over food security in the Arab region than wheat. On average, wheat consumption in the region is around 130 kg per capita annually, double that of the world average. Wheat is a central component to the diet of most Arab countries and, consequently, its availability constitutes an important element of food security. In the Middle East and North Africa, it contributes to almost 40 percent of the population's calorie intake, reaching as much as 50 percent in some countries (FAOSTAT, 2018). Food legumes (faba bean, kabuli chickpea, and lentil) are also important staple foods; they are a valuable source of dietary protein and a critical component in sustainable wheat-based cropping systems. Barley is another strategic crop: as a principal feed, it is of critical importance for the livestock sector in the Arab world. The region is the largest net importer of wheat in the world, importing up to 30 percent of globally traded wheat in 2010 (World Bank and FAO, 2012). Given the cultural importance of wheat in the Arab region's food system, which makes its demand quite inelastic, there is little prospect that there will be a significant decrease in consumption. Thus, increasing wheat productivity and production would significantly contribute to enhancing food security in the region, while reducing the substantial costs of imports and dependence on external sources of food.

Arab countries face severe challenges to increasing their agricultural production, including a limited natural resource base of arable land and water, and low and variable rainfall with frequent droughts. Except for Egypt and Sudan, most food crop production in Arab countries is under rainfed conditions, resulting in large production variability. For instance, Algeria was affected by drought in 2014, which resulted in below-average cereal harvests, six percent below the level of 2013. Similarly, Morocco faced dry conditions during the autumn of 2013, which slowed down wheat planting and led to a reduction of 27 percent in wheat harvests in 2014. In 2016, severe drought pushed the agricultural sector into negative growth in Algeria, Morocco, and Tunisia. Water is the single most binding constraint in the agricultural sector in the region, and the potential for expanding irrigation area is limited. The region uses more than 80 percent of its water resources for agriculture, compared to 65 percent for most other regions. Given population growth and demands from other sectors, it is likely that water resources will increasingly be reallocated from agriculture to domestic and industrial uses. Climate variability and change are expected to reduce water resources even further. Therefore, the agricultural sector must produce more food with less water to feed its expanding population. Improving the efficiency of on-farm water use can directly contribute to saving water. Alternatively, farmers can increase their yields from current levels of water use by using improved water and crop management practices, combined with the use of new crop varieties that perform well under water-limiting conditions. Given that there is little prospect for expanding arable land or irrigation, the key to increasing food production is improving productivity per unit of land and of water.

In the Arab region, there is huge potential to increase the yields of staple crops. Actual farm yields of crops in the region are far below their potential. However, while closing these yield gaps is one way to increase productivity, Godfray et al (2010) note that yield gaps are not static, and "maintaining, let alone increasing, productivity depends on continued innovation to address emerging constraints, for instance to control pest and diseases as they evolve resistance, or spread to new regions. The maximum attainable yield in different regions will also shift as the effects of climate change are felt". Above and beyond these existing constraints, the West Asia and North Africa (WANA) region is most vulnerable to the impacts of climate change. According to the World Bank (World Bank, 2014), the WANA region emerges as one of the hotspots for worsening extreme heat, drought, and aridity. Temperatures are expected to rise by up to 2oC within the next 15–20 years and by over 4oC by the end of the century. These climate projections mean a hotter, drier, and less predictable climate for the region. Agriculture, especially rainfed agriculture, is highly exposed to changing climatic conditions. Lower rainfall and higher temperatures will shorten growing periods for wheat and other food crops in large parts of the region. Changes in rainfall and temperature regimes may affect the spread and severity of plant pests, diseases, and weeds. As a result of regional warming and changes in precipitation patterns, water availability is projected to decrease in most parts of the region throughout the 21st century. Future food and nutritional security will depend on the application of science to identify improved varieties and integrated crop, soil, and water management practices that ensure protection against prevailing and emerging climatic and biological challenges, along with investment in research and the transfer of technologies to farming communities. For national research programs to meet these challenges, they require a cadre of qualified researchers trained in new and emerging research approaches needed to address the specific problems encountered by each country. Evidence shows that the Arab countries in general are facing a "skills gap"—an acute shortage of agricultural researchers. Investment is needed not only in agricultural production, but also in developing the next generation of research and extension staff who will take these efforts forwards.

The main objectives of this project are to boost agricultural productivity and resource conservation through sustainable intensification of the wheat-based production systems in the project countries. This was primarily approached through the introduction of wheat technology packages that are proven to be effective in achieving sustainable intensification. While there are some differences in the number and types of components within the technology packages promoted in each of the project countries, the main components (sometimes referred to as the hardware) are improved varieties. To ensure the exploitation of the full genetic potential of the improved wheat varieties, the project has packaged them with several (up to 10) agronomic, irrigation, and land preparation-related technologies and innovations. The different components of the technology packages may not necessarily be new and unique to the EFSAC project, but the way they have been packaged and promoted are often new. Unlike the common practice of technology packaging, which is entirely based on increasing productivity, technology packaging in the EFSAC project has added two important considerations, namely resource conservation and economic viability. In addition to the technology packaging, the other, perhaps more important, innovation in this project, is the technology promotion approach used. Generally, the approaches used by the EFSAC project for technology promotion and scaling can be classified into three groups:

Mass dissemination approach (Egypt): This approach consists of implementing, at a given site/village, the highest possible number of demonstration plots in farmers' fields to cover different areas, types of soils, and irrigation water management systems. Every plot is supervised by a village-based extension agent linked to a wheat extension agent who works under the supervision of the Governorate extension specialist. In addition, every 8–10 fields are closely supervised by a researcher from the project team, which involves improvement specialists, pathologists, and soil scientists/plant nutritionists.

Leading and satellite (clustered) farmers approach (Tunisia and Morocco): This approach is based on selecting leading progressive farmers in each area. In the selected farmers' fields, an improved wheat production package is fully demonstrated on large plots. In Morocco, these plots are called platforms. Around each leading farmer (platform), a group of 8–10 satellites farmers is selected. The satellite farmers are coached on wheat improved technologies, either through the installation of a simple problem-solving demonstration (Tunisia) or through direct technical advice on the best practices to be used, provided during

Farmers Field Schools by a project extension agent and researchers (Morocco). Moreover, an innovative approach, based on mobile phone and Short Messaging Service (SMS) technologies, was used for the first time in Tunisia to provide farmers with prompt access to technical information and advice. A preliminary impact assessment of the approach shows that SMS technology was welcomed and accepted by farmers.

Multi-tool dissemination approach (Algeria, Sudan, Syria, Jordan, Yemen, and Iraq): This approach is based on the classical technology transfer extension approach. It consists of implementing a limited number of demonstration plots conducted under farmers' conditions being distributed randomly across a given area/site. Farmers Field Schools, field days, and traveling workshops are the main tools to disseminate and popularize the improved technologies.

This report provides a comprehensive assessment of the cumulative adoption and impacts of the different interventions of the project during the three phases (2018–2022 cropping seasons). While more detailed and comprehensive reports are produced for each of the five countries, this report provides more concise and condensed information focusing on the main findings that are worth highlighting, because they have important policy, institutional, and strategic implications for governments, donors, development organizations, and extension personnel.

2. Literature review

Over the years, different conceptual frameworks have been developed for adoption and impact assessment. One of the most common is the sustainable rural livelihoods framework, which is adapted to assess impacts of agricultural research; as described by Kerr and Kolavalli (1999) and Adato and Meinzen-Dick (2003). A more recent framework is Maredia's framework (Maredia, 2009), which uses impact analysis to estimate the total effect of a new technology on a set of outcomes, after some amount of diffusion has taken place. According to Maredia (2009), two key quantities must be estimated in order to arrive at the total impact of a new technology: the extent of adoption and the average effect that adoption has on outcomes for those who have adopted. This is a continuous process, as the effect of adoption on outcomes is not static—because the general equilibrium effects relating to diffusion of a technology change impact over time (Cochrane, 1979).

Various benefits motivate farmers to adopt agricultural technologies. Foster and Rozenzweig (2010) showed that improved technology adoption is an outcome of optimization by households, whereby adoption is a choice that farmers only take when they expect to get benefits from it. The adoption decision is multi-stage, during which the farmer must decide whether to adopt the technology and to what extent (Astebro, 2004; Smale et al., 1991; and Jha et al., 1990). In many developing countries, decisions to adopt a technology are made under imperfect market, credit, and labor conditions (Kerr and Kolavalli, 1999).

Based on adopters' ability to aggregate individual components of the package, Feder et al (1985) distinguished three types of adoption: 1) individual vs. aggregate adoption, 2) singular vs. packets of technologies available for adoption, and 3) divisible vs. non-divisible technologies. The first option is between final adoption at the individual level and the aggregate adoption behavior which is observed with the diffusion of a technology. However, in most cases, agricultural technologies are introduced in bundles, and these bundles are often complementary, as in the second and third options.

The pattern of scaling out technology plays an important role in its dissemination, as adoption by an individual farmer often influences the propensity of other farmers' adoption decisions. Conley and Udry (2010) showed that when a pioneer farmer adopts, this may have spillovers for the other farmers by providing the opportunity to learn from their experience. Factors that determine agricultural technology adoption and its diffusion patterns are well described in the literature. The most important determinant of adoption is farm size, as shown by Neill and Lee (2001), Adesina and Baidu-Forson (1995), and Christine and Barrett (2003). These pioneers have demonstrated that adoption rates of improved agricultural technologies are higher among bigger farms. Alternatively, Feder and Umali (1993) noted that small farms tend to use some components of the technology package which they believe to be more advantageous and requiring less initial investment. They pointed out that while larger farms adopt technologies faster than smaller ones, the latter partially adopt the technology and may eventually fully adopt technologies as they become familiar with them.

The observed patterns of technology adoption are influenced by farmers' risk preferences (Feder et al., 1985). Risk and uncertainty arise from the fact that benefits from technologies are expected in the future, but bearing the cost is immediate (Lee, 2005). The determinant role of risk and uncertainty is shown in that non-adopter farmers refrain from using the technology because they expect to incur certain losses with adoption (De Janvery, 1972). Also, some farmers don't adopt profitable technologies with high risks even when they raise expected profits (Sunding and Zilberman, 2001).

Farmers' characteristics, such as education, health, age, and gender, are also important determinants of adoption. According to Mendola (2007), improvements in health and education services have led to higher adoption of new technologies in Bangladesh. While human capital traditionally focuses on education and health indicators, many studies examined farmers' rationality as a determinant factor in the technology adoption process. For example, Adesina and Baidu-Forson (1995) found that adoption of different sorghum varieties in Burkina Faso was based more on grinding characteristics than on output increases. Similarly, Zinnah et al (1993) showed that farmers' assessments of the relevance of technologies to their specific needs is more important than their exposure to technology during its dissemination.

The requirement for manual labor significantly determines adoption, especially where labor shortage exists. In regions with inadequate labor supply, adoption rates of labor-intensive technologies are expected to be low. For instance, Lee (2005) showed that labor availability influenced adoption of soil conservation technologies in the Philippines and Ethiopia. However, the case is different with subsistence farming, whereby the family size (and therefore labor availability) did not significantly influence adoption. This can be shown by the work of Feder et al (1985), who examined adoption of cassava technologies in subsistence farming in Nigeria and concluded that adoption decisions were not related to labor shortages. They explained this discrepancy by suggesting that subsistence farming does not face the same types of labor shortages as market-oriented agriculture.

Most models of adoption estimate the probability of an event taking a binary outcome dependent variable subject to a subset of explanatory variables. The most widely used models rely on the binary logistic or probit models, which are extended for two-stage or joint estimation of a set of equations. As discussed by Ashford and Snowden (1970) and Amemiya (1974), the binary logistic and probit model's dependent variable can assume only two outcomes: the presence or absence of an event. Both logistic and probit models assume a dichotomous dependent variable and the linearity for the continuous independent variables, but there is no Gaussian assumption on the residuals. The difference between logistic and probit models lies in their distribution: the probit model assumes cumulative density function of the normal distribution, while the logistic model follows a cumulative density function of the logistic distribution.

The multivariate probit model (MVP) is a generalization of the binary probit model. The model simultaneously estimates several correlated equations, each with a binary choice dependent variable and a subset of independent variables (and hence assumes that the error terms across equations are correlated). The MVP model is described in terms of correlated Gaussian distribution for underlying latent variables through a threshold level. The multivariate tobit (MVT) model is used here to estimate the extent (or level) of adoption of the different components of the technology package. This helps to determine the actual quantities of inputs applied by the farmers, while also capturing the endogeneity and simultaneity in the decisions. The rationale behind the endogeneity argument is that one or more of the omitted variables, which have a bearing on the adoption of one component of the technology package, are highly likely to also have a bearing on the remaining components of the technology package. Likewise, factors such as resource constraints are expected to create competition for limited resources, whereby the adoption of one component may limit the farmers' ability to adopt the other components at a higher extent (regardless of their interest to do so). Similarly, the complementarities between different technology components could mean that higher adoption of one component might necessitate higher levels of adoption of another—and hence arises the need for using the MVT model to capture such potential simultaneity across the decisions on the extent of adoption of the different components.

In fields other than agriculture, several previous studies have attempted to model household behavior. Mannering and Winston (1985) are the pioneers in this area. Using data from both a cross section and panel of US households, they estimate a discrete/continuous model of vehicle quantity, vehicle type, and utilization choice. Both vehicle quantity and vehicle type were estimated using the discrete model and utilization choice was estimated using the continuous model. Johansson-Stenman (2002) estimated a version of Cragg's (1971) double hurdle model, including a third decision to model the following: whether a household decides to have a car not; whether a household decides to drive the car or not, given that they have a car; and how much to drive, assuming that this is a driving distance which is larger than zero. The first two decisions are modeled using a probit model, while the last decision is modeled using a truncated regression model. In estimating both the Cragg model and the Heckman model. Johansson-Stenman (2002) find some evidence to indicate that the Cragg model fits the data better, albeit evidence which the author admits not to be wholly conclusive. Many authors have since followed Mannering and Winston's (1985) approach by modeling the joint decisions of car ownership and car use using a variety of econometric methodologies.

On the impact side, estimation of local average treatment effects (Imbens and Angrist, 1994) has been the focus of program evaluation literature. The major challenges in program evaluation are related to establishing a counterfactual which serves as the benchmark against which the treated are to be compared. However, it is practically impossible for a single subject/object to be treated and untreated at the same time. Therefore, establishing a counterfactual becomes vital. In the effort to establish counterfactuals, common challenges pertain to selection bias (where participants self-select themselves into or out of treatment) and endogeneity, where there are factors which affect not only the outcome but also the participation decision. The experimental approach is generally viewed as the most robust evaluation approach because it can minimize or, at best, eliminate both selection bias and endogeneity problems (Burtless, 1995). However, this approach is criticized for being expensive, in addition to problems associated with its design (White and Lakey, 1992). In the developing world, having panel data with complete randomization (necessary for experimental approaches) is mostly difficult. As a result, quasi-experimental approaches and, to a large extent, non-experimental observational surveys are widely available.

Several econometric approaches can be used to address the problem of selection bias in program evaluations using quasi-experimental and observational data. Imbens and Wooldridge (2009) provide a good review of the literature and the developments in causal inference and impact assessment. Propensity score matching (PSM), due to Rosenbaum and Robin (1983), is by far the most widely used approach for improving causal inference and estimation of local average treatment effects (El Shater et al., 2016; Morgan and Winship, 2014; Henderson and Chatfield, 2011; Jalan and Ravallion, 2003). PSM helps in correcting biases introduced only by observable covariates (Heckman and Vytlacil, 2007). Therefore, results from PSM can sometimes be misleading, as unobservable factors (such as skills and motivation) can influence not only the outcome but also the program participation decision, thereby leading to confounding errors (see Austin, 2008 for a critical review of PMS). To overcome this problem, the endogenous switching regression (Maddala and Nelson, 1975) and instrumental variables (Angrist et al., 1996) methods have been proposed. Both methods account for the endogeneity of the participation decision and are potent to correct for selection bias introduced by both observable and unobservable factors.

3. Methods

In this study, several different but complementary methods are used to make estimates about adoption rates and adoption degrees, to explain the decision and intensity of adoption and generate sound estimates of the impacts of the project in the five countries. To make consistent analysis and, at a later stage, make comparative and combined regional studies possible, the methodology used across all five project countries included in this report were standardized, with the same kinds and specifications of models used.

3.1 Adoption rate and adoption degree

In this study, adoption rate is defined as the percentage of farmers using the improved varieties with any other components of the technology package promoted by the Project. Meanwhile, adoption degree is defined as the percentage of the wheat area cultivated using the technology(ies) under consideration. To generate those estimates, descriptive statistics (measures of central tendency and measures of dispersion) are used. The descriptive analysis provides information about the distribution of wheat farmers and their wheat fields with respect to different characteristics and traits. For example, estimates of adoption degrees per sample household are generated as the ratio of total wheat area on which the household cultivated wheat with the specified technology(ies) and the total wheat area cultivated by the household expressed in percentages. Then, the total wheat area owned by each of the sample households in the village is used as weights for aggregation of the household-level adoption degree estimates, in order to generate village-level estimates of adoption degree. Likewise, the village level adoption estimates generated for each of the sample villages are weighted by the total wheat area in each village for aggregation of the estimates to district levels. The district level estimates of adoption degrees are then aggregated to provincial level using the district level total wheat areas as weights. Likewise, for estimation of adoption rates (percentage of farmers) at the different geographic or administrative scales, the total number of wheat farmers (instead of total wheat area) at each scale is used for upward aggregation of the estimates.

3.2 Explaining farmers' propensity and intensity of adoption

The propensity of adoption is defined here as the change in the probability of a farmers' tendency to use a given technology in response to a unit change in the value of a given explanatory variable. On the other hand, intensity of adoption is defined as the magnitude of change in the area a given farmer devotes to the specific technology (or combination of components of a technology package) in response to a unit change in the value of a given explanatory variable. In this study, regression analysis—based on the double hurdle approach (Cragg, 1971), which perceives the adoption decision as a two-step decision—is used to first analyze the causal relationship between the adoption decision and different factors, including farm and farmer characteristics, institutional, policy, and infrastructure. In the first stage, the model uses a binary outcome dependent variable, which takes a value of one when a given farmer's observed decision is to adopt and zero if the farmer is observed to have not adopted the technology component(s) under consideration. In the second stage, the model estimates a regression model with a continuous variable (particularly wheat area put under cultivation using the technology component(s) under consideration) as the dependent variable, with the same or different factors used in the first step as explanatory variables. In the second stage regression, the coefficients on each of the explanatory variables are estimated as the extent of change in area used for the technology in response to a unit change in the value of a given variable (factor), conditional on the fact that the farmer has already made the decision to use the technology. This means that farmers who have made the decision to not use the technology or those who would not adopt the technology (i.e., farmers with propensity score of zero) in the first step are, in effect, excluded from analysis in the second step.

The decision to adopt a given technology component (combination of components) is modeled as a binary function; the latent variable underlying household i's decision to use the improved technology ITi* is specified as:

$$ITi^{*}=x_{1i}'\beta_1 + \varepsilon_{1i} \quad (1)$$

Where the vector x1i reflects determinants of the adoption decision, β1 are parameters, and ε1i is a normally distributed error term with mean zero and constant variance. The corresponding probit is estimated on the observed outcome ITi=1 if ITi*>0 and 0 otherwise.

The desired area planted to ITi is also an unobserved latent value that can be specified as:

$$A^*i = x_{2i}'\beta_2 + \varepsilon_{2i} \quad (2)$$

where x2i are determinants of area, β2 are parameters, and ε2i is a normally distributed error term. Since A*i is a latent variable, we work with observed area (Ai). Observed area = A*i if ITi*>0 and = 0 if ITi*≤ 0. Because we use observed area, the error term is a truncated normal distribution. The parameters β1 and β2 can be estimated separately because the Cragg likelihood function is separable; the marginal effects, however, need special attention (Burke, 2009).

3.3 Measuring impacts

Various models are used for impact analysis, based on their underlying assumptions and potency in eliminating bias arising from observed or non-observed factors, or both. In this study, the instrumental variables (IV) regression approach is mainly used to measure the impacts of adoption of improved wheat technology packages among farmers in the five project countries. The IV approach for measuring causal effects of a treatment on an outcome (Angrist et al., 1996) is designed to filter out both overt and hidden biases and deal with the problem of endogenous treatment. IV methods are becoming common in program evaluation and comparative effectiveness research (Rui Zhang, 2022; Silvia Moler, 2022; He and Perloff, 2016; Kumar and Mangyo, 2011; Heckman and Vytlacil, 2005; Manski and Peppe, 2000). The IV method requires that the "instrument" meets three important conditions: 1) the instrument must be associated with the treatment; 2) the instrument does not affect the outcome except through its effect on the treatment—also known as the exclusion restriction assumption; and 3) the instrument does not share any causes with the outcome. The reliability of the results from IV regression depends on the fitness of the instrument in fulfilling the above conditions (Imbens, 2004; Abadie, 2003). Therefore, for measuring the impacts of agricultural technologies, it is important to identify an instrument(s) which is (are) correlated with the decision to adopt but uncorrelated with the unobserved factors that influence the outcome (Shiferaw et al., 2014; Alene and Manyong, 2007; Heckman, 1996). In some cases where no strong instrument is found, the Endogenous Switching Regression (Maddala and Nelson, 1975) is also used.

Suppose that there is endogeneity between the treatment variable X1 and the outcome variable Y. Suppose also that Z is a matrix of exogenous covariates which qualify as valid instruments for X1. Then, the IV model can be described by equations 3 and 4.

$$y = X\beta + \vartheta \quad (3)$$

$$X\_1 = Z\Pi + \mu \quad (4)$$

Where β and Π are vectors of coefficients and ϑ and μ are the error terms and, $E[X^T\ \vartheta] \neq 0$, $E[Z^T\ \mu] = E[Z^T\ \vartheta] = 0$, $Var(\vartheta) = \sigma^2_\vartheta$, $Var(\mu) = \sigma^2_\mu$ and $Cov(\vartheta,\mu) = \sigma_{\mu\vartheta}$. $\sigma_{\mu\vartheta}$ is a measure of the level of endogeneity between the treatment and outcome variables.

The two-stages least square (2SLS) estimation procedure is then used to estimate equations 3 and 4 jointly, where equation 4 is estimated first and then the predicted values used in equation 2 are in place of the observed values of X.

For farmers to adopt a new technology, it is necessary that they first hear about the technology and obtain adequate information about it. Therefore, participation in efforts—i.e., hosting demonstration trials or attending field days or both—under the EFSAC project that attempted to popularize the technologies is believed to affect farmers' adoption decisions. As demonstration trials on farmers' own fields are done with less intervention from researchers, and field days are often organized to show the results following the use of the new varieties, not to teach farmers the mechanics of cultivating the new varieties, participation in either or both efforts is not expected to directly influence yield, except through its effect on the adoption of the improved varieties. Therefore, participation in either or both of hosting demonstration trials and participation on field days are used as instruments in this study.

To create a more homogenous dataset, logarithmic transformation has been made on all continuous variables (such as income, consumption, farmer age, years of education, farm size, wheat area, and all quantities of inputs) that are included either as dependent or explanatory variables in the IV regression. Several factors, such as varieties, fertilizer amounts, seed, labor, and tillage type used are important in determining yield, which, in turn, affects income and consumption. Therefore, all these variables are included as explanatory variables in the model.

Tests for over-identifying restrictions are also carried out. First, as discussed above, to test whether the instruments are uncorrelated with the error term. Second, to detect if the equation is mis-specified and whether one or more of the excluded exogenous variables should, in fact, be included in the structural equation. Thus, a significant test statistic could represent either an invalid instrument or an incorrectly specified structural equation. The Hausman test for endogeneity (Nakamura and Nakamura, 1981) and the Durbin (Durbin, 1954) and Wu–Hausman (Wu, 1974; Hausman, 1978) statistics, which are reported after 2SLS estimation with a robust variance–covariance matrix of the estimators, were also evaluated if endogeneity is a problem. In all cases, if the test statistic is significant, and hence the null hypothesis of exogenous treatment is rejected, then the treatment variable must be treated as endogenous—justifying the use of the instrumental variables approach. Version 15 of the Stata software (StataCorp, 2017) was used for all econometric estimation in this study.

4. Data

4.1. Sampling design

The sampling design and the data collected in all five project countries was standardized for consistency and comparability, and to make the data amenable for aggregation so it is possible to conduct regional analysis in the future. Moreover, to make it easier to establish counterfactuals for impact analysis, a decision was made to include provinces, districts, villages, and farmers which were and were not served by the project. To this effect, provinces/governorates were purposively samples where all project provinces were included. Then, in countries where other provinces exist—which are like the project provinces in terms of agro-ecological and wheat production conditions, but where the project didn't work—one province was included to serve as a counterfactual. Afterwards, the sampling followed a three-stage mixed sampling procedure. First, districts and villages were stratified into project and non-project districts and villages. Then, random samples of project and non-project districts and villages were selected for inclusion into the sample. Finally, farm households were randomly selected at the village levels (where villages are the primary sampling units).

4.2. Sample size determination

Power analysis was conducted to determine the minimum sample sizes needed in each country to ensure confidence levels of at least 95 percent and precision levels of at least 3 percent. The total number of wheat-producing farm households in the study provinces was used for power analysis. Accordingly, a minimum of 600 households were included in the samples in each of the five project countries. The sample households were then distributed across all the sample provinces, districts, and villages proportional to the number of farmers at each scale, with larger samples taken from areas where there were greater numbers of farmers. Given that the main objective of this study is to draw lessons from the project interventions, there was concern that by taking random samples of farmers at the village levels, we may run the risk of not having enough farmers in the sample who are participating in the project. To mitigate this potential problem, the study team decided to take a random sample equivalent to 66 percent of the total sample size, and then took (using a random sampling procedure) the remaining 33 percent from those who were project participants. By doing so, the team ensured good representation of project participant and non-participant farmers in the sample.

B) Results, discussion, conclusions, and recommendations

5. Egypt

5.1 Background

Wheat area in Egypt for the period 2018-2020 was about 1.16 million ha (Figure 1). Egypt's wheat production has increased by about 33 percent in the last two decades, from about 6.58 million tons in 2000 to about 9.11 million tons in 2020 (MALR, 2022). However, Figure 2 shows that domestic wheat production dropped to 7.17 million tons in 2010. This was attributed to an unusual heatwave that hit Egypt in February 2010—the time of pollination—

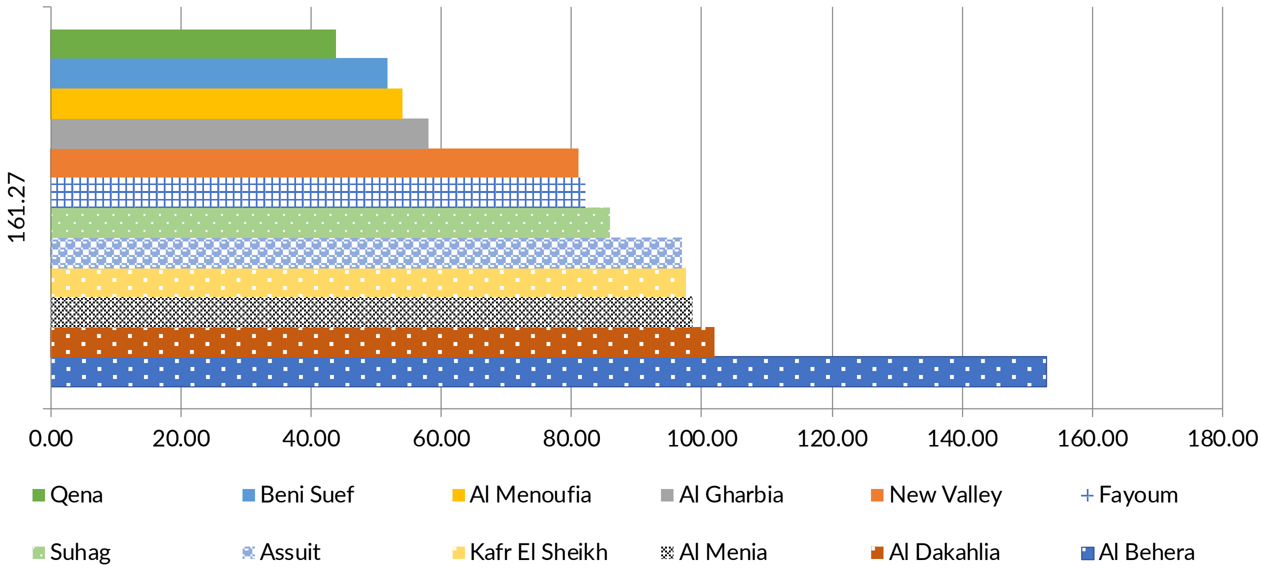

Figure 1. The top-13 wheat-growing governorates in Egypt (Average for 2018–2020).

Source: (MALR 2022).

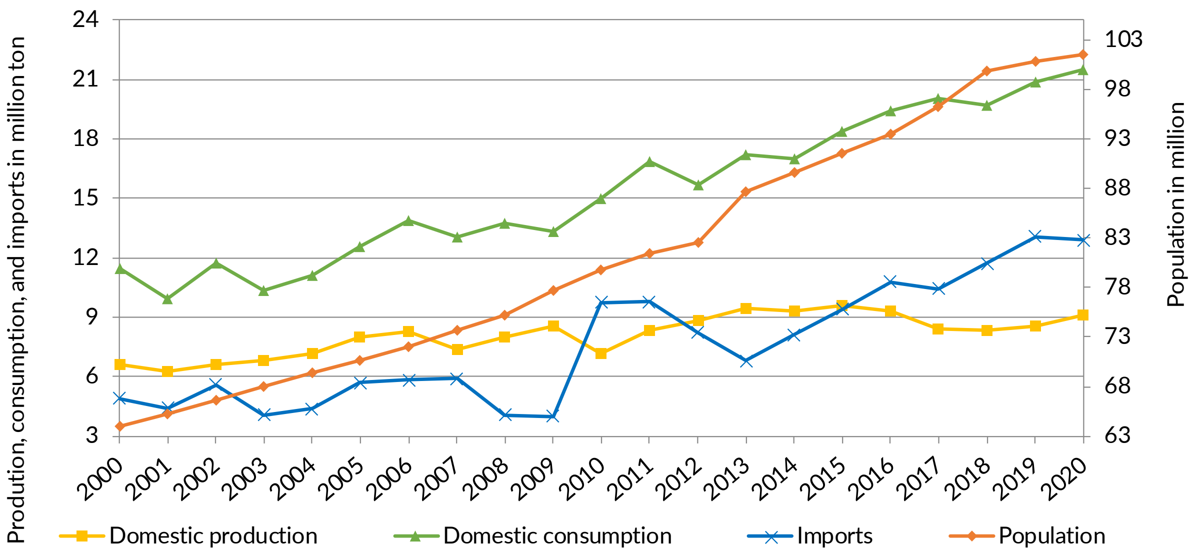

Figure 2. Domestic wheat production, consumption, imports, and population in Egypt (2000–2020).

Source: MALR, 2022; CAPMAS, 2022a.

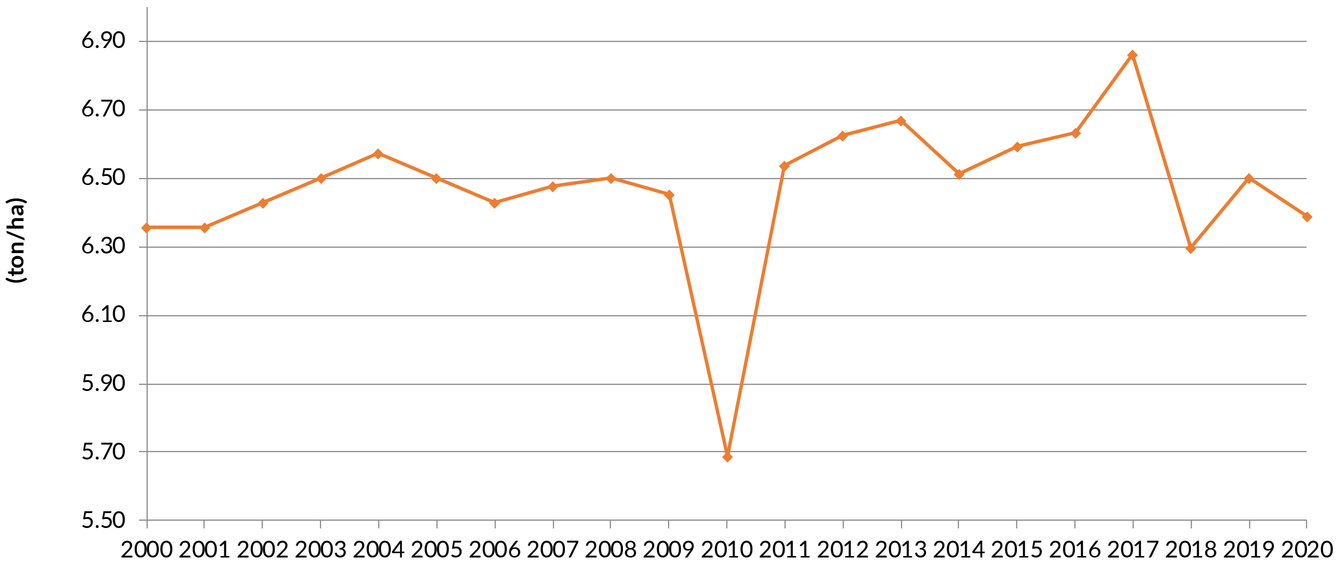

Figure 3. The yield of wheat in Egypt (2000-2020).

Source: Authors elaboration using (MALR, 2022).

in addition to the yellow rust disease that badly hurt the crop that season. However, in 2011, favorable weather conditions and lack of yellow rust resulted in a strong rebound in production, reaching about 8.39 million tons. During that year, Egypt introduced and widely disseminated two new high-yielding varieties of wheat: Misr 1 and Misr 2.

A close look at Figure 3 reveals that Egypt has achieved good progress in wheat productivity since 1999, due to great efforts made to introduce high-yielding and early maturing wheat varieties. According to (MALR, 2022), the country's average wheat yield increased from around 6.357 ton/ha in 2000 to about 6.389 ton/ha in 2020, with a 21-year average yield of around 6.470 ton/ha.

Wheat is the primary input for the most important staple food in Egypt, bread, which is consumed in enormous quantities, heavily subsidized, and at the heart of a politically charged food subsidy policy (Cassing et al., 2007). Figure 2 shows that domestic wheat consumption increased from about 11.44 million tons in 2000 to about 21.35 million tons in 2020 (MALR, 2022). This increase was driven by three main factors: a domestic population estimated at about 101.5 million, with a growth rate of more than 2.5 percent per year (CAPMAS, 2022b); hosting about 5 million refugees from Iraq, Syria, Libya, Yemen, and Sudan (Abdi et al., 2018); and low subsidized bread prices relative to animal feed prices, which encourages farmers to use bread as feed for livestock and poultry.

However, the new bread subsidy system introduced by the government allows every beneficiary to obtain 150 loaves per month, or five loaves per day. This system is more efficient and, if properly implemented, is expected to reduce bread wastage. In fiscal year (FY) 2020/21 (July–June), the government allocated about US$5.32 billion for food subsidies. Bread subsidies represented 53 percent of total expenditures on food subsidies in FY 2020/21 (Elsayed et al., 2021). Figure 2 illustrates that the total imports of wheat into Egypt increased from about 5 million tons in 2000 to around 12.88 million tons in 2020, due to the increasing demand for wheat. Based on Elsayed et al. (2021), Egypt imported about 4.87 and 3.16 million tons of wheat from Russia and Ukraine, respectively, in 2019/2020, contributing to about 80 percent of Egypt's market share. Romania and France followed, with 0.75 and 7.47 million tons (7.5 percent and 7.4 percent, in that order), respectively.

According to (MALR, 2009), the government aims to maximize the share of domestic production in total wheat consumption, reflecting the strategic consideration given the importance of wheat in Egypt's food security. However, the increasing domestic demand for wheat absorbs the improvement in the domestic wheat production, thus lowering the wheat

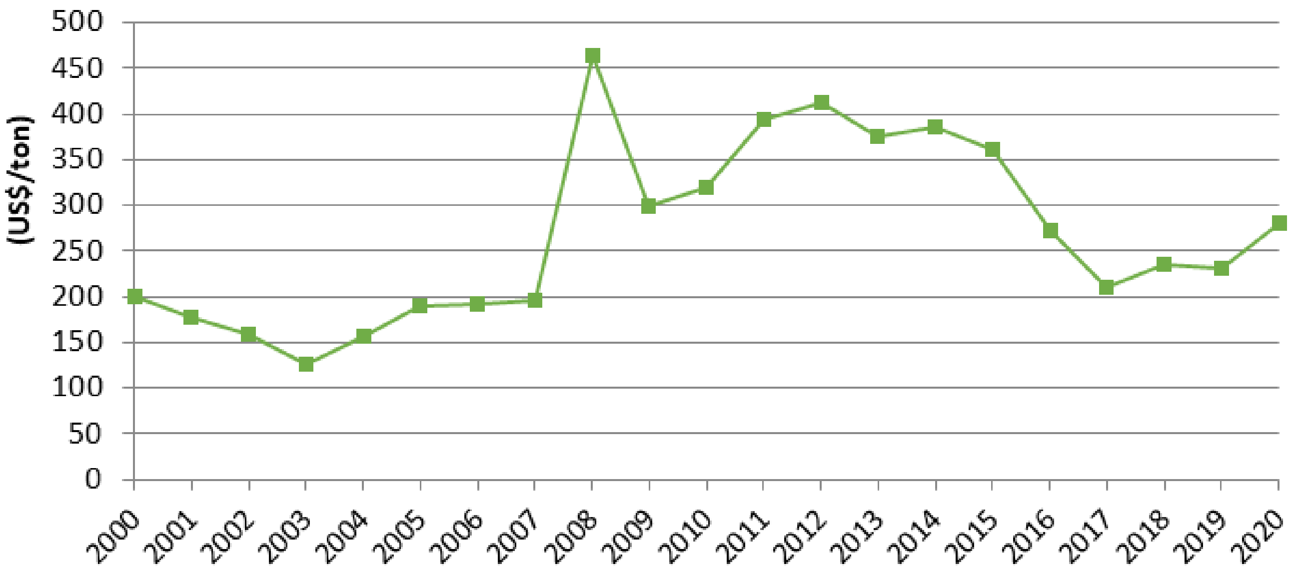

Figure 4. Wheat procurement price in Egypt (2000–2020).

Source: Authors elaboration using (MALR, 2022).

self-sufficiency ratio (SSR)[1]—which reached about 57.5 percent in 2000 and about 66 percent in 2003, but has since reduced to about 46 percent since 2017.

To encourage domestic wheat production, the Egyptian government announces every year the procurement price it will pay local wheat producers, which is always much higher than world prices for wheat. As indicated in Figure 4, the procurement price paid for domestic wheat was set at US$200 per ton in 2000; with the government raising it gradually to reach US$465 per ton in 2008. However, after the sharp currency devaluation in early November 2016, the farm support prices in US$ terms became significantly lower than in the previous years—at US$272 and US$281 per ton in 2016 and 2020, respectively.

5.1.1 Enhancing food security in Arab countries

5.1.1.1 Description of the farming systems in the study areas

The EFSAC Project in Egypt was implemented in three phases. The first phase (hereafter called Phase I) took place in Al Sharkia Governorate and lasted four years, running from the 2010/11 growing season until the 2013/14 growing season. For the second phase (Phase II), the Project worked in Al Dakahlia Governorate from the 2014/15 growing season until October 2018. The third season (Phase III) of the Project was implemented in Al Behera Governorate from the 2018/2019 growing season to the 2021/2022 growing season, concluding by the end of September 2022.

The Project provided farmers with a full pack¬age of nine components, and it was the farmers' decision whether to take up at least the top three indi¬vidual components (improved varieties, planting date, planting method) or the full package. The full technology components provided by the Project, as ranked in order of their importance, were improved varieties, planting date, planting method, N fertilizer application, optimal number of irrigations, seeding rate, land preparation (e.g., tillage, leveling), weed control, and harvest date. Each of these components has its own benefits and applying all components of the package has a collective benefit—an increase in grain yield.

It is worth mentioning that wheat-rice and wheat-maize rotations have negative effects on soil fertility. It was found that *Fahl* berseem, grown after rice or maize and before wheat, reduces the effects of cereal crops succession. Soil analysis reveals that nitrogen content in wheat fields after rice was 35–40 kg of available nitrogen, compared to 80–85 kg of available nitrogen after *Fahl* berseem is grown before wheat. Hence, growing Fahl berseem following rice or maize harvest before wheat is the crop rotation promoted by the Project.

1 The self-sufficiency ratio is defined as the percentage ratio of domestic production over domestic wheat consumption.

Below is a summary of the technological components provided by the Project.

Improved varieties: Old varieties are always being replaced with new varieties. The primary reason for variety change is to help prevent disease resistance, especially rusts. Given the challenge faced from rust, wheat breeding programs must develop lines with resistant to several rusts while ensuring that the new lines also lead to gains in grain yield. After variety testing for rusts' resistance and high grain yield during yield trials at research stations and in varietal verification trials at farmer fields, the next step involves disseminating new varieties through extension plots so these can reach farmers' fields.

Therefore, during the first phase in Al Sharkia Governorate, the Project disseminated five varieties: Gemmiza 11, Sids 12, Misr 1, Misr 2, and Sids 13. For Phase II in Al Dakahlia Governorate, the Project disseminated six varieties: Gemmiza 11, Gemmiza 12, Misr 2, Shandawil 1, Giza 171, and Sids 12. For Phase III in Al Behera Governorate, the Project disseminated five varieties: Giza 171, Misr 3, Sids 14, Gemmeiza 12, and Shandawil 1. Some varieties—Gemmeiza 11, Sids 12, and Shandawil 1—are banned for planting in Delta governorates due to heavy infection by yellow rust and they are recommended for Upper Egypt where yellow rust is not a major problem. Moreover, some varieties face less infection in Delta governorates: Gemmeiza 12, Misr 1, and Misr 2. Based on past research, five varieties are now recommended in Al Sharkia, Al Dakahlia, and Al Behera: Giza 171, Gemmeiza 12, Misr 3, Sids 14, and Sakha 95. These varieties are resistant to yellow rust and are high yielding.

Planting date: The field experiments reveal the optimum planting date is during the period 15–30 November. However, the optimum planting date could start on November 10 in Upper Egypt, whereas it could go as late as December 10 in North Delta. The major benefit of delaying planting in North Delta is achieving the best balance between day and night temperatures and wheat growth stages to maximize crop growth and grain yield. Hence, the planting date accepted by the Project ranged from the second week of November till the first week of December.

Planting method: The Project recommended raised bed as a planting method. In this method, the land is divided into raised beds of 120–130 cm in width, and wheat is sown on the bed's back, either in rows (6–7 rows by machine) or in hills (by hand). During planting, farmers sow seeds either by broadcasting or by using drills.

Application of N fertilizer: Farmers have a tendency to use additional chemical fertilizers, especially nitrogenous fertilizers, believing they increase yields. As a result, the amount of N fertilizer used can reach 270 kg N/ha. Conversely, when the farmer faces economic problems during the crop growing season, they may reduce the amounts of N fertilizer to 140 kg N/ha, leading to lower grain yield. The blanket recommendation by the extension program for N fertilizer rate is 180 kg N/ha. However, the acceptable range of N fertilizer application promoted by the Project was 180–288 kg N/ha, depending on soil type (clay or sandy soil).

Frequency of irrigation: A typical farmer uses an average of 3–4 irrigations, and the amount of irrigation water in farmers' fields can reach up to 5500 m^3/ha per season, depending on temperature. Along with the raised bed method, 4–5 irrigations are recommended by the extension program, at an average total amount of irrigation water of about 4000 m^3/ha, depending on air temperature. This leads to a 25–30 percent reduction in the amount of irrigation water used. Consequently, the optimal number of irrigations promoted by the Project was 4–5 for flood irrigation, with the recommended amount of irrigation water being 4760–5712 m^3/ha.

Seeding rate: The seeding rate used in farmer's fields varies between 160–190 kg/ha, depending on whether flat planting dry or wet. In spreading seeds with the wet planting method, seeding rate reaches 190 kg/ha as the depth of seed is not homogenous, and consequently seed germination and emergence is lower. Spreading with the dry planting method is slightly better, with the seed rate reaching 160 kg/ha. Drilling and raised bed methods entail lower seed rates due to the homogeneity in seed depth, seed germination, and emergence and perfect number of plants per unit area, and consequently higher grain yield. The seeding rates for drilling and raised bed methods reached 107 kg/ha. Consequently, the Project recommended a seeding rate ranging from 107–143 kg/ha with +/- 5, namely: 143 kg/ha for broadcast planting, 119 kg/ha for drill planting, and 107 kg/ha for raised bed.

Land preparation (e.g., tillage, leveling): For land preparation, the Project recommended twice tillage practice: twice Chisel plough and disc rotavator, then land leveling. Zero tillage is a good practice encouraged by the Project wherever raised beds have been built in a farmer's land since at least the previous season.

Weed control: Farmers vary in their application of weed control based on the spread of weeds in their fields and whether the weeds have broad or narrow leaves. The Project recommended chemical control as a method for weed control.

Harvest date: The harvest date is decided after 10 days of the crop reaching physiological maturity (when the peduncle color changes into a yellow color) and the grains become hard and dry. These signs are easily understood by farmers. Therefore, harvest dates accepted by the Project ranged from the third week of April until the second week of May.

5.1.1.2 Descriptions of the dissemination strategies used by the project

The number of the farmers participating in the Project: The total number of farmers participating in the first phase of the Project in Al Sharkia Governorate was 885 (96 participants in the first year, 250 participants in the second, 249 in the third, and 290 in the fourth). For the second phase in Al Dakahlia Governorate, the total number of participating farmers was 1,140 (220 participants in the first year, 280 in the second, 340 in the third, and 300 in the fourth). In the third phase in Al Behera Governorate, the total number of participating farmers was 490 (100 in the first year, 120 in the second year, 130 in the third, and 140 in the fourth).

The selection procedure of the farmers participating in the Project: Farmers participating in the Project were selected from all the districts of both governorates based on the weight of these districts in wheat production (i.e., a proportionally higher number of farmers were selected from districts which have larger wheat area). The number of demonstration plots (fields) in a certain district was proportional to the area of wheat in the district.

The selection procedure for the farmers starts with the local extension agent, as they best know the farmers in each village. The local extension agent tells the farmers about the Project objectives and the benefits they will receive (for one season only), such as free seed of new varieties, one sack of N fertilizer, and half the expenses required for weed control. Many farmers decide to participate in the Project at this point, indicating that the benefits (services) offered by the Project are the main motive behind participation. Some of the farmers who decide to participate in the Project are highly accomplished, follow instructions, and like to be leaders in their villages.

The support provided by the Project to the participating farmers: In addition to the inputs provided to cover part of the required amounts described above, the project offered farmers technical support throughout the growing season in the form of field schools, field days, and harvest days. However, participating farmers must personally cover the part of the input costs, including the price of two sacks of N fertilizer (50 kg urea 46.5% N), irrigation costs, 50 percent of weed control costs, harvesting costs, and threshing costs.

Project farmers receive support usually for only one season. In subsequent seasons, support is given to other farmers in the same village or in other villages to reach as many farmers as possible with the limited resources available to the Project. After that, the farmer is left to decide whether to adopt the technology and work on his/her own, or dis-adopt it altogether. Farmers who decide to continue using the new technology package, covering the full cost by themselves, continue to receive visits from extension agents and researchers. Application of the full technology package during the current season is an important condition in the unwritten agreement between the Project participant farmer and the Project administration, in order for the farmer to receive the Project's free benefits.

The participating farmers have access to all components of the production package (inputs and technical support). However, the non-participating farmers also have access to all the components of the production package if they decide to adopt the technology or have the financial ability to buy it.

The strategies used by the project to disseminate the new wheat technology package (unique): To promote the technology package, the Project organized field schools followed by field days. Farmers were selected and required to sign an agreement to host demonstration trials and serve as field schools. Then, other farmers were invited for field days to observe the performance. What was particularly unique is that the Project rented buses and brought farmers from different locations, including neighboring villages, which significantly increased participation. All participants received first-hand information complemented by demonstrations of the successful performance of the technology package.

One mistake was that no registration of farmers was taken, so the Project does not know if the participating farmers were closer neighbors or from farther away. Only counts of the total number of participants were taken. From experience in other projects, more than 90 percent of those who participated in field days adopted the technology. The reason why the remaining 10 percent didn't adopt is not fully known—but hypotheses include lack of access to the machine that makes raised beds, and higher fertilizer prices may limit farmers' ability to adopt or reduce their application rates and compel them to not follow recommendations.

Due to the success of EFSAC in Egypt, a national campaign has been launched by the government to promote the same technology packages in all wheat growing areas in the country as those championed by the Project. The main factors that distinguish the EFSAC Project's promotional approach from that of the national campaign are:

1. EFSAC provides support with input costs and helps with the cost of preparing the raised beds.
2. The Project holds monthly field schools in districts of the project.
3. EFSAC ensures the full involvement of the Agricultural Research Center (ARC) researchers.
4. The Project rents buses and brings farmers from other villages to observe the fields.

Using the sampling design described in the data section (Section 4), a total of 600 farmers were selected from the three provinces. The sample was then distributed into 9 districts and 164 villages (Table 1). Of the total sample, 360 (60 percent) were randomly selected, while 240 (40 percent) were purposively selected from among the participant farmers.

The average age of household heads is 56 years, with a minimum age of 25 and a maximum of 89. Male household heads were dominant in the sample, representing about 99 percent. The household heads varied in terms of education levels, with about 21 percent and 45 percent university and high school graduates, respectively. Moreover, some 7 percent were primary and preparatory school graduates, and about 15 percent can only read and write. The remaining household heads were illiterate, representing about 12 percent. The average years of education of household heads is 9.4, with a maximum of 27 years. The average farming experience of household heads is about 35 years, with a minimum level of 5 years and a maximum of 67 years.

Regarding demographics, the average family size is 5, with a minimum of 1 and a maximum of 17. About 32 percent of the household heads in the study area depend mainly on agricultural production for their livelihoods, while about 68 percent make a living from

Table 1. Sampling design.

Governorate	Number of districts per governorate	Number of villages per governorate	Sample size per governorate		
			Randomly selected	Purposively selected	Total
Al Sharkia	3	45	71	49	120
Al Dakahlia	3	76	217	143	360
Al Behera	3	43	72	48	120
Total	**9**	**164**	**360**	**240**	**600**

Source: The sampling design used to conduct the socio-economic survey in the 2020/2021 season.

off-farm activities. Agriculture contributed to about 64 percent of the total family cash income, whereas crop contributed to about 43 percent of the total cash income from sales of agricultural products. The share of wheat in total cash income from sales of all crop produced by the household is about 45 percent.

Among the 600 sampled households, 98.2 percent of the respondents were the heads of households, with only 1.8 percent representatives of household heads. Previously, 34.5 percent of the sampled households had hosted wheat demonstration trials on their own land and also attended field days, and 5.5 percent had only hosted wheat demonstration fields on own land. Thirty-three percent and 19 percent had only attended field days and only heard about the Project activities, respectively. Eight percent had not heard about the Project at all.

The average agricultural area cultivated by the sample households is about 1.86 ha, with a minimum of 0.63 ha and a maximum of 21 ha. The average wheat area grown per household is about 0.60 ha, with a minimum of 0.21 ha and a maximum of 6.3 ha.

About 27 percent and 0.33 percent of the soils in the sample plots were of medium and high salinity levels, respectively. About 98.5 percent of the soils in the sample plots were clay, with 1 percent and 0.5 percent of them loamy and sandy, respectively.

Even though eight percent of farmers didn't know about the project, all the interviewed farmers expressed awareness of the recommended planting date, Nitrogen rates, seed rate, and harvesting date promoted by the Project.

Most of the interviewed farmers visited the extension agents in 2020/2021, and about 95 percent of them received visits by extension agents. Both approaches involved an average of two to five visits. Visits to/by researchers in 2020/2021 were less frequent than those of extension agents. While almost all interviewed farmers reported the existence of agricultural cooperatives in their villages, 45.5 percent of them are not members.

Forty-three percent of interviewed farmers cited visits from extension agents, cooperatives, relatives, neighbors, TV, text messages on their mobile phone, videos through social media (e.g., WhatsApp), and conferences as their main sources of agricultural information. Meanwhile, 29 percent reported visits from extension agents, cooperatives, relatives, neighbors, merchants, and conferences as the main sources of their agricultural information. Twenty-eight percent reported visits from extension agents, cooperatives, relatives, neighbors, radio, TV, agricultural projects, videos through social media (e.g., WhatsApp), and conferences as the main sources of their agricultural information.

Interviewed farmers were also asked to rank the sources of their agricultural information in terms of their usefulness (from one to three, with one being the most useful). Visits from extension agents ranked first as the most useful source of agricultural information for 82.5 percent of interviewed farmers, followed by agricultural cooperatives (5.3 percent), relatives and neighbors (4.8 percent), and conferences and agricultural projects (4.4 percent). Mass media (e.g., TV, radio, newspapers, etc.) represented only 2.7 percent, and merchants and social media (e.g., WhatsApp, Facebook, YouTube, etc.) ranked last with less than 0.3 percent.

Forty-five percent and 50.5% of the interviewed farmers reported that they sometimes and often exchange agricultural information with farmers in their village, respectively—showing the importance and potential of farmer-to-farmer information exchange for technology promotion and scaling. Only four percent rarely exchange agricultural information with farmers in their village, and less than one percent mentioned never doing that. Sixty-two percent and 22 percent of the farmers also responded that they sometimes and often exchange agricultural information with farmers outside their village, respectively. About 14.5 percent rarely exchange agricultural information with farmers outside their village, while the rest reported never doing that.

Interviewed farmers were asked about their (or any household members') degree of involvement in the community (e.g., attending meetings, volunteering their time in other ways, etc.). About 10 percent mentioned they are very active in their local community, while 64 percent were moderately active and 26 percent were not active.

Only 31 percent of the interviewed farmers participated in training courses in agriculture and the rest did not.

5.2 Measuring the rate and degree of adoption

The project promoted a technology package comprising a total of 10 components. The project team prioritized the technologies as follows: 1) improved varieties, 2) planting date, 3) method of planting, 4) rotation, 5) N fertilizer, 6) frequency of irrigation, 7) seeding rate, 8) type of tillage, 9) weed control, and 10) harvest date. In addition, the project promoted the raised bed technology as the "11th technology", mainly to conserve water and enhance yield. From among the 459 randomly selected sample farm households, excluding the raised bed technology, only 16 (3 percent) adopted the whole technology package comprising all 10 components. This should not come as a surprise, as the project has only been working for a few years and it normally takes longer for farmers to completely understand the science, mechanics, and benefits of technology components. In view of the short life of the project, in this study, an adopter is defined as "a farmer who uses the improved varieties with any other components of the technology package promoted by the Project in the 2020/2021 season". However, we also vary the definition to include only single or different combinations of two or more of the technology components and try to determine the adoption levels, as this is believed to be instrumental in guiding future interventions and promotion strategies.

Of the 243,642 wheat growing families in the three study governorates (Al Sharkia, Al Dakahlia, and Al Behera), 193,939 (79.6 percent) have adopted the improved varieties and at least three other components, while 125,232 families (51.4 percent) have adopted the recommended improved varieties and at least six other components. The improved varieties and at least six other components together are most adopted in the Al Sharkia Governorate (92.7%)—likely due to the direct and indirect effects of the long period of time (12 years) since the EFSAC project started working there—followed by Al Behera Governorate (65.4%). Al Dakahlia Governorate exhibits low adoption rate of the improved varieties and at least six other components, at 33.3 percent. The adoption rate and degree of improved varieties and at least two, three, and four other components are the highest in the Al Sharkia Governorate, followed by Al Dakahlia Governorate and then Al Behera Governorate.

Of the total wheat area of 449,910 ha in the three study governorates, a total of 356,506 ha (79.4 percent) was cultivated using the improved varieties and at least three other components. Meanwhile, 230,337 ha (51.3 percent) was cultivated using the improved varieties and at least six other components. With only slight differences in the magnitude of the percentage values, the adoption degrees (as percentage of total wheat area under the technologies) in each governorate follows the same pattern as the adoption rates. Even though the national campaign is working to promote the same technology packages, experts say that adoption levels for some of the most important technology package components in the rest of the country are much lower than in the three project governorates. This calls for a review of the prioritization of technology components under the national campaign to promote wheat technologies that are proven to be beneficial for the farmers in the three sample governorates and possibly other governorates.

In terms of individual technology components, Al Sharkia Governorate has the highest adoption rates and degrees for the recommended improved varieties, and frequency of irrigation. Al Behera Governorate is leading in terms of adoption rates and degrees for the recommended planting method, raised bed, rotation with fahl berseem, seeding rate, weed control, planting date, and number of tillages. Al Dakahlia Governorate seems to be trailing behind in the adoption of almost all recommended technology components, and only leads with regard to higher adoption rates and degrees for zero tillage (Table 2).

5.3 Factors affecting the decision and intensity of adoption

The results of the double hurdle model used to identify the factors that positively or negatively influence decisions to adopt improved varieties and at least six other components, and the size of land area to be devoted to these components once the adoption decision is made, are reported in Table 3. The estimates show that farmers who participated in demonstration and field days had very high tendencies to adopt the improved varieties and at least six other components—showing that the technology promotion techniques used by the EFSAC Project were highly effective. Farmers in Al Sharkia Governorate were also found to have higher tendency to adopt the improved varieties and at least six other components—further confirming the efficacy of Project interventions in enhancing adoption.

Table 2. Weighted adoption rates and degrees (%) for the recommended package components by Governorate (region).

Technology component(s)	Al Sharkia Governorate		Al Dakahlia Governorate		Al Behera Governorate		Total	
	Adoption rate	Adoption degree	Adoption rate	Adoption degree	Adoption rate	Adoption degree	Adoption rate	Adoption degree
Recommended improved varieties	100	100	77.25	76.9	66.9	66.6	79.6	79.4
Recommended planting date	83.74	83.7	78	77.8	99.2	99	83.44	83.3
Raised bed	47.2	47.2	17.72	17.7	56.69	56.7	31.4	31.4
Recommended Nitrogen rates	40.65	40.3	27.3	27.2	52.76	52.5	35	34.92
Recommended number of irrigations	91.87	91.8	85.45	85.4	81.89	81.9	85.99	85.9
Recommended seed rate	87.8	87.8	33.6	33.6	98.43	98.4	57.3	57.3
Recommended number of tillage	92.7	92.7	52.65	52.5	100	100	70.06	69.9
Recommended weed control	68.2	86.5	51.85	51.7	94.5	94.5	67.2	67.2
Recommended harvesting date	95.12	95.1	97.35	97.2	100	100	97.45	97.3
Planting method	56.1	55.8	17.99	17.99	67.72	67.7	35.51	35.4
Zero tillage	17.89	17.8	28.3	28.3	25.2	25.1	25.6	25.5
Rotation with fahl berseem	88.6	88.5	77.3	77.2	92.9	92.1	82.6	82.4
At least the top 2 components	100	100	77.25	76.96	66.93	66.66	79.62	79.39
At least the top 3 components	100	100	77.25	76.96	66.93	66.66	79.62	79.39
At least the top 4 components	99.19	99.18	69.05	68.76	66.93	66.66	74.52	74.29
At least the top 5 components	98.37	98.37	51.06	50.77	66.93	66.66	63.54	63.31
At least the top 6 components	92.7	92.68	33.33	33.2	65.35	65.09	51.43	51.3
At least the top 7 components	74.8	74.79	23.8	23.70	54.3	54.1	39.97	39.85
At least the top 8 components	43.1	43.09	16.67	16.56	37	36.75	25.96	25.84
At least the top 9 components	17.07	17.07	2.38	2.4	31.5	31.2	11.2	11.09

Table 3. Parameter estimates of the double hurdle model for using improved varieties and at least six other components.

Explanatory variables	Double hurdle-Tier1				Double hurdle-Tier2			
	Coef.	Std. Err.	z	P>|z|	Coef.	Std. Err.	z	P>|z|
Sex (1=male, 0=female)	0.399	0.660	0.6	0.546	-0.451	1.253	-0.36	0.719
Education (years)	0.001	0.011	0.05	0.958	0.015	0.012	1.26	0.206
Farming experience (years)	0.005	0.006	0.83	0.409	0.026	0.007	3.82	0
Off-farm employment (1=yes, 0=no)	-0.110	0.138	-0.8	0.426	-0.047	0.145	-0.32	0.745
Al Sharkia Governorate (1=yes, 0=no)	0.996	0.223	4.47	0.000	0.341	0.171	1.99	0.046
Al Dakahlia Governorate (1=yes, 0=no)	-0.797	0.153	-5.2	0.000	0.066	0.195	0.34	0.734
Demonstration and field days (1=yes, 0=no)	0.503	0.212	2.37	0.018	-0.186	0.206	-0.9	0.367
Demonstration (1=yes, 0=no)	-0.048	0.303	-0.16	0.874	-0.298	0.354	-0.84	0.4
Participation in other projects (1=yes, 0=no)	0.678	0.206	3.28	0.001	0.132	0.209	0.63	0.527
Wheat area (ha)	0.193	0.063	3.09	0.002	0.777	0.029	27	0
Family size	0.033	0.042	0.79	0.432	0.025	0.040	0.62	0.538
Constant	-1.045	0.722	-1.45	0.148	-0.983	1.323	-0.74	0.457

Source: Field survey results in the 2020/2021 season.

The long history of the EFSAC Project in Al Sharkia was also found to increase the propensities of adoption compared to in Al Behera and Al Dakahlia. This is consistent with the theory and empirical evidences in the literature on technology adoption, whereby technology adoption is a long and gradual process which requires time for farmers to be exposed, evaluate, and decide whether to use the technology; on how big a land; and how soon to fully replace old technologies with the new (Astebro, 2004; Smale et al., 1991; Jha et al., 1990). Those with a relatively larger wheat area are found to have more tendency to adopt these technologies.

Participation in other projects has a significant effect on farmers' decisions to adopt the top six technologies jointly. Other factors, such as family size, off-farm employment, and education, were found to not have a significant effect on farmers' decisions to adopt the top three technologies jointly.

Once farmers decide to adopt the improved varieties and at least six other components, those who have larger wheat areas tend to cultivate larger areas of wheat using the new technologies. More experienced farmers are also found to dedicate larger areas to the technologies. While the dissemination approaches used by the project are effective in convincing farmers to adopt the improved varieties and at least six other components, our results show that once farm households decide to adopt all the improved varieties and at least six other components, the dissemination approaches didn't convince farmers to adopt them on larger areas. With few exceptions, double hurdle models estimated for identifying important determinants of the adoption of individual technology components gave similar results as for the adoption of the improved varieties and at least six other components. The possible explanation for these results is that, to reach more farmers with the limited financial, human, and technological resources available, the Project's support was limited to providing participating farmers with free seeds and required inputs for only half a hectare. Therefore, those who decided to adopt the technology package—mainly due to their participation with the project—did so on a limited amount of land that was proportionate to the amount of input they received. As such, the technology dissemination and scaling approach by the national campaign will need rethinking.

5.4 Impacts of the Project interventions

After working for 10 years (2010–2021) in Al Sharkia Governorate, six years (2014–2021) in Al Dakahlia Governorate, and four years (2018/2021) in Al Behera Governorate, the Project commissioned this study to evaluate its achieved impacts. To this effect, we estimated the IV regression method by considering the individual and combination of the improved varieties and at least any other components. The summary results of the IV regression model estimations are presented in Table 4. Model results show that while adoption of individual technology components, such as the recommended urea rates, number of tillages, planting method, and zero tillage lead to high yield gains, individual adoption of components, such as weed control and harvesting date, had no effect on yields. These results are not unexpected, as these technologies are not supposed to be adopted individually and instead act as an important component of a holistic package.

Table 4. Summary of the minimum impacts of the recommended package components on wheat yield (kg/ha), net margins (EGP/ha), water use efficiency (kg/m3) and household marketable surplus of wheat (%), based on estimation of IV regression models.

Technology component(s)	Al Sharkia	Al Dakahlia	Al Behera	Total impact
Improved varieties	N/A	N/A		
Planting date	1324.8	594.9	N/A	987.4
Raised bed	2094	1159		1310.8
Nitrogen rates	1005	1034.6	1558.1	1547.6
Number of irrigations	Not significant	1590	Not significant	1554.9
Seed rate	962	589.6	953	1319
Number of tillage	Not significant	Not significant	Not significant	399.7
Weed control	Not significant	Not significant	Not significant	Not significant
Harvesting date	Not significant	Not significant	Not significant	Not significant
Planting method	376.18	167.08	Not significant	332.4
Zero tillage	477.37	228.2	Not significant	429.4
Rotation with Fahl berseem	-399.4	-200.5	Not significant	-254.25
Improved varieties & >= 6 other comp.	2892	2230	1545	2698
Improved varieties & >= 7 other comp.	2162.4	1817	1629	2443
Improved varieties & >= 8 other comp.	2168.49	2129.5	1807.3	2615.8

Note: "&>= 5 other comp." stands for "...and at least 5 other components of the technology package)
Source: Field survey results in the 2015/2016 season.

In terms of individual technology component usage, Al Sharkia Governorate is achieving highest yield gains, likely because of the long history of the EFSAC Project in the region.

It is worth noting that the yield gain from the adoption of a combination of improved varieties and at least six, seven, and eight other components is more than the impact of each individual component.

5.4.1 Impact of the recommended package on wheat net margins (profits)

The joint adoption of the improved varieties and at least six, seven, and eight other components promoted by the Project showed clear advantages, with yield gains of 2,698 (38.1 percent), 2,443 (34.5 percent), and 2,615.8 (36.9 percent) kg/ha, respectively. Such adoption also leads to net margins of 6,168.7 (25.6 percent), 6,282.08 (26.1 percent), and 5,046.85 (21 percent) EGP/ha (or [2]US$390.4, US$397.6 and US$319.4 per ha, respectively) (Table 5); water use efficiency gains of 0.0882, 0.0909, and 0.0938, kg/m3, respectively; and marketable surplus wheat gains of 3.61 percent, 3.55 percent, and 3.71 percent, respectively, relative to using traditional methods. At its current adoption level of 51.3 percent of total wheat area in the three study governorates, the joint use of the improved varieties and at least six other components led to an increase in total wheat production of up to 0.62 million tons (19.6 percent) per year. If these technologies are fully

Table 5. Impact of the recommended package components on wheat net margins (profits) (EGP/ha).

Technology component(s)	Al Sharkia	Al Dakahlia	Al Behera	Total impact
Improved varieties	N/A	N/A		
Planting date	7329	3656.3	Not significant	4495.86
Raised bed	3716.3	4285.513	5755.8	6156.7
Nitrogen rates	Not significant	5692	Not significant	5700
Number of irrigations	Not significant	3895.4	Not significant	5874.7
Seed rate	Not significant	Not significant	Not significant	2632
Number of tillage	-227.0	-296.9	Not significant	Not significant
Weed control	Not significant	Not significant	Not significant	Not significant
Harvesting date	Not significant	Not significant	Not significant	Not significant
Planting method	1900.4	1054.03	Not significant	1687.9
Zero tillage	1236.5	603.9	Not significant	983.58
Rotation with Fahl berseem			Not significant	
At least the top 6 components	7467.96	6690.8	6946.8	6168.7
At least the top 7 components	6701.9	6946.6	5584.8	6282.08
At least the top 8 components	5460.3	5000		5046.85

Source: Field survey results in the 2020/2021 season.

2 Average exchange rate in 2020: US$1 = 15.8108 EGP.

promoted to cover 75 percent and 100 percent of total wheat areas in the three study governorates, it will be possible to increase wheat supply by at least 28.6 percent and 38.1 percent, respectively.

5.5 Conclusions and recommendations

The EFSAC Project has been actively working in Egypt for the last 12 years. In its first phase, the Project began disseminating an improved wheat technology package in Al Sharkia Governorate during the 2010/11 growing season and continued until the 2013/14 growing season. In its second phase, the project moved its activities to the Al Dakahlia Governorate, where it started during 2014/15 growing season and continued until the 2017/2018 growing season. In its third phase, the project moved its activities to the Al Behera Governorate, where it started during the 2018/19 growing season and continued until the 2020/2021 growing season. The 10 components included in the wheat technology package, in order of their importance, were: 1) improved varieties, 2) planting date, 3) method of planting, 4) rotation, 5) N fertilizer, 6) frequency of irrigation, 7) seeding rate, 8) type of tillage, 9) weed control, and 10) harvest date. In addition, the project promoted the raised bed technology as the “11th technology”, mainly to conserve water.

Using a sample size of 600 farm households drawn from the three project governorates, this study tried to estimate adoption levels for improved varieties alone and in combination with at least one other technology component in the three study governorates. In estimating adoption rates (percentage of farm households using the technology), the number of wheat-growing families at the different administrative levels were used as weights for upward aggregation—from village to district to governorate and finally to the entire study region. Our results showed that 51.4 percent of all sample farm households are using the improved varieties and at least six other components together. We also used the total wheat area at the different administrative levels as weights for upward aggregation of adoption estimates. Accordingly, 51.3 percent of the total wheat area in the three study governorates is estimated to be under the improved varieties and at least six other components together. The literature on technology adoption reveals that it takes between 8 and 12 years for a given technology to reach 75-percentile. Therefore, given that the technology constituted not only one but a suit of components, the adoption degree of 92.7 percent in Al Sharkia Governorate—where the project introduced the technologies between 2010/11 and 2020/2021—is a good indicator of great success for the EFSAC Project.

While several factors are useful in enhancing adoption rate, the technology promotion methods employed by the Project were found to be very effective. However, once farmers decided to use the different technology components, the Project’s promotion approaches were not effective in encouraging farmers to increase the area of land they dedicated to the technology components. It will be important to develop further understanding of why this was the case.

The Project also demonstrated clear impacts on the livelihoods of farm households which adopted technologies. For example, the joint adoption of the improved varieties and six, seven, and eight other components promoted by the Project showed clear advantages, with yield gains of 2,698 (38.1 percent), 2,443 (34.5 percent), and 2,615.8 (36.9 percent) kg/ha, respectively. Such adoption also led to net margins of 6,168.7 (25.6 percent), 6,282.08 (26.1 percent), and 5,046.85 (21 percent) EGP/ha, respectively (US$390.4, US$397.6, and US$319.4 per ha, respectively); water use efficiency gains of 0.0882, 0.0909, and 0.0938 kg/m3; and marketable surplus wheat gains of 3.61 percent, 3.55 percent, and 3.71 percent, respectively, relative to using all traditional methods.

At its current adoption level of 51.3% of total wheat area in the three study governorates, the joint use of the improved varieties and at least six other components led to an increase in total wheat production of up to 0.62 million tons (19.6 percent) per year. If these technologies are fully promoted to cover 75 percent and 100 percent of total wheat area in the three study governorates, it will be possible to increase wheat supply by at least 28.6 percent and 38.1 percent, respectively. The livelihood gains obtained by farmers, the increased supply of domestically produced wheat in the three study governorates, and the efficacy of technology promotion approaches employed by the EFSAC Project, highlight the important role the Project has already played in enhancing food security in Egypt. Therefore, the Project is expected to achieve further success by scaling the proven technology package within and outside the study governorates.

Another interesting story from the EFSAC Project is related to the introduction of the raised bed technology. Along with other national efforts, due to its promotion by the EFSAC Project, a total of 76,504 farmers (31.4 percent) in the three study governorates are currently using the raised bed technology on a total of 140,986 ha of wheat land (31.4 percent). Technology is expanding fast and having good impacts. The adoption of the technology, regardless of whether the farmer is associated with the Project or not, is leading to yield gains of 1310.8 kg/ha and water use efficiency gains of 0.08 kg/m3. However, our results show that adoption is not necessarily associated with a reduction in the quantity of water applied per hectare of land—indicating that many farmers are still using the same amount of irrigation water as before they adopted raised beds. The raised bed technology has great potential to mitigate the current water shortage problems in the country and act as a good adaptation strategy in the face of adverse climate change effects and other causes of reduced water availability in the country. However, the technology is knowledge-intensive, so all farmers adopting the technology may not be able to fully exploit its benefits. This calls for more intensified education and farmer training on the specifications (including bed width, spacing between beds, depth of furrows, etc.) and the mechanics of the technology.

6. Jordan

6.1 Background

Wheat is the main source of food in Jordan, and its straw plays a vital role as feed for livestock—making this crop important for food security in the country. Yet, national production of the crop covers less than three percent of national needs; and this discrepancy can be explained in light of several changes facing wheat farming in Jordan. For instance, wheat production is mainly under rainfed conditions in limited areas of land that receive precipitation of above 300 mm. Land in these areas is often improperly cultivated and increasingly facing problems of tree cultivation, urban expansion, and, more importantly, the undesirable effects of climate change—which lead to a reduction in the amount and fluctuation of precipitation and the recurrence of extreme events, including droughts.

Considering the above challenges, efforts to improve wheat production in Jordan have primarily focused on increasing productivity under a limited water supply. In addition, focus has been on increasing the profitability of wheat farmers, so they can continue producing wheat and maintaining the areas in which wheat is cultivated. Since 1958, the research unit under the Ministry of Agriculture, which later became the National Agricultural Research Center (NARC)—an autonomous research organization—has been developing and disseminating to farmers proven sustainable wheat technologies, including high yielding and adapted varieties, along with a full

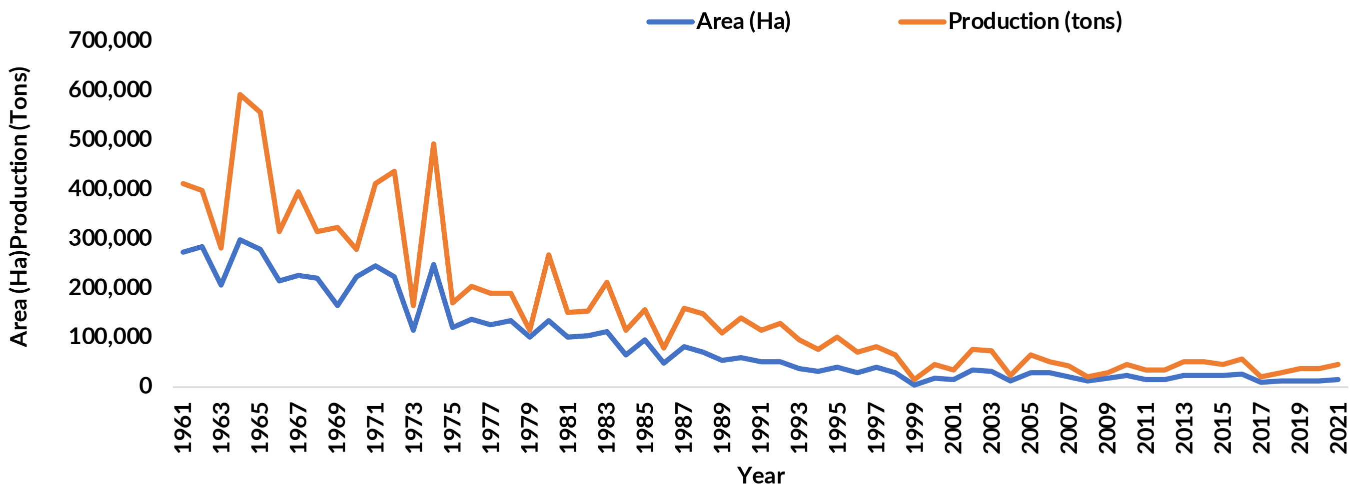

Figure 5. Evolution of wheat production in Jordan.

package of improved practices, including conservation agriculture. While these wheat technology packages have substantially improved wheat yields in agricultural research stations and on farmers' demonstration fields, the challenge has been scaling these technologies to narrow the gap between actual and potential yields in Jordan's wheat production areas.

To support the wider dissemination of improved wheat technologies, Jordan joined the EFSAC Project during its first phase, which started in the 2011/2012 growing season. During the first, second, and third phases, the Project has afforded the NARC wheat program highly valuable opportunities to develop, introduce, disseminate, and expand efficient measures so that the recommended technologies can be scaled to a larger number of wheat farmers.

Phases I and II saw several achievements and success. Apart from many other indirect benefits, the Project succeeded in increasing farmers' awareness and knowhow, wheat yields, and profitability, and significantly increased wheat production. Alongside these successes, the Project played an important role in helping build the capacity of researchers at NARC.

Following the achievements of Phase I and II of the project, a third phase of the project was launched during the 2018/2019 growing season to extend the sustainable wheat technology package into new sites in Jordan. This expansion also aimed to enhance food security in Jordan, which became even more crucial following a sharp increase in wheat demand due to the influx of Syrian refugees. Additionally, this next phase aimed to meet demand of a large number of smallholder farmers who were keen to join the Project.

Several national breeding and production methods, strategies, and practices have been adopted to increase the yield and stability of the crop. The most important recommendations to increase wheat production in Jordan involve focusing on the use of high yielding and drought tolerant varieties, along with a full package of integrated cropping practices. While such practices and technologies successfully improve wheat productivity—with the national average of wheat productivity ranging from 0.8–1.4 ton/ha compared with 2.5–4 ton/ha under NARC agricultural stations—many farmers remain skeptical of their benefits, as they don't believe they can make the technologies work equally or because the extension system was not efficient in organizing field days for the farmers to witness with their own eyes.

The major components of the full integrated technology package promoted by the EFSAC Project are:

1. Varieties: Including new promising varieties Acsad 1103, Acsad 1105, Acsad1187, and Acsad 1275, and certified cultivars such as Deiralla-6 and UmQais.
2. Weed control: This includes two types of weed control, broad leaves and narrow leaves herbicides.
3. Di ammonium phosphate (DAP).
4. Urea fertilizer.
5. Sowing date: Between November 15 and December 15.
6. Recommended seed rate.
7. Recommended use of seed drillers.
8. Recommended harvesting in June and July.
9. Recommended use of crop rotation.

There is always a desire by NARC to disseminate new varieties by planting them in farmers' demonstration fields. This affords farmers a firsthand look and allows them to compare the new varieties with those they already have at hand. In this project, the introduction of the new varieties is carried out as part of a large-scale demonstration of integrated cropping practices. Under this activity, farmer's fields are divided into two parts: half for farmers to plant the wheat variety and half for planting of the new variety, both using their usual management practices. This allows farmers to directly compare the productivity of the varieties. The new varieties are also demonstrated under cultivation using the full package of improved management practices. This approach helps farmers to see the impact of different management practices on both traditional and new varieties.

The second component of the technology package involves conservation agriculture, whereby each field is divided into two sections to allow for comparison between the new system of conservation agriculture and conventional tillage. The conventional section underwent two tillage operations before seed drilling, while, in the other section, seeding is done using zero-till seeders. Both sections were planted with the same variety of wheat and following the same other components of the new integrated cropping practices.

The third new technology involves the introduction of narrow leaf herbicides. Before the Project intervention, chemical weed control was only targeting broad leaf weeds—subjecting the crop to significant yield reduction by uncontrolled grass weeds.

The remaining package components already existed, but most farmers were either skeptical or did not have access to them.

Each component of the recommended production package has its own benefit, and together, they help increase grain and biomass yield, as well as support the conservation of natural resources. This study focuses on documenting the adoption and impacts of the individual and combination of these technologies on wheat grain yield and associated farm income. While they are expected to be significant, the additional economic and environmental gains due to other benefits (such as increased biomass yield) and synergies created in the wheat production system as a result of the project, have not been studied.

For this study, a total sample of 569 farm households was systematically drawn from the Project areas, out of which 458 households were associated with the Project (participants) and the remaining 111 were non-participant households. The sample households were distributed across 58 villages in 9 districts (Table 6. The average age of household heads was 50.3 years, with a minimum age of 23 and a maximum of 85. Male household heads were dominant in the sample, representing about 99 percent. The household heads varied in terms of level of education. About 14.3 percent and 27.2 percent of household heads were university and high school graduates, respectively. Moreover, 14.3 percent were primary and preparatory school graduates, and 0.2% were illiterate. The average years of education of household heads was 12.8 years, with a maximum of 18 years. The average farming experience of household heads was about 19.8 years, with a minimum level of 2 years and a maximum of 60 years.

Descriptive statistics from our sample showed that the average family size is 4.4, with a minimum of 1 and a maximum of 22. In total, 21.8 percent of household heads in the study areas depend primarily on agricultural production for their livelihoods, while 78.2 percent have off-farm activities as their main sources of livelihoods. Agriculture contributed 89 percent of the total family cash income, with crop contributing to about 93 percent of the total cash income from sales of agricultural products. The share of wheat in total cash income from sales of all crops produced by the households is about 75 percent.

In the past, 46.2 percent of the sampled households had hosted wheat demonstration trials on their own land and attended field days, while 23.4 percent had only hosted wheat demonstration fields on own land. Meanwhile, 16.2 percent and 4 percent of them only attended field days and only heard about the Project activities, respectively.

Table 6. Sampling design.

Category	Districts									
	Qasbat Irbid	Bani Obaid	Al Ramtha	Taebieh	Bani kaneneh	West Irbid	Madaba	Thiban	Naour	Total
Un-treated	59	10	11	0	17	3	3	2	6	111
Treated	203	26	43	64	78	5	21	17	1	458
Total	262	36	54	64	95	8	24	19	7	569

Source: The sampling design used to conduct the socio-economic survey in the 2020/2021 season.

6.2. Measuring the rate and degree of adoption

As described above, the project has promoted a technology package comprised of a total of eight components. According to their order of importance, the project team prioritized the technologies as follows: 1) improved varieties, 2) chemical weed control (broadleaf and narrowleaf herbicides), 3) Urea fertilizer rate; 4) DAP fertilizer rate), 5) seed rate, 6) sowing date, 7) sowing methods, 8) harvest date, and 9) rotation.

From among the 569 selected sample farm households, only 34.8 percent adopted the entire technology package comprising all nine components. A low adoption level was expected, as the project has only been underway for a few years and it normally takes a while for farmers to fully understand the science, mechanics, and benefits of all these technology components. In view of the short life of the project, in this study, an adopter is defined as "a farmer who uses the improved varieties with any other components of the technology package promoted by the Project in the 2020/2021 season".

However, we also vary the definition to include single or different combinations of two or more of the technology components and try to determine the adoption levels, as this is believed to be instrumental in guiding future interventions and promotion strategies.

Using the number of wheat-growing families at each administrative level as weights, our estimates show that, out of the total 1,779 wheat-growing families in the study governorates, 904 families (50.8 percent) have adopted the improved varieties and at least 6 other components. A total of 1,164 families (65.4 percent) have adopted the improved varieties and at least 3 other components, while 620 families (34.8 percent) have adopted the improved varieties and at least 8 other components (Table 7).

Out of the total wheat area of 41,517 ha across the three governorates, 25,948 ha (62.5 percent) was cultivated using the improved varieties and at least 6 other components. Meanwhile, 28,646.7 ha (69 percent) was cultivated using the improved varieties and at least 3 other components, and 19,928.2 ha (48 percent) was

Table 7. Weighted adoption rates and degrees (%) for the recommended package components by Governorate (region).

	Adoption rate	Adoption degree
Improved variety	65.4	69.2
Weed control (Herbicides)	58.9	79
Urea	86.8	92
DAP	64.7	81
Seed rate	61.5	72.4
Sowing date	72.2	84
Sowing methods	49.7	32
Harvest date	100	100
Rotation	62.04	80.1
Improved varieties &>=3 other comp.	65.4	69
Improved varieties &>=4 other comp.	64.7	68.8
Improved varieties &>=5 other comp.	59.4	66
Improved varieties &>=6 other comp.	50.8	62.5
Improved varieties &>=7 other comp.	46.1	60
Improved varieties &>=8 other comp.	34.8	48
Full package	8.44	8.6

Note: "&>=3 other comp." stands for "and at least 3 other components of the technology package".
Source: Field survey results in the 2020/2021 season.

cultivated using the improved varieties and at least 8 other components. There was only a slight difference in the magnitude of the adoption degrees (as percentage of total wheat area under the technologies). Adoption degrees in each governorate also follow the same pattern as the adoption rates. Although the national extension system has been trying to promote some of the technology package components, it seems it has not been effective in promoting some of the most important ones. As such, the national extension system should review their prioritization of wheat technologies in the three sample governorates and possibly other governorates.

6.3. Factors affecting the decision and intensity of adoption

The results of the double hurdle model, used to identify the factors that positively or negatively influence decisions to adopt the top six recommended package components, and the size of land area to be devoted to these components, are reported in Table 8. The estimates show that farmers who previously participated in both field days and hosting demonstration trials have higher tendencies to adopt the improved varieties and at least six other components together. This shows that the technology promotion techniques used by the EFSAC Project were very effective in enhancing the adoption of these technology components. Farmers in Irbid districts were also found to have a higher tendency to adopt the improved varieties and at least six other components than those in the other districts. The continued work over a longer period by the EFSAC project in Irbid has led to significantly higher adoption rates, which is consistent with the theory and empirical evidence in the literature on technology adoption.

Once farmers decide to adopt the improved varieties and at least six other components, the technology dissemination approaches used by the Project have a positive effect on the size of land cultivated using the new technology package. Farmers in Irbid districts were also found to increase the size of land they cultivated using the new technology package more than those in the other districts. This could, in part, be due to the extended period that the Project took place in region, and thus the fear of risk decreased among the farmers as time went on.

Table 8. Parameter estimates of the double hurdle model for using at least the top six components.

Explanatory variables	Double hurdle-Tier1				Double hurdle-Tier2			
	Coef.	Std. Err.	z	P>|z|	Coef.	Std. Err.	z	P>|z|
Education (years)	0.027	0.020	1.35	0.177	-0.015	0.058	-0.26	0.795
Farming experience (years)	0.004	0.006	0.65	0.516	-0.010	0.027	-0.37	0.714
Off-farm employment (1=yes, 0=no)	-0.379	0.183	-2.07	0.038	-0.076	0.042	-1.79	0.073
Family size	0.042	0.021	2.04	0.041	0.005	0.005	1.12	0.265
Demonstration and field days (1=yes, 0=no)	0.799	0.136	5.89	0	-0.115	0.042	-2.72	0.007
Demonstration (1=yes, 0=no)	0.873	0.155	5.64	0	0.003	0.045	0.06	0.956
Participation in other projects (1=yes, 0=no)	0.023	0.374	0.06	0.951	-0.181	0.084	-2.16	0.03
Wheat area (ha)	0.001	0.000	2.37	0.018	0.805	0.012	66.93	0
Irbid Governorate (1=yes, 0=no)	0.005	0.002	2.45	0.00	-0.190	0.052	-3.67	0
Constant	-0.888	0.400	-2.22	0.026	0.901	0.197	4.57	0

Source: Field survey results in the 2020/2021 season.

6.4. Impacts of the Project interventions

We used the IV regression method to measure the impacts of the Project interventions: a combination of improved varieties and at least one other component. A results summary of IV regression model estimations are presented in Table 9. They show that the adoption of individual technology components, such as the improved wheat varieties, weed control (herbicides), fertilizer rate, seed rate, sowing date, and rotation lead to high yield gains, while the individual adoption of components, such as sowing methods, have no effect on yields. Generally, these results are acceptable, as the technologies are not supposed to be adopted individually; they are important and complementary components of a broader technology package.

The yield gained from adopting a combination of improved varieties and at least three, four, five, six, seven, or eight components is greater than from adopting any individual components of the recommended package. All the recommended components had a significant impact on yield, except the sowing methods technology, which had no effect on yield, net margin, and marketable surplus. Moreover, as described previously, the technology package considered not only yield gains but also other factors, such as resource conservation and risk management.

The joint adoption of the improved varieties and three, four, five, six, seven, or eight other components showed clear advantages, with yield gains of 713 (25.5 percent), 704 (25.2 percent), 713 (25.5 percent), 816 (29.2 percent), 773 (27.7 percent), and 772 (27.7 percent) kg/ha, respectively. Further, such adoptions led to net margins of 289 (23 percent), 285 (22.8 percent), 304 (24.2 percent), 351 (28 percent), 335 (26.7 percent), and 339 (27 percent) US$/ha, respectively. Gains in marketable surplus wheat grains of 2 percent, 2.1 percent, 2 percent, 2.6 percent, 2.5 percent, and 2.5 percent, respectively, were also obtained.

Table 9. Summary of the minimum Impacts of the recommended package components on wheat yield (kg/ha) and net margins (US$/ha): results from the IV regression model.

Technology component(s)	Yield	Net margins	Marketable surplus
Improved variety	65.4	65.4	69.2
Weed control (herbicides)	58.9	58.9	79
Urea	86.8	86.8	92
DAP	64.7	64.7	81
Seed rate	61.5	61.5	72.4
Sowing date	72.2	72.2	84
Sowing methods	49.7	49.7	32
Harvest date	100	100	100
Rotation	62.04	62.04	80.1
Improved varieties &>=3 other comp.	65.4	65.4	69
Improved varieties &>=4 other comp.	64.7	64.7	68.8
Improved varieties &>=5 other comp.	59.4	59.4	66
Improved varieties &>=6 other comp.	50.8	50.8	62.5
Improved varieties &>=7 other comp.	46.1	46.1	60
Improved varieties &>=8 other comp.	34.8	34.8	48
Full package	8.44	8.44	8.6

Note: "&>=3 other comp." stands for "and at least 3 other components of the technology package".
Source: Field survey results in the 2020/2021 season.

At its current adoption level of 62.5 percent of total wheat area in the study area, the joint use of the improved varieties and at least 6 other components led to an increase in total wheat production by up to 21,173 tons (18.3 percent) per year. If these technologies were fully promoted to cover 75 percent and 100 percent of total wheat area in the study areas, it would be possible to increase wheat supply by at least 21.9 percent and 29.2 percent, respectively.

6.5. Conclusions and recommendations

Following the progresses achieved in Phase I and Phase II of the EFSAC Project, a third phase was launched in the 2018/2019 growing season to extend the sustainable wheat technology package into new sites in Jordan. This expansion also aimed to enhance food security in Jordan, which became an even more pressing issue following a sharp increase in wheat demand as a result of an the influx of Syrian refugees.

The results of this study demonstrate the success of the EFSAC Project in disseminating a useful wheat technology package that can increase agricultural productivity in the country's major wheat producing areas. While the Project's technology promotion technique was effective in convincing many farmers to adopt the different components of the technology package, it was ineffective in influencing farmers' decisions on the size of area to be devoted to the technologies. As such, it will be important to understand what the limiting factor is in this respect and incorporate a solution in the scaling effort in the third phase. Moreover, our results clearly show that adoption rates and degrees reduce as the number of components in a package increases. Understanding the logic, mechanics, and benefits of the entire technology package might be too difficult for the farmers to fully understand, and simultaneously introducing many changes could appear too risky for farmers, thereby reducing their desire to adopt. Therefore, scaling the technology package in the future should very carefully prioritize specific components: farmers should be introduced to only three or four of the most important to start, then gradually introduced to the remaining components.

7. Morocco

7.1 Background

The cereal sector, with its significant wheat component, is one of the main sectors of agricultural production in Morocco. Wheat is the predominant crop for almost all farms (around 1.4 million), and plays an important role in the diets of Moroccans (200 kg/inhabitant/year)—contributing to more than 58 percent of calorie intake and 60 percent of protein intake. The cereal value chain, especially wheat, involves a set of interrelated activities including production, distribution, and processing. The sector also holds major economic weight, representing between 10–20 percent of agricultural gross domestic product (GDP) depending on annual rainfall, and has a major role in trade: with cereal imports totaling about 8 billion Moroccan Dirham (MAD), which represents nearly 70 percent of agricultural imports.

During the 2020–2021 cropping season, Moroccan cereal production reached a record high of 7,543,847.9 tons, while in 2019–2020, production did not exceed 2,561,897.5 tons—indicating great variability from year to year. Autumn cereals occupy 5 million ha on average, or more than 60 percent of the country's arable land. Wheat and barley each account for about 40 percent of this area, and durum wheat 20 percent.

Morocco usually uses wheat imports to cover the gap in domestic production (40–50 percent, on average) and to meet the growing needs of the population. The figure below shows the evolution of imports for wheat (common wheat and durum wheat) over the last 10 years. While imports of durum wheat have remained constant, amounts have increased for soft wheat. Imports are made solely by the flour mills according to available stocks and follow signals given by the Office National Inter-professional of Cereals and Legumes (ONICL), whose role is to regulate the country's supply of cereals considering the domestic market and developments in the international market.

EFSAC was implemented in Morocco to enhance agricultural production, particularly wheat productivity, through the promotion of improved crop and water management technologies. The Project was undertaken in the Chaouia Region, representing rain-fed agriculture, and in the Tadla irrigated perimeter, with several farmers selected in both sites and demonstration trials for the new technologies.

The Project provided farmers with a full technological pack¬age: those in rainfed regions received eight components, while those in the irrigated zones received nine components. Following the Project's dissemination program, farmers decided whether to take up at least the top three indi¬vidual components (improved varieties, planting date, DAP (18-46-0) rate) or the full package (the DAP rate is replaced by irrigation management in irrigated zones). In general, farmers do not simultaneously adopt all technologies, but adopt a single or few components to begin and then add further components over time.

The full technology components provided by the Project, as ranked in order of their importance, included: 1) improved varieties, 2) sowing date, 3) seeding rate, 4) optimal number of irrigations, 5) N fertilizer application, 6) DAP fertilizer application, 7) weed control, 8) seed method, 9) crop rotation, and 10) harvest date. The components are summarized below.

Improved varieties:
At Tadla site, three newly released bread wheat varieties were disseminated by the project (Amal, Salama, and Raja). These varieties are very productive under favorable conditions and they have a good grain quality.

At Chaouia site, three newly released bread wheat varieties—with high yield potential and resistance to Hessian fly and some diseases (Arrihane, Radia, and Faraj)—were compared to a local cultivar commonly used by farmers in the region (Achtar).

Planting/sowing date:
All the studies conducted by National Institute of Agricultural Research (INRA) Morocco showed that, when moisture is adequate, sowing wheat early is a winning strategy: on average, the yield is improved by about 30 percent. Sowing wheat early helps prevent crop failure caused by frequent end of season droughts, and the crop benefits from the first autumn rains. The optimum period for sowing wheat as recommended by the Project is early November.

Seeding rate:
The seeding rate is a function of the achievable objective yield, the inputs provided (fertilizers, mainly irrigation), and the variety used (weight of 1,000 seeds or size of the seed to be sown). The germination rate and the method of sowing are also important factors to consider. The germination rate is mainly related to seed storage conditions and post-harvest and post-harvest diseases. If certified seeds are used, the project team recommends 150 and 180 kg/ha for rainfed zones and irrigated zones, respectively.

Irrigation management:
Three to five complimentary irrigations of 60–70 mm per application, depending on rainfall, can significantly increase yields. The three most sensitive stages of wheat to water are sowing, tillering, and heading. Supplementary irrigation at sowing (starter) ensures good germination and a good seedling. Irrigation at the

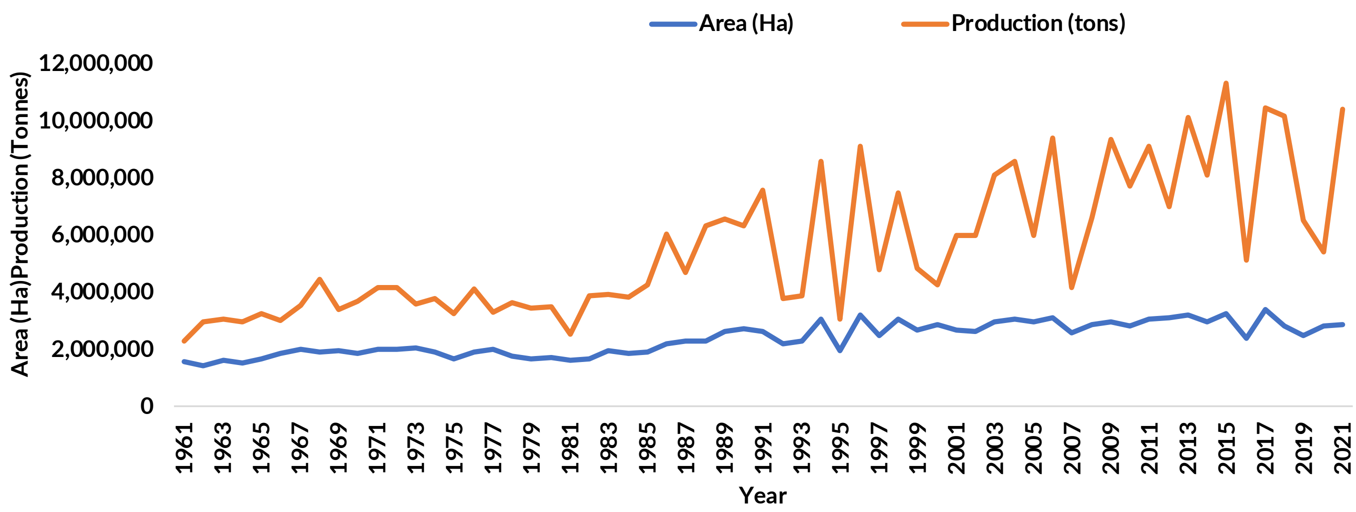

Figure 6. Evolution of wheat production in Morocco.

Source: FAO, 2023.

tillering stage makes it possible to increase the number of tillers per foot, and thereafter the number of kernels (and hence yield) produced per unit area. Irrigation at the heading stage makes it possible to improve the weight of the grain and reduce the detrimental effect of hot winds in the region at the end of the crop cycle.

Application of N fertilizer:
The recommended amounts of nitrogen are 160 and 120 units per hectare for irrigated and rain-fed areas, respectively. Nitrogen supply is split over two to three periods, depending on the moisture of the crop cycle. After planting, it is recommended to make contributions at the tillering and heading stages to ensure good tillering and fertile ears. The intake during these stages is conditioned by the rains, knowing that nitrogen is toxic in case of water deficit in the soil. In the case of a good rainy year, one could reach 40–60 kg of nitrogen for each intake stage. If the year is dry, inputs should be minimized if no irrigation is planned. The two most used nitrogen fertilizers are ammonium nitrate (33.5 percent) and urea (46 percent).

DAP rate:
Soil analysis is required to evaluate fertilizer inputs. Phosphorus and potassium inputs should be re-evaluated every two to three years, while nitrogen inputs should be evaluated annually before the start of the campaign. The intake is reasoned according to the richness of the soil in its nutritive elements but also the expected target yield. In the absence of these analyses, recommendations are based on previous data from the region. The Project recommended 200 kg/ha of DAP for irrigated regions and 150kg/ha for rainfed zones.

Weed control:
Early weed control is recommended by the Project. From the 3–4 leaf stage, farmers should chemically treat weeds when they're still young to limit their competition with the wheat plant. The most common weeds are bromegrass, sterile oats (monocots) and astragalus, mallow, diplotax, poppy, and thistle (broadleaf). Depending on the frequency of occurrence of weeds during the cycle, it is recommended (if necessary) to treat before the heading stage.

Seed method:
The Project recommended raised beds as a planting method. In this method, the land is divided into raised beds of 120–130 cm in width, and wheat is sown on the bed's back, either in rows (6–7 rows by machine) or in hills (by hand). During planting, farmers sow seeds either by broadcasting or by using drills.

Adequate rotation:
The most reliable crop rotation for the wheat-based production system at each site is considered in the demonstration trials. Crop rotation is one of the most effective agricultural control strategies, as it comes with numerous advantages that are highly important in reducing chemical use on farms and supporting long-term soil fertility. INRA research on rotations shows that if the same crop is grown continuously, the plant always drains the same nutrients from the soil, which eventually leads to nutrient depletion and soil infertility. The Project recommended crop rotation with sugar beet in irrigated areas and crop rotation with food legumes in rainfed zones.

Harvest date:
The harvest date is decided after 10 days of the crop reaching physiological maturity (when the peduncle color changes into a yellow color) and the grains become hard and dry. These signs are easily understood by farmers. Therefore, harvest dates accepted by the Project ranged from the third week of April till the second week of May.

Several farmers, increasing from season to season, were selected in the three regions and demonstration trials were implemented (Table 10). Fine tuning trials were also conducted at the experiment stations in both locations. The scale of the interventions was expanded during the second and third seasons, following interesting farmer-level results showing that the technological package substantially improved wheat grain yield and water productivity. Further, enhanced willingness of farmers to cooperate with the project resulted in a larger sample of farmers in the third and final season of the first phase.

Numerous meetings, field days, farmer's field schools, study tours, workshops, and symposiums were organized during each season, with relevant stakeholders participating. These events aimed to accelerate the diffusion of technology, which facilitates the extension of project interventions to other farmers in the selected sites, capacity building of project actors, and sensitization on the Project's objectives.

A total of 412 farmers were selected from the three regions. The sample was then distributed into 49 districts and 120 villages. Of the total sample, 85 (20.6 percent)

Table 10. Sampling design.

Category	Region			Total
	Doukkala-Abda	Gharb	Tadla-Azilal	
Untreated	23	31	31	85
Treated	89	119	119	327
Total	112	150	150	412

Table 11. Weighted adoption rates and degrees (%) for the recommended package components by governorate (region).

	Morocco	
	Adoption rate	Adoption degree (%)
Recommended improved varieties	66.3	67.6
Recommended planting date	36.9	37.8
Recommended seeding rate	35.4	36.3
Recommended nitrogen rates	63.1	63.5
Optimal number of irrigations	61.5	63
Recommended DAP rate	54.4	56
Recommended weed control	98.5	98.5
Recommended seed method	84.2	85.7
Rotation	42	43.5
Improved varieties and >= 1 other comp.	66.3	67.6
Improved varieties and >= 2 other comp.	66.3	67.6
Improved varieties and >= 3 other comp.	65.3	66.5
Improved varieties and >= 4 other comp.	59.5	60.5
Improved varieties and >= 5 other comp.	51.2	53.5
Improved varieties and >= 6 other comp.	40.8	42.7
Improved varieties and >= 7 other comp.	24	25.4
Improved varieties and >= 8 other comp.	17	17.7
Improved varieties and >= 9 other comp.	6.5	7

were randomly selected, while 327 (79.4 percent) were purposively selected from among the participant farmers (Table 10).

The average age of farmers was 50 years, with a minimum age of 24 and a maximum of 90. Male household heads were dominant, representing 99 percent of the sample. The average years of education of household heads was 4.5 years, with a maximum of 18 years. The average farming experience of household heads was 14.1 years, with a minimum level of 2 years and a maximum of 70.

Descriptive statistics from our sample showed that the average family size is 6.5, with a minimum of 1 and a maximum of 26. About 85.9 percent of household heads in the study areas depend primarily on agricultural production for their livelihoods, while about 14.1

percent had off-farm activities as their main sources of livelihoods.

In total, 13.1 percent of the sampled households had previously hosted wheat demonstration trials on their own land and attended field days, while 33.3 percent and 33.3 percent had only attended field days or only heard about the Project's activities, respectively. Of the households, 20.4 percent had not previously heard about the Project's activities.

7.2 Estimation of adoption rates and degrees

Of the sampled households, 65.3 percent simultaneously adopted the top three technology components on 66.5 percent of their total wheat land. Meanwhile, 66.3 percent (representing 67.6 percent of total wheat growers in the region) are using improved wheat varieties recommended by the Project (Table 11).

Of wheat growers, 36.9 percent adopted the recommended planting date, while the total area under early sowing technology is 37.8 percent. Further, 35.4 percent, 63.1 percent, and 54.4 percent of farmers adopted the recommended seeding rate, nitrogen, and DAP rate, respectively. Finally, 40.8 percent adopted the improved varieties and at least 6 other components recommended on 42.7 percent of their total wheat land.

7.3 Factors affecting the decision and intensity of adoption

Results of a double hurdle model (Table 12) show that the propensity and intensity of adoption of the top six components of the recommended technology package are directly related to the household's farming experience and age.

The estimates show that farmers who previously participated in both field days and hosting demonstration trials have higher tendencies to adopt the improved varieties and at least six other components together. This demonstrates that the technology promotion techniques used by the EFSAC Project were highly effective in enhancing adoption of these technology components.

Table 12. Parameter estimates of the double hurdle model for using at least the top six components.

Explanatory variables	Double hurdle-Tier1				Double hurdle-Tier2			
	Coef.	Std. Err.	z	P>|z|	Coef.	Std. Err.	z	P>|z|
Education (years)	0.033	0.017	1.96	0.05	0.009	0.011	0.78	0.437
Farming experience (years)	0.011	0.005	2.14	0.032	-0.009	0.004	-2.45	0.014
Off-farm employment (1=yes, 0=no)	-0.073	0.197	-0.37	0.711	-0.272	0.140	-1.94	0.052
Demonstration and field days (1=yes, 0=no)	0.745	0.195	3.82	0	-0.149	0.115	-1.29	0.197
Participation in other projects (1=yes, 0=no)	-0.068	0.195	-0.35	0.727	-0.081	0.136	-0.6	0.55
Wheat area (ha)	-0.003	0.004	-0.72	0.474	0.036	0.003	11.69	0
Family size	0.031	0.017	1.86	0.063	0.009	0.012	0.72	0.473
Constant	-1.031	0.262	-3.94	0	1.429	0.187	7.63	0
Irbid Governorate (1=yes, 0=no)	0.005	0.002	2.45	0.00	-0.190	0.052	-3.67	0
Constant	-0.888	0.400	-2.22	0.026	0.901	0.197	4.57	0

7.4 Impacts of the Project interventions

This study was commissioned to evaluate the impacts of the Project during the first phase (between 2010/2011 and 2013/2014), second phase (between 2014/2015 and 2017/2018), and third phase (between 2020 and 2021) of activities. The summary results of the IV regression model estimations are presented in Table 13. They show that, while adoption of the individual technology components of improved varieties, recommended DAP rate, weed control, optimal number of irrigations, and seeding rate led to high yield gains, the individual adoption of the components planting date, nitrogen rates, and seed method had no effect on yields. These results are mainly due to the characteristics of new improved varieties, which have high yield potential but are exigent in term of good agronomy (sowing date, fertilizer quantity, and weed and disease management).

The joint adoption of the improved varieties and at least three, four, five, six, seven, and eight other components promoted by the Project showed clear advantages, with yield gains of 432 (15.6 percent), 438 (15.8 percent), 653 (23.6 percent), 744 (26.9 percent), 512 (18.5 percent), and 483 (17.5 percent) kg/ha, respectively. Such adoption also led to net margins of 100.5 (21 percent), 106.8 (22.2 percent), 157.1 (32.7 percent), 182.2 (37.9 percent), 120.6 (25.1 percent), and 113.1 (23.5 percent)[3] US$/ha, respectively. Gains in marketable surplus wheat grains of 2.6 percent, 2.5 percent, 2.5 percent, 3 percent, 2.6 percent, and 2.4 percent, respectively, were also obtained.

Table 13. Summary of the minimum impacts of the recommended package components on wheat yield (kg/ha), net margins (MAD/ha), water use efficiency (kg/m^3), and household marketable surplus of wheat (%) based on estimation of IV regression models.

Technology component(s)	Yield	Net margins (MAD/ha)	Marketable surplus
Recommended improved varieties	439	996.12	1.8
Recommended planting date	Not significant	Not significant	Not significant
Recommended seeding rate	216	602.61	1.1
Recommended nitrogen rates	Not significant	Not significant	Not significant
Optimal number of irrigations	669	1395	1.2
Recommended DAP rate	200	446.4	1.3
Recommended weed control	NA	NA	NA
Recommended seed method	Not significant	Not significant	Not significant
Rotation	368	837	1.3
Recommended harvest date	196	446.4	2
Improved varieties and >= 1 other comp.	298	613.8	2.1
Improved varieties and >= 2 other comp.	298	669.6	2
Improved varieties and >= 3 other comp.	432	892.8	2.6
Improved varieties and >= 4 other comp.	438	948.6	2.5
Improved varieties and >= 5 other comp.	653	1395	2.5
Improved varieties and >= 6 other comp.	744	1618.2	3
Improved varieties and >= 7 other comp.	512	1071.36	2.6
Improved varieties and >= 8 other comp.	483	1004.4	2.4

3 Average exchange rate in 2020: 8.88 MAD = US$1.

7.5 Conclusions and recommendations

The EFSAC Project was implemented in Morocco to enhance agricultural production, particularly wheat productivity, through the promotion of improved crop and water management technologies.

The Project promoted a technology package comprising a total of 10 components. According to their order of importance, the Project team prioritized the technologies as follows: 1) improved varieties, 2) sowing date, 3) seeding rate, 4) optimal number of irrigations, 5) N fertilizer application, 6) DAP fertilizer application, 7) weed control, 8) seed method, 9) crop rotation, and 10) harvest date.

At its current adoption level of 42.7 percent of total wheat area across the study areas, the joint use of the improved varieties and at least 6 other components led to an increase in total wheat production in the study area by up to 13,189 tons (11.4 percent) per year. If these technologies were fully promoted to cover 75 percent and 100 percent of total wheat area in the study governorates, it would be possible to increase wheat supply by at least 20 percent and 26.64 percent, respectively.

These results show that the EFSAC Project interventions were potent in achieving the food security, livelihood, and natural resource conservation objectives that enhance the sustainability of Morocco's wheat-based production systems. Even though most of the technology components were not new in the country, the main innovations (namely the way the different components were combined and the technology dissemination approaches used by the project) were highly effective in achieving goals related to the Project, national food security, and environmental sustainability.

8. Tunisia

8.1 Background

In Tunisia, wheat is the major staple food crop and food security is a strategic national objective. As a result, the country has been aiming to increase cereal productivity to ensure a minimum supply of cereals from domestic production and to establish strategic stocks. Yet, despite strong efforts, the gap between national demand and domestic production has been growing steadily, leaving the country increasingly reliant on imports (Figure 7).

The widening gap between national demand and local production is primarily due to population growth and growing per capital consumption. The average annual per capita wheat consumption has significantly increased over the past 23 years—with a minimum of 247 kg in 2001 to a peak of 325 kg in 2007—placing Tunisia among the highest large per capita consumers of wheat in the world. Average total national wheat consumption is about 2.8 million tons per year. Currently, the country imports 40 percent of its durum wheat and 85 percent of its bread wheat needs; with imports accounting for about 51 percent of total wheat consumption. Most of Tunisia's wheat imports come from Ukraine, Italy, France, and Romania.

Yield levels are generally low (below 1.3 t/ha) and fluctuate considerably. However, much higher grain yields are obtained at research stations—indicating large scope for productivity improvement if appropriate technologies are adopted. Inherent factors, including

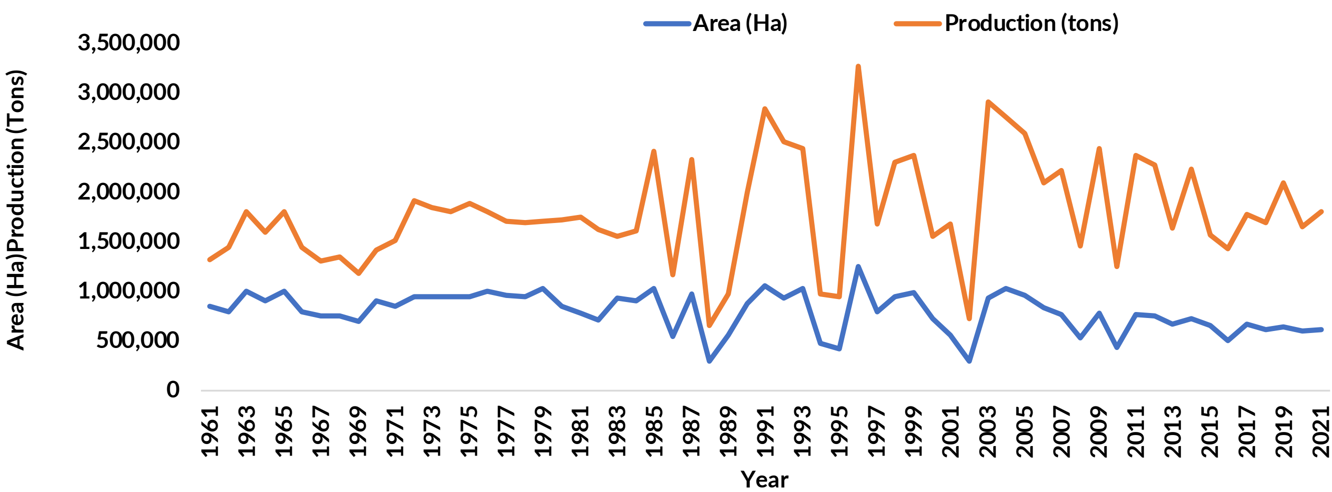

Figure 7. Evolution of wheat production in Tunisia.

low adoption of new agricultural technologies by farmers, poor crop management, a lack of improved cultivars, unfavorable growing conditions, and biotic and abiotic stresses are behind current yield variability. In addition, water use efficiency does not exceed 0.9 kg/m^3 in irrigated areas, while the potential at research plots is greater than 1.6 kg/m^3. Crop management is generally inadequate and needs strengthening for cereal productivity to improve under various cropping systems.

This recognition led to the establishment of a new strategy which aimed to ensure national food security in cereals, particularly durum wheat. Through the better transfer and adoption of appropriate technological innovations, there have been new efforts to extend irrigated wheat areas and increase yields to ensure a minimum production of 1 million tons in drought years. As a result, the country successfully grew its irrigated wheat areas (from 61,252 ha in 2008 to 100,000 ha in 2013) and increased its wheat production by about 48 percent, from 0.84 million tons in 2000 to 1.25 million tons in 2018. Rainfall has a dramatic impact on yield outcomes: for instance, in 2002, due to severe drought in the country, domestic wheat production dropped to 0.423 million tons, while favorable weather conditions in 2003 resulted in a production of around 1.98 million tons.

As part of the national effort, the first phase of the EFSAC Project started in 2010/2011 and introduced an improved wheat production technology package in two sites: Fernana and Chebika. Chebika is in semi-arid area of Kairouan governorate, while Fernana is located in the sub-humid areas of Jendouba governorate. Annual rainfall in Chebika ranges from 250–400 mm, with an average of above 290 mm/year. The main crops cultivated in the area are wheat, vegetables, fodder, and olives. There is around 1,157 farmers in the irrigated area of Chebika region, of which 1,035 are wheat farmers. The total cereal area is about 13,000 ha, and the irrigated cereal area is around 4,500 ha, of which 2,746 ha is wheat. The average cereal yield under irrigated conditions is 4.0 t/ha, but only 1.1 t/ha under rainfed conditions. The second project site, Fernana, is a sub-humid zone in which the annual rainfall ranges from 450–1,500 mm/year with an average of 700 mm. The total area under cereals in the region is about 15,000 ha (10,000 ha wheat), of which only 650 ha is irrigated. The wheat yield under rainfed conditions is very low, approximately 1.2 t/ha, and about 2.5 t/ha under irrigation.

The main components of the technology package disseminated during the third phase of the Project were: 1) improved varieties, 2) sowing method, 3) planting date, 4) seed rate, 5) recommended till, 6) Agricultural Nutrient Assistant (ANA) fertilizer, 7) DAP fertilizer, 8) chemical weed control, 9) pest control, and 10) recommended number of irrigations.

During the 2020/21 season, the EFSAC Project launched an intensive investigation on technology adoption and impact assessments of introduced technologies, to generate knowledge and an evidence base to address food security issues in Tunisia.

Using power analysis, a sample of 604 farmers was drawn to estimate the levels of adoption and impacts of the individual and combination of the wheat technology components introduced by the EFSAC Project (Table 14). The survey covered 105 villages in 22 districts in the four regions (governorates).

Of the 604 sampled households, 28.9 percent had previously hosted wheat demonstration trials on their

Table 14. Sampling design.

Category	Region				Total
	Béja	Kairouan	Siliana	Zaghouan	
Untreated	89	83	84	182	438
Treated	59	42	37	28	166
Total	148	125	121	210	604

Source: The sample designed to conduct the socio-economic survey in the 2020/2021 season.

own land and attended field days, while, 1 percent had only hosted wheat demonstration fields on their own land. Further, 4.7 percent and 14.8 percent had only attended field days and only heard about the Project's activities, respectively, while 50.6 percent had not even heard about the Project's activities. Male household heads were dominant in the study sample, representing 97.5 percent of participants. The household heads varied in terms of education levels: 12.6 percent of the household heads were high school graduates, 43.3 percent were primary and prep. school graduates, 40.86 percent can read and write, and the rest (3.3 percent) were illiterate. In total, 63 percent of the households depended on agricultural production as their main source of livelihoods, while 37 percent relied on off-farm activities.

About 33 percent of the interviewed farmers expressed knowledge of the fertilizer level, sowing date, seed rate, frequency of irrigation, and weed control components promoted by the Project. Meanwhile, out of the 33% who expressed knowledge of the recommendations, 67 percent, 78 percent, 67 percent, 79 percent, and 87 percent of respondents, respectively, could correctly state the fertilizer level, sowing date, seed rate, frequency of irrigation, and weed control promoted by the project.

8.2. Measuring the rate and degree of adoption

In view of the short life of the project, for the purpose of this study, an adopter is defined as "a farmer who uses the improved varieties with any other components of the technology package promoted by the EFSAC Project in the 2020/2021 season". However, we also vary the definition to include single or different combinations of two or more of the technology components and try to determine the adoption levels—as such a treatment in this analysis is believed to be instrumental in guiding future interventions and promotion strategies.

Out of the total 1,779 wheat-growing families across the two study areas, 596 (33.5 percent) adopted the improved varieties and at least 3 other components, and 484 (27.2 percent) adopted the improved varieties and at least 6 other components. A further 139 families (7.8 percent) adopted the improved varieties and at least 8 other components.

Of the total wheat area of 41,517 ha in the study area, 15,984 ha (38.5 percent) was cultivated using the improved varieties and at least 3 other components. A total of 13,285 ha (32 percent) was cultivated using the improved varieties and at least 6 other components, and 5,065.1 ha (12.2 percent) was cultivated using the improved varieties and at least 8 other components. (Table 15).

8.3. Factors affecting the decision and intensity of adoption

The results of the double hurdle model, which was used to identify factors that influence adoption decisions for the top recommended package components, as well as the size of area of land devoted to these components once the adoption decision is made, are reported in Table 16. The estimates show that households with more years of farming experience have higher propensity of adopting the improved varieties and at least six other components ($p<0.01$). Farmers who participated in either or both field days and/or hosted demonstration fields have a very high tendency to adopt the improved varieties and at least six other components together. This indicates that the technology promotion techniques used by the EFSAC Project were highly effective in enhancing the adoption of these technology components.

In addition, our results show that once farm households decide to adopt the improved varieties and at least six other components, the dissemination approaches used by the Project also convince farmers to adopt them on larger areas: farmers who participated in field days or hosted demonstration fields had a greater tendency to cultivate larger areas of wheat using the new technologies. The number of visits made by extension agents, the number of visits made by researchers, and household farming experience also had a significant effect in influencing farmer's decisions on the size of land to dedicate to the new technologies.

8.4. Impacts of the Project interventions

This study was commissioned to evaluate the levels of adoption and impacts of the individual and combination of components promoted by the Project. To this effect, we estimated the IV regression method by considering the individual and the improved varieties with any other technology components provided by the Project, the

Table 15. Weighted adoption rates and degrees (%) for the recommended package components by region.

Technology component(s)	Adoption rate	Adoption degree
Variety	34	35.8
Sowing method	97.6	97
Planting date	66.5	70
Seed Rate	72.3	75.1
Recommended till	29.7	32.3
ANA fertilizer	53.6	55.7
DAP fertilizer	61.9	65.2
Chemical weed control	89.6	91.1
Pest control	20.0	25.4
Recommended number of irrigations	97.7	98
Improved varieties and >= 3 other comp.	33.5	38.5
Improved varieties and >= 4 other comp.	33.3	38
Improved varieties and >= 5 other comp.	31.5	34.1
Improved varieties and >= 6 other comp.	27.2	32
Improved varieties and >= 7 other comp.	17.6	22
Improved varieties and >= 8 other comp.	7.8	12.2
Improved varieties and >= 9 other comp.	1.08	1.6

Source: Survey results.

Table 16. Parameter estimates of the double hurdle model for using the improved varieties and at least six other components.

Explanatory variables	Double hurdle-Tier1				Double hurdle-Tier2			
	Coef.	Std. Err.	z	P>|z|	Coef.	Std. Err.	z	P>|z|
Education (years)	-0.152	0.106	-1.43	0.153	0.458	0.117	3.91	0
Farming experience (years)	0.247	0.085	-2.91	0.004	0.015	0.006	2.6	0.009
Wheat area (ha)	0.054	0.042	1.29	0.198				
Participation in other projects (1=yes, 0=no)	0.623	0.237	2.63	0.008	0.434	0.187	2.32	0.02
Demonstration and field days (1=yes, 0=no)	0.718	0.125	5.76	0	0.327	0.141	-2.33	0.02
Demonstration (1=yes, 0=no)	0.989	0.503	1.97	0.049	0.183	0.390	0.47	0.638
Family size	0.298	0.137	2.17	0.03	0.005	0.139	0.04	0.972
Number of visits by extension agents	-0.171	0.088	-1.94	0.052	0.286	0.093	3.08	0.002
Number of visits by researchers	0.480	0.244	1.97	0.049	0.417	0.207	2.01	0.044
Constant	-0.494	0.278	-1.78	0.076	1.228	0.232	5.29	0

summary results of which are presented in Table 17. The results show that the adoption of individual technology components, namely improved variety, pest control, seed rate, and recommended till all led to high yield gains, while the individual adoption of the components sowing method, planting date, chemical weed control, and recommended number of irrigations have no significant effect on yields. The results are consistent with theoretical expectation, as these technologies are not meant to be adopted individually but as important components of a more holistic package.

The yield gain from the adoption of the improved varieties and at least three, four, five, six, and seven other components is more than that from the adoption of individual components. Ranking the importance of each component was done subjectively by the Project coordinator and their team, and hence may not necessarily reflect the component's actual economic and/or biophysical benefits. As a result, and as presented in the other country case studies,

The joint adoption of the improved varieties and at least three, four, five, six, seven, and eight other components promoted by the Project showed clear advantages, with yield gains of 1,025.7 (30.3 percent), 1,151 (34 percent), 1,286.4 (38 percent) , 1,384.5 (40.9 percent), 1448.9 (42.8 percent), and 1,540 (45.5 percent) kg/ha, respectively. Such adoption also led to net margins of 294.4 (28.7 percent), 297.5 (29 percent), 337.5 (33 percent), 368.3 (35.9 percent), 366.3 (35.7 percent), and 437 (42 percent)[4] US$/ha, respectively, and marketable surplus wheat gains of 3.4 percent, 3.5 percent, 4 percent, 3.69 percent, 3.67 percent, and 4.26 percent, respectively.

Table 17. Summary of the minimum impacts of the recommended package components on wheat yield (kg/ha), net margins (Tunisian dinar/ha), and marketable surplus wheat gains based on estimation of IV regression models.

Technology component(s)	Yield	Net margins	Marketable surplus
Variety	1063	797.1	3.8
Sowing method	Not significant	Not significant	Not significant
Planting date	Not significant	Not significant	Not significant
Seed rate	74.5	69.8	1.8
Recommended till	609.3	328.7	Not significant
ANA fertilizer	788.8	640.0	2.9
DAP fertilizer	1218.7	872.8	Not significant
Chemical weed control	Not significant	Not significant	Not significant
Pest control	1083.3	987.4	1.3
Recommended number of irrigations	Not significant	Not significant	Not significant
Improved varieties and >= 3 other comp.	1025.7	834.9	3.4
Improved varieties and >= 4 other comp.	1151.0	843.7	3.5
Improved varieties and >= 5 other comp.	1286.4	957.1	4
Improved varieties and >= 6 other comp.	1384.5 (40.9%)	1044.4 (35.9%)	3.69
Improved varieties and >= 7 other comp.	1448.9 (42.8%)	1038.6 (35.7%)	3.67
Improved varieties and >= 8 other comp.	1540 (45.5%)	1239.3 (42.6%)	4.26
Improved varieties and >= 9 other comp.	NA	NA	NA

Source: Field survey results in the 2015/2016 season.

4 Average exchange rate in 2020: 2.8357 TND = US$1.

8.5. Conclusions and recommendations

At its current adoption level of only 32 percent of total wheat area, the joint use of the improved varieties and at least 6 other components led to an increase in the total wheat production in the two study governorates by up to 116,416 tons (13.1 percent) per year. However, if these technologies continue to be promoted and uptake saw them cover 75 percent and 100 percent of total wheat area in the two study governorates, it would be possible to increase wheat supply by at least 30.6 percent and 40.9 percent respectively. Even more importantly, the promotion of these technologies in the study governorates, as well as other similar wheat-growing governorates, can lead to substantial increases in wheat supply from domestic production—thereby helping the country reduce its dependency on imports for its main staple.

9. Sudan

9.1 Background

Sudan is the third largest country in Africa, with a total area of 1.89 million km² (MoFEP, 2020), a population of 37.9 million people (CBS, 2020), and with a per capita GDP of US$1,753—resulting in Sudan's ranking as 166 out of 187 countries in the 2017 World Development Report. Agriculture is the main sector in Sudan's economy, contributing to over 33 percent of the country's GDP, 90 percent of export earnings, and 70 percent of employment.

Wheat is an important crop in Sudan, and significantly contributes to its international trade. However, as a result of decreased production and increased demand, the country has become a net wheat importer, with a low self-sufficiency ratio that ranged between 20 percent and 39 percent from 2001–2011 (MoFEP, 2012). Wheat imports amounted to 1.72 million tons in 2011, covering almost 75 percent of consumption and costing US$1.5 billion (CBS, 2013).

Average yields are generally low compared to other producing countries, as they are affected by myriad production and environmental factors. A key factor behind low wheat yield and the wide gap between farmers' potential and actual yields is slow adoption of the recommended packages of improved practices (Rashid et al., 1993). However, with continual research and technology transfers, notable improvements have been achieved (Ageebet et al., 1995). Due to wheat project activities led by Support to Agricultural Research for the Development of Strategic Crops in Africa (SARD-SC)—primarily involving the generation of agricultural technologies, dissemination and adoption of agricultural technologies, and capacity strengthening of project stakeholders—there has been an increase in wheat-producing farmers' yields and incomes (Alawia, et al., 2018) (Figure 8).

Even though a set of recommendations and cultural practices were developed to increase yields, they are far from meeting their potential, which poses a great challenge for wheat self-sufficiency in the country (Babiker and Faki, 1994; WRP, 2013). The average national yield was 1.8 ton/ha between 1982 and 2011, which is far below the yield potentially attainable

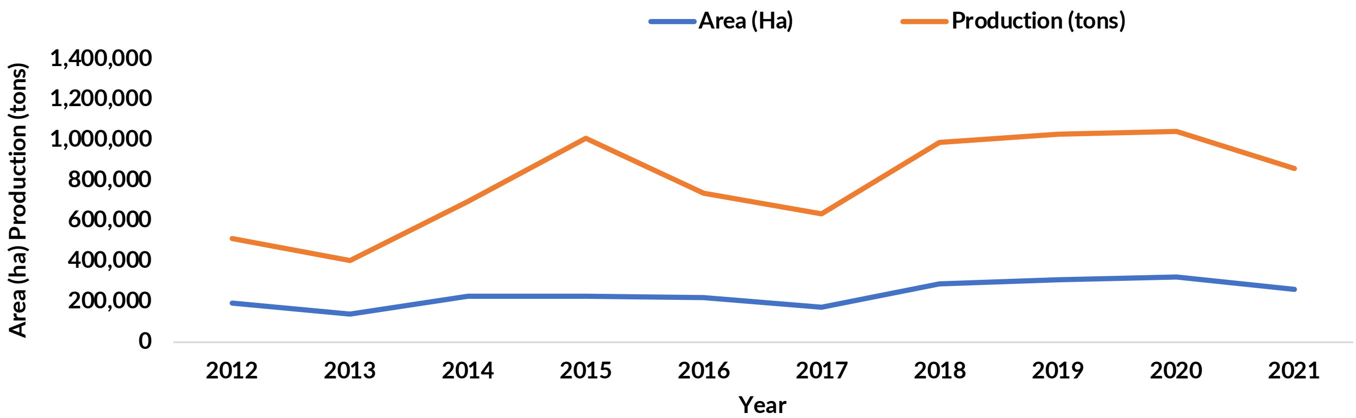

Figure 8. Evolution of wheat production in Sudan (2012-2021).

on well-managed farms (3.9 ton/ha). This yield gap is mainly attributed to ineffective extension, limited access to inputs, inefficient credit systems, and poor marketing (Fageer et al., 2013). Other factors include inadequate supply of improved seeds and limited access to fertilizers, chemicals, and irrigation water (AEPRC, 2006).

To help overcome these issues, EFSAC was designed to increase local wheat production by enhancing farmer adoption of an improved technologies package. The Project's recommended technical package consisted of improved wheat varieties (Imam, Gumriya, Zakia, Bohaine, Dibeira, and other varieties) and components including: recommended sowing date (between mid-November and the first week of December); using fertilizer rates of 240 and 120 kg/ha of nitrogen in the form of urea and DAP, respectively; recommended seeding rate of 120 kg/ha; using recommended herbicides (2,4–D and Traxos) for weed control; and recommended irrigation frequency (every 14 and 10 days during the vegetative and reproductive stages, respectively).

To ensure the adequate scaling of interventions, farmers were selected to host demonstration plots (around 1 ha in size) at their own fields under close supervision from extension and research staff, who facilitated knowledge sharing and feedback. Wheat demonstration sites were selected at different locations to ensure maximum outreach, taking into consideration the potential of each selected farmer to effectively participate in the dissemination process.

Farmers who hosted demonstrations were provided with free inputs and technical support during three consecutive seasons, 2010/11–2012/13. Inputs included 50 kg of improved wheat seeds, 50 kg of phosphorus fertilizer in the form of DAP, 100 kg of nitrogen fertilizer in the form of urea, broad leaf herbicides (mainly 1 L of 2,4-D), and narrowleaf herbicides (0.7 L of Traxos or Topik). Different farmers were selected to receive free inputs every season, meaning that farmers were only provided with free inputs for one season. For the purposes of the current study, participant farmers are defined as those who either hosted demonstration plots, attended field days, or both. Adopters are defined as those farmers who continued to use the technology package at least for three seasons after the Project stopped providing them with free inputs.

The study data was primarily obtained from one round of a household survey conducted in 2020–2021 involving a sample of 500 farmers (Table 18). The average age of household heads was 51.9 years, with a minimum age of 23 and a maximum of 85. Male household heads were dominant in the sample, representing 98.9 percent of participants. The household heads had varied education levels. In total, 16.6 percent and 37 percent were university and secondary school graduates, respectively, while 40 percent were primary school graduates and 3.8 percent were Khalwa (non-formal education). The remainder (2.64 percent) were illiterate. Household heads' average years of education was 11 years, with a maximum of 25 years. The average farming experience of household heads was about 25.1 years, with a minimum of 2 years and a maximum of 70.

Descriptive statistics from our sample showed the average family size was 5.2, with a minimum of 2 and a maximum of 29. In total, 46.5 percent of the household heads in the study areas mainly depend on agricultural production for their livelihoods, while 53.5 percent of the make a living from off-farm activities.

Of the sampled households, 18.2 percent had previously hosted wheat demonstration trials on their own land and attended field days, while 12.2 percent had only hosted wheat demonstration trials on their own land. Further, 20.25 percent and 31.6 percent had only attended field days and only heard about the Project activities, respectively, and 17.8 percent were not aware of the Project's activities.

9.2 Measuring the rate and degree of adoption

Out of the total 17,306 wheat-growing families in the study region (Gezira scheme), 16,752 (96.8 percent) adopted the improved varieties and at least 3 other components. A total of 10,349 families (59.8 percent) adopted the improved varieties and at least 6 other components.

Out of the total wheat area of 66,662 ha in the study region, 61,329 ha (92 percent) was cultivated using the improved varieties and at least 3 other components (Table 19), and 38,930 ha (58.4 percent) was cultivated using the improved varieties and at least 6 other components.

9.3 Factors affecting the decision and intensity of adoption

The results of the double hurdle model, used to identify the factors that influence the adoption decision of the top six recommended package components, along with the size of land area to be devoted to these components once the adoption decision is made, are reported in Table 20. The estimates show that farmers who participated in either or both field days or hosting demonstration fields had a very high tendency to adopt the improved varieties and at least six other components together. This indicates that the technology promotion techniques used by the EFSAC Project were highly effective in enhancing adoption of the technology components (Table 20).

Table 18. Sample distribution of wheat farmers in the Gezira scheme, 2020–2021.

Category	Total
Untreated	282
Treated	218
Total	500

Table 19. Weighted adoption rates and degrees (%) for the recommended package components by region.

Technology component(s)	Adoption rate	Adoption degree
Variety	98	96.7
Sowing date	83.5	77.9
Seeding rate	93.7	92.3
Urea rate	63.9	61.2
DAP rate	92.9	91.1
Number of irrigations	60.9	55.8
Weed control	94.7	94.8
Improved varieties and at least 3 other components	96.8	92
Improved varieties and at least 4 other components	95	92
Improved varieties and at least 5 other components	88.6	85.1
Improved varieties and at least 6 other components	59.8	58.4
Full package	1.08	1.6

Table 20. Parameter estimates of the double hurdle model for using the improved varieties and at least 6 other components.

Explanatory variables	Double hurdle-Tier1				Double hurdle-Tier2			
	Coef.	Std. Err.	z	P>|z|	Coef.	Std. Err.	z	P>|z|
Hosted wheat demonstration trials on own land and also attended field days (1=yes, 0=no)	0.268	0.143	1.88	0.05	0.039	0.024	1.64	0.07
Farming experience (years)	-0.101	0.089	-1.15	0.252	0.044	0.013	3.27	0.001
Participated in other projects	0.390	0.157	2.49	0.013	0.006	0.025	0.25	0.806
Off-farm employment (1=yes, 0=no)	0.172	0.111	1.55	0.100	0.044	0.018	2.45	0.014
A member of the cooperative (1=yes, 0=no)	0.727	0.247	2.94	0.003	-0.048	0.033	-1.45	0.147
Number of visits by researchers	-0.063	0.041	-1.53	0.088	0.001	0.007	0.14	0.885
Number of visits by extension agents	0.044	0.042	1.05	0.295	-0.014	0.007	-1.99	0.046
Wheat area (ha)					-0.010	0.015	-0.65	0.519
Constant	-0.670	0.367	-1.83	0.048	0.774	0.060	12.83	0

Our results also show that once farm households had decided to adopt all the improved varieties and at least six other components, the Project's dissemination approaches further convinced them to adopt the technologies on larger areas—with farmers who participated in the field days or hosted demonstration trials having a greater tendency to cultivate larger areas of wheat using the new technologies. Other factors, including off-farm employment, number of visits made by extension agents, and farming experience also had a significant effect in influencing farmers' decisions regarding the size of land to dedicate to the new technologies.

9.4 Impacts of the Project interventions

This study aimed to evaluate the levels of adoption and impacts of the individual and combination of components promoted by the Project. To this effect, we estimated the IV regression method by considering the individual and the improved varieties with any other technology components provided by the Project. The summary results of the IV regression model estimations are presented in Table 21. They show that the adoption of individual technology components, namely improved variety, sowing date, seeding rate, urea rate, weed control, and recommended number of irrigations all lead to high yield gains. Meanwhile, the individual adoption of the components seed rate and DAP rate had no effect on yields. These results are consistent with theoretical expectation, as the technologies are not meant to be adopted individually but as an important component of a holistic package.

The yields gained from the adoption of the improved varieties and at least four, five, and six other components is more than any individual impact of any recommended technology. As a result, the improved varieties with any other technology components provided by the Project may lead to higher yields than the adoption of some of the individual components.

The joint adoption of the improved varieties and at least four, five, and six other components promoted by the Project showed clear advantages, with yield gains of 1,082 (27.6 percent), 1,677.9 (42.8 percent), and 1,764.2 (45 percent), respectively. Such adoption also led to net margins of 195 (22.1 percent), 346.3 (39.3 percent), and 396 (44.9 percent) US$/ha, respectively, and marketable surplus wheat gains of 2.6 percent, 3.2 percent, and 4.2 percent, respectively.

At its current adoption level of 58.4 percent of total wheat area across the two study regions, the joint use of the improved varieties and at least 6 other components led to an increase in total wheat production in the two study governorates of up to 68,681 tons (29.5 percent) per

Table 21. Summary of the minimum impacts of the recommended package components on wheat yield (kg/ha), net margins (SDG/ha), and marketable surplus wheat gains based on estimation of IV regression models.

Technology component(s)	Yield	Net margins (SDG/ha)	Marketable surplus
Sowing date	807.6 (20.6%)	59717.2 (18%)	1.2
Seeding rate	Not significant	Not significant	Not significant
Urea rate	560.6 (14.3%)	44456.1 (13.4%)	1.1
DAP rate	Not significant	Not significant	1.2
Irrigation	901.7 (23%)	106164 (32%)	3.2
Weed control	1097.7 (28%)	72987.7 (22%)	1.6
Improved varieties &>=4 other comp.	1082 (27.6%)	73319.4 (22.1%)	2.6
Improved varieties &>=5 other comp.	1677.9 (42.8%)	130051 (39.3%)	3.2
Improved varieties &>=6 other comp.	1764.2 (45%)	148961 (44.9%)	4.2

year. If the promotion and uptake of these technologies continues so that they cover 75 percent and 100 percent of total wheat area in the two study governorates, it would be possible to increase wheat supply by at least 37.9 percent and 50.5 percent, respectively.

9.5 Conclusion and recommendations

This study was conducted to evaluate the adoption and impacts of the improved varieties with different combinations of components of the technology package promoted by the EFSAC Project. The evaluation period for the study covered three phases, from 2010-2021. Five-hundred farmers were selected using a multi-stage random sampling approach from among all wheat farmers in the study areas, after which analysis of adoption and impacts was carried out.

At its current adoption level of 58.4 percent of total wheat area in the two study regions, the use of improved varieties and at least 6 other components led to an increase in the total wheat production in the two study governorates of up to 68,681 tons (29.5 percent) per year. If the promotion of these technologies continues and the technologies cover 75 percent and 100 percent of total wheat area in the two study governorates, it would be possible to increase wheat supply by at least 37.9 percent and 50.5 percent, respectively.

Based on the above conclusions, this study recommends future projects and initiatives: 1) targeting small-scale farmers to enhance their adoption of the recommended full package and taking advantage of the benefits, and 2) adopting the approach used by the Project to reach many farmers in other locations.

C) Returns on investment (RoI)

10. Country-specific and project-level RoI

10.1 Summary of adoption, impacts, and RoI for only Phase 3 of the EFSAC Project

As shown in the previous sections, considerably higher adoption and yield levels were achieved during Phase III of the project in almost all countries. This is mainly attributed to the experience in scaling technologies that the Project gained during the first two phases. Table 22 provides summary of adoption and impacts in the third phase of EFSAC.

10.2 Summary of adoption, impacts, and RoI in all three phases of the EFSAC project

In this section, we present the rates of RoI made by the donors on the EFSAC Project. First, we carried out estimations for the four-year period duration of each phase in each country, then aggregated the ROI for: 1) all 12 years of the Project in each country, covering all the three phases; and 2) all five countries encompassing all 12 years of the Project. In Table 23, we present the investments made by all donors in each phase for each country (as per the values in the agreement and discounted to their 2022 US$ equivalents using each country's discount factors over the years).

The area-weighted and 12-year aggregate adoption and impacts on wheat yield, total national production, gross margin gains per unit area, and total national monetary

Table 22. Summary of adoption and impacts in the third phase of the project only.

Parameters/Variables	Country					
	Egypt	Jordan	Morocco	Sudan	Tunisia	Total - 5 countries
Names of provinces/governorates where the EFSAC project worked in Phase III	Al-Bheira	1-Irbid 2-Madeba	1- Tadla 2- Doukkala-Abda 3-Gharb (Kenitra)	1-Northern State 2- Gezira Scheme	1-Zaghouan 2-Kairouan 3-Siliana 4-Beja	
Wheat area in the new or old (from phase 2) provinces/governorates where the EFSAC project worked in phase 3 ('000 ha)	159.85	1.61	555.00	49.58	361.06	1,127.10
Number of wheat farmers in the new or old (from phase 2) provinces/governorates where the EFSAC project worked in phase 3	223,055	1,510.00	200,877.00	84,393.00	22,615.72	532,450.72
Percentage of area newly reached in phase 3	100%	100.00%	100%	100%	100%	100.00%
Average family size in the project provinces/governorates	4.99	5.90	6.80	7.48	4.82	6.06
Total population directly dependent on wheat produciton in the project provinces/governorates	1,113,044.45	8,909.00	1,365,963.60	631,259.64	109,007.77	3,228,184.46
Adoption level for the recommended improved wheat varieties (% of total wheat area in the project provinces)	66.60%	69.20%	67.60%	96.70%	35.80%	58.55%
Adoption level for the recommended planting date (% of total wheat area in the project provinces)	99.00%	84.00%	37.80%	77.90%	70.00%	58.62%
Adoption level for the recommended number of tillage (% of total wheat area in the project provinces)	100.00%	NA	NA	NA	32.30%	24.53%
Adoption level for zero tillage (% of total wheat area in the project provinces)	25.10%	NA	NA	NA	NA	3.56%
Adoption level for the recommended planting method (% of total wheat area in the project provinces)	67.70%	82.23%	85.70%	NA	97.00%	82.99%
Adoption level for raised beds (% of total wheat area in the project provinces)	56.70%	NA	NA	NA	NA	8.04%
Adoption level for rotation with leguminous crops (% of total wheat area in the project provinces)	92.10%	80.10%	43.50%	NA	NA	34.60%
Adoption level for the recommended phosphorus fertilizer rates (% of total wheat area in the project provinces)	NA	81.00%	56.00%	91.10%	65.20%	52.58%
Adoption level for the recommended Nitrogen fertilizer rates (% of total wheat area in the project provinces)	52.50%	92.00%	63.50%	61.20%	55.70%	59.38%
Adoption level for the recommended number of irrigations (% of total wheat area in the project provinces)	81.90%	NA	63.00%	55.80%	98.00%	76.49%
Adoption level for the recommended seeding rate (% of total wheat area in the project provinces)	98.40%	72.40%	36.30%	92.30%	75.10%	60.05%
Adoption level for the recommended weed control method (% of total wheat area in the project provinces)	94.50%	79.00%	98.50%	94.80%	91.10%	95.37%
Adoption level for the recommended harvest date (% of total wheat area in the project provinces)	100.00%	100.00%	37.00%	NA	NA	32.54%
Adoption level of recommended wheat varieties and at least 4 (6 for Egypt) other practices (% of total wheat area in the project provinces)	66.60%	68.80%	60.50%	58.40%	38.00%	54.08%
Yield that current adopters of recommended varieties and at least 4 (6 for Egypt) other practices are obtaining (kg/ha)	7,593.33	3,009.85	2,942.43	4,007.06	4,098.72	4,019.38
Yield that current adopters of recommended varieties and at least 4 other practices would have obtained if they had adopted utmost 1 of the recommended agronomic practices and no new varieties = Control (kg/ha)	6,048.33	2,305.85	2,504.43	2,925.06	2,947.72	3,167.27
Yield gain by new adopters in phase III due to adoption of recommended wheat varieties and at least 4 (6 for Egypt) other practices (kg/ha)	1,545.00	704.00	438.00	1,082.00	1,151.00	852.11
Yield gain in Phase III by farmers who had already adopted recommended wheat varieties and at least 2 other practices in PhaseII (kg/ha)	1,335.20	7.45	39.55	19.15	783.40	460.65
gross margins that current adopters of recommended varieties and at least 4 other practices are obtaining (US$/ha)	1,894.16	750.81	733.99	999.56	1,022.43	1,002.64
gross margins that current adopters of recommended varieties and at least 4 other practices would have obtained if they adopted utmost 1 of the technologies without the new varieties (US$/ha)	1,508.76	575.19	624.73	729.66	735.31	790.08
Additional gross margins due to adoption of recommended wheat varieties and at least 4 other practices (US$/ha) for new adopters in PhaseIII	385.40	175.61	109.26	269.90	287.12	212.56
gross margin gain in Phase III by farmers who had already adopted recommended wheat varieties and at least 2 other practices in PhaseII (US$/ha)	333.07	1.86	9.87	4.78	195.42	
Gross margin gain due to adoption of recommended wheat varieties and at least 4 (6 for Egypt) other practices (US$/ha)	385.40	175.61	109.26	269.90	287.12	212.56
Total national additional wheat production due to the current adoption level of recommended wheat varieties and at least 4 (6 for Egypt) other practices during the 4-years of the project life (tons)	896,473.57	2,069.15	370,668.18	79,403.29	408,747.91	1,757,362.09
Total national net monetary value generated due to the current level of adoption of recommended wheat varieties and at least 4 (6 for Egypt) other practices during the 4-years of the project life (in 2022 US$)	213,865,344.97	476,219.48	84,609,586.33	19,732,872.93	95,757,827.94	414,441,851.65
Minimum share of the current adoption levels that can be safely attributed to the EFSAC project (%)	30%	90%	85%	50%	50%	64%
Total national additional wheat production during the 4-year project period due to EFSAC investment (tons)	268,942.07	1,862.23	315,067.95	39,701.64	204,373.95	829,947.85
Total national net monetary value generated during the 4-year project period due to EFSAC investment (in 2022 US$)	64,159,603.49	428,597.53	71,918,148.38	9,866,436.47	47,878,913.97	194,251,699.84
Total budget for the EFSAC project (in 2018/19 US$)	278,920.00	210,568.68	213,568.68	210,568.68	210,568.68	1,124,194.72
Total budget for the EFSAC project (in 2022 US$)	483,604.61	243,975.49	235,739.86	368,285.94	283,727.65	1,615,333.55
Benefit:cost ratio (BCR) for EFSAC project	132.67	1.76	305.07	26.79	168.75	120.25
Total number of farm households directly benefited from EFSAC investment in Phase III	44,566.39	934.99	103,301.00	24,643.13	4,296.99	177,742.50
Total population that directly benefited from EFSAC investment in Phase III	222,386.28	5,516.45	702,446.78	184,330.63	20,711.48	1,135,391.63

gains are presented in Table 24. The area-weighted adoption level throughout the 12 years of the Project for variety and at least 2 other components was a maximum of 78.69 percent in Egypt and minimum of 27.45 percent in Morocco—leading to an overall adoption level of 37.95 percent across the total 2.73 million ha of wheat area in all five countries.

The RoI estimates provided below for all the three phases of the Project can be considered conservative (i.e., they represent the lower bound of the actual benefits), as we have made the following assumptions:

1. Adoption of the technologies introduced by the Project during each phase was expected to increase after the phase they were introduced—hence they are expected to have increasing impacts. However, for this analysis, the adoption level at the last year of the preceding phase is assumed in the subsequent years.
2. Normally, varietal turnover in the region is slow (e.g., Yigezu et al., 2019, estimated it to be 22 years in Morocco). However, for the estimation of RoI in this study, the variety and other associated technologies were assumed to become obsolete, and hence farmers will dis-adopt them (or replace them with latest technologies) after only five years from the end of the phase.
3. The total funds for each phase were assumed to be made available to ICARDA at the beginning of each phase (regardless of the actual dates of fund disbursements).
4. Of the total adoption level, measured using the survey conducted at the end of the third year of each phase, we assumed no adoption in the first

Table 23. Investment made by country and by phase.

Phase/country	Country						Total project budget	% of total
	Egypt	Jordan	Morocco	Sudan	Tunisia	Total 5 countries	for all 10 countries	project budget
Phase I	854,306	527,815	881,806	854,306	881,806	**4,000,039**	**5,436,479**	**39%**
Phase II	844,046	799,046	804,046	670,190	806,546	**3,923,874**	**5,909,825**	**43%**
Phase III	278,920	278,920	281,920	278,920	278,920	**1,397,600**	**2,486,098**	**18%**
Total	**1,977,272**	**1,605,782**	**1,967,772**	**1,803,416**	**1,967,272**	**9,321,514**	**13,832,402**	**100%**
% of total project budget	**14%**	**12%**	**14%**	**13%**	**14%**	**67%**	**100%**	
	Budget in 2022 US$ equivalents (using each country's historical discount factors)							
Phase I	3,237,547.06	820,992.13	1,185,931.03	3,744,585.05	1,690,963.77	10,680,019.05	16,357,957.77	**55%**
Phase II	2,245,344.42	1,072,695.91	979,651.98	1,935,068.18	1,286,582.85	7,519,343.33	13,083,816.44	**44%**
Phase III	434,536.89	323,170.77	311,186.93	500,632.67	364,292.12	1,933,819.38	375,294.70	**1%**
Total	**5,917,428**	**2,216,859**	**2,476,770**	**6,180,286**	**3,341,839**	**20,133,182**	**29,817,069**	**100%**
% of total project budget	**20%**	**7%**	**8%**	**21%**	**11%**	**68%**	**100%**	

Table 24. Average adoption levels for individual and combination of different technology components introduced during the three phases of the project and associated yield and gross margin gains.

Parameters/Variables	Country					
	Egypt	Jordan	Morocco	Sudan	Tunisia	Total - 5 countries
Names of provinces/governorates where the EFSAC project worked in Phase III	1-Al Sharkia 2-Al Beheira 3-Al Bheira	1- Irbid 2- Madeba	1- Tadla 2- Sidi Bennour 3- Settat 4- Benslimane 5- Doukkala-Abda 6-Gharb (Kenitra)	1-Northern State 2- Gezira Scheme	1-Jendouba 2- Kairouan 3-Zaghouan 4-Siliana 5-Beja 6-Tozeur	
Total wheat area in the project provinces/governorates ('000 ha)	450.13	45.19	1,428.42	226.47	580.01	2,730.22
Total number of wheat farmers in the project provinces/governorates	921,025.00	3,649.00	438,396.65	191,834.00	59,564.37	1,614,469.02
Average family size in the project provinces/governorates	5.21	5.90	6.80	7.48	4.82	5.90
Total population directly dependent on wheat produciton in the project provinces/governorates	4,798,540.25	21,529.10	2,981,097.24	1,434,918.32	287,100.27	9,523,185.18
Adoption level for the recommended improved wheat varieties (% of total wheat area in the project provinces)	79.18%	63.45%	39.80%	80.65%	42.13%	50.57%
Adoption level for the recommended planting date (% of total wheat area in the project provinces)	60.87%	75.94%	25.27%	81.75%	72.64%	46.73%
Adoption level for the recommended number of tillage (% of total wheat area in the project provinces)	88.53%	NA	NA	NA	55.82%	26.45%
Adoption level for zero tillage (% of total wheat area in the project provinces)	11.95%	NA	0.40%	NA	NA	2.18%
Adoption level for the recommended planting method (% of total wheat area in the project provinces)	68.49%	79.62%	33.30%	NA	82.74%	47.61%
Adoption level for raised beds (% of total wheat area in the project provinces)	31.48%	NA	NA	NA	NA	5.19%
Adoption level for rotation with leguminous crops (% of total wheat area in the project provinces)	53.54%	89.17%	20.61%	NA	11.64%	23.56%
Adoption level for the recommended phosphorus fertilizer rates (% of total wheat area in the project provinces)	NA	62.95%	30.78%	71.05%	75.91%	39.17%
Adoption level for the recommended Nitrogen fertilizer rates (% of total wheat area in the project provinces)	30.65%	61.53%	38.44%	73.67%	53.88%	43.74%
Adoption level for the recommended number of irrigations (% of total wheat area in the project provinces)	87.51%	NA	27.48%	74.95%	91.47%	54.45%
Adoption level for the recommended seeding rate (% of total wheat area in the project provinces)	86.25%	58.70%	19.38%	43.74%	67.49%	43.30%
Adoption level for the recommended weed control method (% of total wheat area in the project provinces)	79.46%	54.12%	50.35%	86.83%	83.59%	65.30%
Adoption level for the recommended harvest date (% of total wheat area in the project provinces)	87.35%	89.88%	14.38%	NA	15.91%	26.79%
Adoption level of recommended wheat varieties and at least 2 other practices (% of total wheat area in the project provinces)	78.69%	47.96%	27.45%	34.69%	32.71%	37.95%
Yield that current adopters of recommended varieties and at least 2 other practices are obtaining (kg/ha)	6873.68	2018.96	2664.27	2885.59	3727.87	3,591.90
Yield that current adopters of recommended varieties and at least 2 other practices would have obtained if they had adopted at maximum 1 of the recommended agronomic practices and no new varieties = Control (kg/ha)	6198.00	1344.25	2264.19	1874.15	2874.66	2,994.87
12-year average yield gain due to adoption of recommended wheat varieties and at least 2 other practices (kg/ha)	675.68	674.72	400.07	1,011.44	853.21	597.03
12-year average gross margins that current adopters of recommended varieties and at least 2 other practices are obtaining (US$/ha)	1,714.64	503.63	664.60	719.81	929.92	896.00
gross margins that current adopters of recommended varieties and at least 2 other practices would have obtained if they adopted utmost 1 of the technologies without the new varieties (US$/ha)	1,546.09	335.32	564.80	467.51	717.08	747.07
Additional gross margins due to adoption of recommended wheat varieties and at least 2 other practices (US$/ha)	168.55	168.31	99.80	252.30	212.83	148.93
Annual average national additional wheat production due to the current adoption level of recommended wheat varieties and at least 2 other practices (tons)	239,346.16	14,620.84	156,854.56	79,459.51	161,872.12	652,153.20
Annual average national net monetary value generated due to the current level of adoption of recommended wheat varieties and at least 2 other practices (US$)	59,704,900.55	3,647,168.72	39,127,369.92	19,821,175.26	40,379,000.33	162,679,614.79

Table 25. National wheat supply, and income gains, number of beneficiaries, and returns on investment by the project.

Parameters/Variables	Country					
	Egypt	Jordan	Morocco	Sudan	Tunisia	Total - 5 countries
Total national additional wheat production due to the introduction of recommended wheat varieties and at least 2 other practices during the 1st phase of the project (tons)	68,624.50	9,868.70	27,152.02	53,925.84	5,890.43	**165,461.49**
Total national net monetary value generated due to the introduction of recommended wheat varieties and at least 2 other practices during the 1st phase of the project (in 2022 US$ equivalents)	49,235,572.61	3,439,628.00	8,470,505.86	42,445,244.51	2,428,094.81	**106,019,045.80**
Total national additional wheat production during phase 2 due to the introduction of recommended wheat varieties and at least 2 other practices in the 1st phase of the project (tons)	109,799.20	15,789.93	43,443.23	86,281.34	9,424.69	**264,738.38**
Total national net monetary value generated during phase 2 due to the introduction of recommended wheat varieties and at least 2 other practices in the 1st phase of the project (in 2022 US$ equivalents)	62,303,385.75	5,007,882.08	12,728,470.68	52,983,525.81	3,510,911.27	**136,534,175.60**
Total national additional wheat production during phase 3 due to the introduction of recommended wheat varieties and at least 2 other practices in the 1st phase of the project (tons)	109,799.20	15,789.93	43,443.23	86,281.34	9,424.69	**264,738.38**
Total national net monetary value generated during phase 3 due to the introduction of recommended wheat varieties and at least 2 other practices in the 1st phase of the project (in 2022 US$ equivalents)	36,262,315.73	4,322,168.29	11,531,366.22	31,654,114.04	2,774,499.25	**86,544,463.52**
Total additional production obtained in all 3 phases due to phase I interventions (tons)	288,222.89	41,448.56	114,038.48	226,488.52	24,739.82	**694,938.26**
Total national net monetary value generated in all 3 phases due to phase 1 interventions (in 2022 US$ equivalent)	147,801,274.09	12,769,678.37	32,730,342.76	127,082,884.36	8,713,505.33	**329,097,684.92**
Total national additional wheat production due to the introduction of recommended wheat varieties and at least 2 other practices during the 2nd phase of the project (tons)	61,330.31	25,935.23	28,919.51	77,883.40	42,374.19	**236,442.64**
Total national net monetary value generated due to the introduction of recommended wheat varieties and at least 2 other practices during the 2nd phase of the project (in 2022 US$ equivalents)	26,813,817.48	7,722,926.25	8,123,127.55	38,537,125.91	14,313,656.48	**95,510,653.67**
Total national additional wheat production during phase 3 due to the introduction of recommended wheat varieties and at least 2 other practices in the 2nd phase of the project (tons)	111,023.34	46,949.32	52,351.61	140,988.61	76,707.99	**428,020.88**
Total national net monetary value generated during phase 3 due to the introduction of recommended wheat varieties and at least 2 other practices in the 2nd phase of the project (in 2022 US$ equivalents)	36,435,087.46	12,822,600.00	13,875,061.62	51,279,640.24	22,489,487.55	**136,901,876.86**
Total additional production obtained in the last two phases due to phase II interventions (tons)	172,353.65	72,884.55	81,271.12	218,872.01	119,082.18	**664,463.52**
Total national net monetary value generated in the last two phases of the project due to phase II interventions (in 2022 US$ equivalent)	63,248,904.94	20,545,526.25	21,998,189.16	89,816,766.15	36,803,144.04	**232,412,530.54**
Total national additional wheat production due to the introduction of recommended wheat varieties and at least 2 other practices during the 3rd phase of the project (tons)	896,473.57	2,069.15	370,668.18	79,403.29	408,747.91	**1757362.09**
Total national net monetary value generated due to the introduction of recommended wheat varieties and at least 2 other practices during the 3rd phase of the project (in 2022 US$ equivalents)	213,865,344.97	476,219.48	84,609,586.33	19,732,872.93	95,757,827.94	**414441851.65**
Total national additional wheat production due to the introduction of recommended wheat varieties and at least 2 other practices during the 12-years of the project life (tons)	1,357,050.12	116,402.26	565,977.78	524,763.81	552,569.91	**3,116,763.87**
Total national net monetary value generated due to the introduction of recommended wheat varieties and at least 2 other practices during the 12-years of the project life (in 2022 US$)	424,915,524.00	33,791,424.10	139,338,118.25	236,632,523.44	141,274,477.31	**975,952,067.11**
Total national additional wheat production during the 12-year project period due to EFSAC investment (tons)	407,115.04	101,068.03	461,559.08	234,926.98	273,188.70	**1,477,857.83**
Total national net monetary value generated during the 12-year project period due to EFSAC investment (in 2022 US$)	127,474,657.20	29,339,917.91	113,631,268.79	105,935,972.42	69,845,626.71	**446,227,443.04**
Total duration of the project (in years)	12.00	12.00	12.00	12.00	12.00	**12.00**
Total budget for phase I of the EFSAC project (in 2010/11 US$)- We assumed that all funds were disbursed in the first year of the project	854,306.00	527,815.00	881,806.00	854,306.00	881,806.00	**1,477,857.83**
Total budget for phase II of the EFSAC project (in 2014/15 US$)- We assumed that all funds were disbursed in the first year of the project	844,046.00	799,046.00	804,046.00	670,190.00	806,546.00	**446,227,443.04**
Total budget for phase III of the EFSAC project (in 2018/19 US$)- We assumed that all funds were disbursed in the first year of the project	278,920.00	278,920.00	281,920.00	278,920.00	278,920.00	**60.00**
Total budget for phase I of the EFSAC project (in 2022 US$)	3,237,547.06	820,992.13	1,185,931.03	3,744,585.05	1,690,963.77	**10,680,019.05**
Total budget for phase II of the EFSAC project (in 2022 US$)	2,245,344.42	1,072,696.91	979,651.98	1,935,068.18	1,286,582.85	**7,519,343.33**
Total budget for phase III of the EFSAC project (in 2022 US$)	434,536.89	323,170.77	311,186.93	500,632.67	364,292.12	**1,933,819.38**
Total budget of the EFSAC project in all 3 phases (in 2022 US$)	**5,917,428.37**	**2,216,858.81**	**2,476,769.94**	**6,180,285.90**	**3,341,838.74**	**20,133,181.76**
Total investment by AFESD in all 3 phases (in 2022 US$)	**2,355,834.71**	**1,031,081.27**	**1,028,317.61**	**2,712,019.16**	**1,360,902.01**	**8,488,154.76**
Share of AFESD in total project budget (%)	40%	47%	42%	44%	41%	**42%**
Benefit:cost ratio (BCR) for EFSAC project	21.54	13.23	45.88	17.14	20.90	**22.16**
Benefit:cost ratio (BCR) for AFESD investment	**21.54**	**13.23**	**45.88**	**17.14**	**20.90**	**22.16**
Total number of farming households that directly benefited from AFESD investment in Phase II	**86,566.81**	**706.67**	**40,741.55**	**13,073.02**	**3,922.69**	**145,010.75**
Total population that directly benefited from AFESD investment in Phase II	**451,013.10**	**4,169.38**	**277,042.57**	**97,786.16**	**18,907.38**	**848,918.59**
Total additional wheat production due to AFESD investment in all three Phases of the project (tons)	**151,178.29**	**21,199.05**	**197,597.09**	**57,102.68**	**124,602.45**	**551,679.54**
Total monetary value generated due to AFESD investment in all three Phases of the project (in 2022 US$)	**37,794,571.60**	**5,299,761.31**	**49,399,271.39**	**14,275,668.80**	**31,150,613.01**	**137,919,886.11**
Total value added by the AFESD investment in all three Phases of the project (in 2022 US$)	**35,438,736.90**	**4,268,680.04**	**48,370,953.78**	**11,563,649.63**	**29,789,711.00**	**129,431,731.35**
Total number of farm households directly benefited from EFSAC investment in all three Phases	**217,440.09**	**1,519.37**	**98,128.69**	**29,791.45**	**9,632.59**	**356,512.19**
Total population that directly benefited from EFSAC investment in all three Phases of the project	**1,132,862.88**	**8,964.31**	**667,275.09**	**222,840.02**	**46,429.06**	**2,078,371.36**

year and 25 percent of the estimated adoption in the second year. We estimated the same adoption in the fourth year as in the measured estimates for the third year.
5. While the price of wheat can reach up to US$400/t, considering the fluctuations, we assumed an average world market price of only US$250/t for all years and all project countries.
6. The average production cost for adopters and non-adopters of the technologies was assumed to be the same (some components of the package reduce cost while others increase it; and the net effect is often negative, i.e., reduction in cost). In this analysis, it is assumed to be zero, thereby underestimating the benefit:cost ratio.

Therefore, these and other conservative assumptions mean that the estimates provided here are the minimum investment benefits for the donors on the EFSAC Project (Table 25).

During the project's lifetime, the area-weighted average wheat yield gain was highest in Sudan (1,011.44 kg/ha under fully irrigated conditions) and lowest in Morocco (400.07 kg/ha under mostly rainfed conditions), leading to an average yield gain of 597.03 kg/ha and total annual additional wheat production of 652,000 t, that has an annual value of US$162.7 million across all five project countries (with the highest of US$59.7 million in Egypt and US$3.6 million in Jordan). Of the area-weighted average adoption level of 37.95 percent, only 63 percent (i.e., 63%x37.95% = 24.01%) is conservatively attributed to the EFSAC Project, while the remaining 13.94 percent is attributed to other government and non-government efforts—some of which may have been induced by the EFSAC Project.

Considering the 24.01 percent adoption level that was purely attributed to the EFSAC Project, in its 12 years of operation, the Project activities led to the total production of 1.4 million t of wheat. Using available discount rates for each country, this level of wheat production was valued at US$446.2 million (in 2022 US$ equivalents). With a total 12-year gain of US$127.5 million (in 2022 US$ equivalents), Egypt led the group, while Jordan generated the least in the group (US$29.3 million in 2022 US$ equivalents) (Table 24). Considering the discounted project cost (presented in Table 22), the benefit:cost ratio for all three phases in all five countries was estimated at 22.16. This means, every dollar (in 2022 US$ equivalents) that donors invested in the project has brought a minimum return of US$22.16 in 2022 US$ equivalents. For a long investment period of 12 years, an RoI of 22.16 is, by any standards, high. Even considering the total cost for all 10 countries where the project was implemented, and the benefits for only the five major countries included in this study, the benefit:cost ratio is 14.97. Bearing in mind that RoI estimates are based on conservative assumptions, the EFSAC Project has generated very high donor RoIs. A total of 356,500 households, comprising 2.1 million members, directly benefited from the Project.

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