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Implications of Adoption of Zero Tillage (ZT) on Productive Efficiency and Production Risk of Wheat Production

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Abstract: The impacts of zero tillage (ZT) on soil physical, biological, and chemical properties have been fairly documented in the literature. However, there is still an information gap in the developing world in general and in integrated crop–livestock production systems in dry areas of the world in particular. Using a sample of 621 farmers in Syria, this study assessed the implications of adoption of ZT technology on productive efficiency, input-specific resource use efficiency, and production risk. A stochastic production frontier model, which explicitly and simultaneously accounts for technical inefficiency and production risk, was used to estimate total factor and input-specific technical efficiencies and the risk of obtaining lower levels of yields for each of the sampled farms. Model results show that adoption of ZT proved to be an effective risk management strategy in this dryland production system, where it led to 95% and 33.3% reductions in the risk of obtaining wheat yield levels below 1000 kg/ha and 1500 kg/ha, respectively. Overall, the results have a clear indication that using ZT leads to improvements in productive efficiency as the adoption of ZT led to 93% reduction in the risk of obtaining efficiency levels below 40%. Future research will be needed to shed light on whether coupling ZT with the other components of conservation agriculture will reverse some of these effects.

Keywords: productive efficiency; conservation tillage; conventional cultivation; production risk; stochastic frontier analysis

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1. Introduction

Increasing productivity has been identified as one of the main ways of improving farm income and the economic well-being of farmers [1]. This motivated many government and non-government organizations to incorporate resource use efficiency considerations in their policy formulation processes and even in the promotion of productivity enhancing initiatives and programs.

One of the promising technologies that can provide some solutions for these longstanding agricultural challenges in the region is conservation agriculture (CA), defined as cropping with minimal soil disturbance and retention of stubble and wind rotations [2]. However, due to lack of information and evidence, CA is often looked upon with high degree of skepticism, particularly of its effectiveness and profitability related to traditional tillage and other agronomic practices [3].

CA has direct impacts that have the potential to turn around the daily and seasonal calendar and, in the long term, change the rhythm of the farmer's family because of the reduced labor requirements for tillage, land preparation, and weeding. More available time offers real opportunities for diversification options such as, for example, poultry farming or on-farm sales of produce, or other off-farm small enterprise developments [1].

One of the most noticeable changes for the farmer is the reduced requirement for farm power and labor. CA helps lower the overall requirement for farm power and energy for field production by up to 60%, compared to conventional farming [1].

Globally, the total cropland under CA has increased from 50 million ha in 2000 to 180 million (12.5%) in 2016, showing that it has expanded at a rate of 6.8 million ha (9%) annual increase [4]. Zero tillage (ZT), an important cropping technology by itself as well as a defined component of CA, has been widely adopted in some southern and northern regions in America and Australia [5–8]. Except for a few success stories in certain pockets of South Asia and Africa [2–9] and West Asia [10,11], the vast majority of the developing world has not yet benefitted from the advances of CA technology in general and ZT in particular.

Adoption of ZT has been found to reduce fuel, labor, and machinery costs [12] and conserve soil moisture. In addition, a reduction in wind and water erosion provides significant environmental benefits. ZT can often lead to higher yields, increased net returns, and reduced yield and income variability, which is particularly important in dryland areas. As in many high income countries, CA can lead to possible benefits to resource-poor farmers and consumers, and improve rural and national economies in low and middle income countries in the Middle East, Asia, and Africa, especially those dryland regions [13]. ZT is thought to be the most important component of CA for the Middle East, providing immediate benefits to farmers.

There have been no studies that measured the effect of ZT technology on total factor and input-specific technical efficiency and production risk in field crops in the region. Therefore, the work in this paper will be the first attempt to do such an important analysis. Using data from small holder wheat farmers in Syria, this study estimated the effects of farmer adoption of ZT on technical efficiency and production risk and their determinants.

Measuring efficiency and production risk provides a way of quantifying and comparing the performance of each farmer, as well as of identifying factors that explain any sort of inefficiencies and differences in performance. The identification of factors affecting inefficiency and risk can help stakeholders improve productivity and identify controllable and uncontrollable factors affecting efficiency that have to be taken into account in designing interventions.

2. Conservation Agriculture and ZT—Brief Synthesis of the Literature and Syrian Experience

2.1. Synthesis of the Literature

CA is an inclusive technology package that offers a wide range of interrelated practices such as zero or no tillage for minimum soil disturbance, crop residue retention for soil cover (mulching), and diverse crop rotation, mainly involving rotation between cereals and leguminous crops, for nitrogen fixation and control of crop diseases and pests. Those practices have been developed and promoted to farmers around the world as a response to food security, farm profitability, and land degradation concerns [14]. There is a wide literature on CA practices: [15] have provided a comprehensive review and synthesis of recent research on farmers' adoption of CA; similarly, [14,16–18] have provided a synthesis of the farm-level economics of CA for resource-poor farmers. A general consensus emerging from those reviews is that there are few if any universally accepted determinants of the adoption of CA practices. This is partly because of the heterogeneity between regions, farmers in a particular region, and institutional factors that influence technology adoption. Therefore, the economic outcomes of CA tend to be specific to particular people, places, and situations. This highlights the importance of considering site-specific conditions in promoting and determining the financial and economic attractiveness of CA.

In general, factors that influence the adoption of CA practices can broadly be categorized into four groups: farmer and farm household characteristics such as age, education, and experience; farm biophysical characteristics such as farm size, area planted and soil type; farm financial and management characteristics such as use of hired labor, farm profitability, and expenditure on key inputs;

and exogenous factors such as input and output prices, and the use and availability of extension and technical assistance. The characteristics of the innovation (i.e., practice being adopted), especially its relative advantage over existing practices and trialability, are other key factors. Relative advantage is the degree to which an innovation is perceived as being better than the practice it supersedes and trialability is the ease of physically establishing a trial and the factors that influence the ability to learn from a trial [19]. There is empirical evidence that adoption is also affected by risk-related issues, especially the perceptions about the riskiness of the technology, attitudes toward risk, and the option value of delayed adoption [20]. From a theoretical perspective, it is assumed that farmers will only adopt a new innovation if they expect that it will help them achieve their social, economic, or environmental goals.

Adoption of a new technology is a dynamic process that involves three interrelated decisions: the choice of whether to adopt the technology and in which sequence or combination; the extent of the adoption, such as choice of how much land to allocate to new and old technologies; and the intensity of adoption, such as choice of the rate of fertilizer to apply per hectare [21–23]. The combination of these three decisions composes the technology adoption decision and, aggregated over farms of the national area, is the diffusion of the technology. Final adoption is defined as the degree of use of a new technology in the long-run when there is full information about the technology and its potential [23].

The focus of this study is on ZT. As in Syria and other countries in the region, the trade-offs and synergies involved in the use of crop residues for animal feed or soil mulch in mixed crop–livestock systems represent some of the major interactions between crop and livestock production. ZT is the technology being verified and promoted in Syria, along with associated enhancements of early sowing and reduced (appropriate) seed rates [10]. There is empirical evidence that the main drivers of adoption of ZT (or at least reduced tillage) are reduced cost of production, increased yields, and, therefore, increased net farm return. For example, [24] estimated the economic benefits from reduced tillage in wheat production in Punjab, India, and found that profit increases were attributed to cost savings. Reduced costs come mainly because of labor savings in land preparation as well as in cases where herbicide use replaced manual weeding. A review of a number of studies on the economics of ZT in the Indo-Gangetic Plains consistently showed the benefits of ZT adoption in terms of cost savings and increased yields [25].

2.2. History of Conservation Agriculture (CA) in Syria

A number of efforts have been made by the governments of Syria and Iraq to introduce CA in general, and ZT and a few other components of CA in particular, using local resources and funding from international development organizations, including the Arab Agency for Agricultural International Development (AAAID), Arab Center for Studies of Arid Zones (ACSAD) and the Australian aids program under the Australian Center for International Research (ACIAR-AusAID). ZT was a fairly recent introduction in Iraq and its adoption rate and impacts are still relatively low. However, in Syria, given the awareness created through earlier efforts since 2001 by the government through funds from AAAID and ACSAD, ZT has been well received by a relatively larger number of farmers in a fairly short duration. It was reintroduced through the ACIAR-AusAID-funded project in early 2005.

Survey results from Syria show that adoption is taking place rapidly [10]. From discussions with Syrian farmers, one of the major constraints to a wider adoption of ZT technology is the lack of adapted and affordable ZT seeders. The ACIAR-AusAID-funded project discussed and demonstrated ZT seeding technologies and requirements with local seeder manufacturers. Various prototype ZT seeders were developed with modifications to suit local conditions, including the wide (≈4 m) trailed machines for extensive areas in eastern Syria and the narrow (≈2.5 m) 3-point linkage machines with spring-loaded tines for rocky areas in the north and east. The efficacy of those machines was proved in studies at the International Center for Agricultural Research in the Dry Areas (ICARDA) research station in Tel Hadiya village of Aleppo province and in farmer fields across the cropping areas of Syria. As a result, the total number of seeders has grown from 3 in 2007 to 105 in 2011, where 23 of the machines are privately owned by farmers while the rest are owned by the project implementers (ICARDA, Aga Khan Foundation, Aleppo Agricultural Machinery Center) and private rental companies. A system has developed where farmers who did not own seeders either rented or borrowed from the project implementers, contractors, or seeder-owning farmers. By 2010/11, the total area under ZT had grown to about 15,000 ha and it is estimated that the areas may have reached 50,000 ha in 2012/13.

3. Data

The data used for this analysis come from a farm survey conducted in 2011 by ICARDA scientists and collaborating project institutions. Given that ZT was introduced only five years prior to the time of data collection, only the 28 villages in which ZT was popularized were purposively included in the survey. These 28 project intervention villages are distributed across 17 districts found in the seven major wheat producing governorates of Syria. Using power analysis [26], the minimum sample size required under the simple random sampling technique for ensuring 95% confidence and 3% precision levels in capturing up to 10% adoption was determined to be 374. Given that adoption in all the 28 villages is believed to be homogenous, the cluster sampling technique was chosen as the best method, where the villages that are the primary sampling units (PSUs) are used as the clusters. Therefore, accounting for the design effect, the minimum sample size under the cluster sampling technique required for ensuring the same levels of confidence, precision, and adoption levels as in the simple random sampling technique was determined to be 459. To account for missing data and possible non-response, a decision was made to increase the sample size to 500. Accordingly, a random sample of 18 or 17 farm households was taken from each of the 28 clusters. For the sake of clarity, this sample of 500 is referred to as "the random sample" in the remainder of this paper.

Given the short history of ZT in the study area, the number of adopters in the random sample was not adequate. Therefore, in addition to the random sample of 500 farms, 320 farms that had previously tested ZT on their own farms through the project's participatory development and extension program were purposively included into the sample. All the 320 farms had tried the ZT technology at least once, in tests or demonstrations involving ZT and conventional tillage comparisons, and were still using the technology after the project withdrew its support. Therefore, the total sample was 820 farm households.

Farmers in the study area graze their livestock on green barley and in bad seasons they can graze the entire barley crop—making the measurement of impacts on barley producers very difficult. This study is therefore concerned with measuring the impact of ZT on the income and consumption of wheat producers. Consequently, only the observations relating to the 621 wheat farmers in the sample (308 from the random sample and 313 from the purposive sample) were used for analysis, with barley growers excluded. Details of the sampling design are summarized in Table 1.

For the purpose of this study, adoption is defined as the use of the ZT technology for at least one year without any support from the project. On-farm demonstration trials are considered pre-testing, not real adoption. Hence, among the farmers who tested the ZT through support from the project, only those who continued to use ZT even after the project withdrew its support are called real adopters, while the rest are non-adopters. Hence, the variable "Area under ZT" in Table 2 refers only to the area cultivated using ZT by farmers who do not receive any support from the project.

All of the 313 wheat farms that were purposively selected were exposed to ZT through their involvement in the project; 257 (82%) of them tried ZT on their own farms with support from the project, while the rest participated only in field days. At the time of this survey, from among the farmers who tried ZT with the project support, 36 (14%) did not continue using ZT after the project withdrew its support. On the other hand, none of the 308 randomly selected farms were exposed to the ZT through the project. Nonetheless, 52% of them had some knowledge about ZT, which must have come either from farmer-to-farmer information exchanges or from the local extension offices. Only 15 (5%) out of the 308 wheat farms in the random sample adopted ZT.

A structured survey questionnaire was used to collect data on farmer and farm characteristics, production data including tillage cost, seeding cost, cost of planting, cost of fertilizers, cost of herbicides, cost of insecticides, cost of weeding, cost of harvesting, cost of transport (inclusive of labor and machinery costs) and quantities of grain and biomass outputs (descriptive statistics provided in Table 2).

The sample farms were small to medium-sized (range of 1.4 to 401 ha) with an average size of 127.5 ha. Farming seemed to be done by those with little formal education and of old age, with the typical farmer having 3.5 years of schooling and 26 years of farming experience. Among the 621 sample wheat producers, 197 (32%) only hosted on-farm demonstrations/tests, 56 (9%) participated in field days only, and 60 (10%) engaged in both. Out of the total sample of 621 farmers, 249 were real adopters of the new ZT technology, while the remaining 372 were non-adopters. The average number of years the typical adopter used the ZT was 2.1 years, which is not surprising as the technology was only recently introduced.

There were no significant differences between adopters and non-adopters in terms of their farming experience, agro-ecological zones, distance to the nearest market, and average value of total assets. Adopters and non-adopters differed significantly in terms of many other variables, including their participation in field days, hosting of demonstration trials, total and wheat area, knowledge about ZT, duration since they heard about ZT and input levels (Table 2). Of particular interest were the differences in yield and the two impact indicators, namely, net wheat income and per-capita wheat consumption. The average yield among adopters of ZT was about 1.73 tons per ha while that of non-adopters was 1.24 tons per ha, representing about 40% difference. Moreover, with an average net wheat income of about 37,995 Syrian pounds (SYP) or USD 760 per ha, adopters of ZT earned 45% (USD 243) more net wheat income than non-adopters, who earned only SYP 27,335 or USD 537 per ha. The typical member of an adopter family consumed about 80 kg of wheat per year, while the corresponding figure for a non-adopter family was 49 kg/year, showing that adopter families consumed almost double the amount of non-adopter families.

Table 1. Survey details.

Governorates Included in the Sample	Districts Included in the Survey						
	District Name	Number of Villages Included in the Sample	Total Population in the Sample Villages	Sample Size from the District:			
				Whole Sample		Randomly Selected	
				Total	Wheat Producer [1]	Total	Wheat Producers
Aleppo	Al Bab	1	650	36	25	18	12
	Ein Al Arab	2	700	40	31	36	21
	Sama'an	2	800	26	19	36	22
	Sfiera	1	900	43	33	18	11
Al-haska	Kamshly	4	347	96	75	70	43
	Tel-Hamis	1	66	31	23	18	11
	Malkia	1	190	25	19	18	12
	Amoda	1	270	21	16	18	11
	Hasaka	1	700	62	49	18	12
	Ras-Alain	1	600	22	17	18	11
Edleb	Khan-Shikon	1	400	23	17	18	11
	Almara	4	3270	174	131	70	43
Hamah	Slmiah	3	2400	94	71	54	33
	Sabora	2	1200	50	38	36	22
Homs	Ksier	1	380	26	18	18	12
Deraa	Alshajra	1	410	25	19	18	10
Alswieda	Salked	1	800	26	20	18	11
Total		**28**	**14,083**	**820**	**621**	**500**	**308**

[1]: Only the 621 wheat producers are included into this analysis. Source: survey data.

Table 2. Explanatory variables included in the models.

Variables	Unit	Average Values for the Entire Sample of 621 Farmers			Average Values only for the Random Sample of 308 Farmers		
		Adopters	Non-Adopters	Total	Adopters	Non-Adopters	Total
Number of farmers	Number	249	372	621	15	293	308
Average farming experience of household head (^)	Years	23.7	27.5	26.0	18.7	26.8	26.5
Average education level of household heads (^) (***)	Years	4.2	3.0	3.5	3.9	2.8	2.9
Proportion of farmers with salinity-affected soil ***	%	5.2	23.7	16.3	0.0	27.3	26.0
Average time since farmer started using ZT (***)	Years	2.1	0.0	0.8	2.0	0.0	0.1
Proportion of farmers who are in zone one ([a]) (^)	%	33.0	36.0	34.8	33	36	36
Total area (average) cultivated (^) (***)	Hectare	40.0	19.2	27.5	10.7	17.9	17.5
Total wheat area (average) cultivated (***)	Hectare	20.8	8.7	13.6	8.7	7.6	7.7
Proportion of farmers who know about ZT technology (^) (***)	%	100.0	59.4	75.5	100.0	50.0	52.6
Average distance to the nearest input market (^)	Km	13.8	15.4	14.7	13.0	18.0	17.7
Average value of total assets in million Syrian Pounds (^)	Million SYP	1.6	1.6	1.6	1.9	1.6	1.6
Average time since the farmer first heard about ZT technology	Year	2.3	1.0	1.6	2.2	1.0	1.1
Area under ZT (***)	(Ha)	15.2	0.0	6.1	8.6	0.0	0.0
Proportion of area under the ZT technology (**)	%	73.4	0.0	32.4	95.2	0.0	8.0
Average tillage cost (**)	SYP/ha	98	1800	1117.6	300	1700	1632
Average herbicides cost	SYP/ha	947	603	741	1000	550	572
Average seed quantity (^) (***)	(kg/ha)	110.7	145.1	131.3	118	140	138.9
Average fertilizer quantity (^) (*)	(kg/ha)	107.2	150.8	133.3	120	145	143
Average labor inputs (^) (***)	(hour/ha)	22.7	36.6	31	24	35	34.5
Proportion of farmers using improved wheat variety (^) (***)	%	66.2	33.8	65.7	59	51	51.4
Average yield	kg ha^{-1}	1727.1	1242.5	1436.8	1740	1251.8	1275.5
Average net wheat income (**)	SYP/ha	37,995	27,335	31,610	38,207	27,535	28,055

[a] Syria is divided into five agro-ecological zones where zone one represents the relatively wetter areas with average annual precipitation of about 350 mm with 33% probability to be less than 350 mm, while the remaining four zones are even drier. The survey covers only zones one and two. ^ Indicates variables included in the regression. Variables described here as % are included in the regressions as dummies for each observation. ***, **, * represent significance at 0.01%, 0.05% and 0.1%, respectively.

4. Methodology

Frontier techniques are the most widely applied methods for efficiency measurement in agriculture [27–33]. Indeed, the frontier methods can be grouped into parametric and non-parametric ones.

The typical stochastic frontier production function can be specified as:

$$\ln(y_i) = f(x_i,\ \beta) + v_i - u_i, \tag{1}$$

where y_i is a scalar output of production unit i, x_i is a vector of N inputs used by producer i, $f\ (x_i, \beta)$ is the deterministic part of the production frontier, β is a vector of technology parameters to be estimated, and v_i and u_i are noise and inefficiency components, which can take a number of forms, depending on specific assumptions. The specification given by (1) is consistent with the typical Just–Pope framework [34] under the following assumption:

$$u_i = 0,$$
$$v_i \sim N\left(0, \sigma^2_{vi}\right),$$
$$\sigma^2_{vi} = \exp(z_i\gamma),$$

where z_i is an input vector that may or may not equal x_i and γ is a vector of parameters. So the Just–Pope framework takes the form:

$$y = f(x_i,\ \beta) + h(z_i,\ \gamma), \tag{2}$$

where the function $h(z_i,\ \gamma)$ represents the output risk function. More recent advances in efficiency analysis show that stochastic production frontier models can include the technical inefficiency and production risk simultaneously [27,28,35,36]. This approach allows for heteroscedasticity in the noise component to investigate risk effects, while also allowing for heterogeneity in the mean of the inefficiency term during analysis of inefficiency effects. The model requires the estimation of (l) with the following assumptions:

$$\begin{aligned} v_i &\sim N\left(0, \sigma^2_{vi}\right), \\ \sigma^2_{vi} &= \exp(z_i\gamma), \\ u_i &\sim N^+\left(\overline{\mathrm{u}}_i,\ \sigma^2_{ui}\right), \\ \overline{\mathrm{u}}_i &= \omega_i\alpha. \end{aligned} \tag{3}$$

Following the conventional specification in the stochastic production frontier model, the random error v_i follows a normal distribution with zero mean and variance σ^2_{vi}, and the inefficiency term u_i follows a truncated-normal distribution with mean $\overline{\mathrm{u}}_i$ and variance σ^2_{ui}. To capture the heterogeneity of the efficiency and risk terms, the mean efficiency and risk functions are determined by exogenous factors. The vector ω_i denotes exogenous variables that have influence on the mean value of production inefficiency.

The risk function is assumed to have an exponential functional form with the vector of the exogenous factors z_i as explanatory variables [35,37–39]. The notation α is a vector of parameters associated with the mean of the production inefficiency, while the notation γ is the vector of parameters associated with the production risk. The consistent estimators of Equation (3) can be obtained by using the maximum likelihood estimation method on the following log-likelihood function [37,40–43].

$$\begin{aligned} lnL &= constant - \tfrac{1}{2}\sum_i \ln[\exp(z_i\gamma) + \exp(k_i l)] \\ &\quad + \sum_i \ln\phi\left(\tfrac{h_i a}{\sigma_i\lambda_i} - \tfrac{\varepsilon_i\lambda_i}{\sigma_i}\right) - \tfrac{1}{2}\sum_i \tfrac{(\varepsilon_i + h_i\alpha)^2}{\sigma_i^2}, \end{aligned} \quad (4)$$

where $\sigma_i^2 = \sigma_{vi}^2 + \sigma_{ui}^2$; $\varepsilon_i = y_i - x_i\beta$; $\lambda_i = [\exp(k_i l - z_i r)]^{0.5}$.

Following [28,36,37,44], we estimated the stochastic production frontier models that included the technical inefficiency and production risk simultaneously for the wheat farmers in the study area. The measure of output-oriented technical efficiency (TE) for the *i*th farmer (i.e., the ratio of the outputs with and without inherent inefficiencies) can then be computed as:

$$TE_i = \frac{f\left(X_{ij}, \beta_{ij}, v_i, u_i\right)}{f\left(X_{ij}, \beta_{ij}, v_i\right)}, \quad (5)$$

$$TE = \exp(-u_{it}) = \exp(-z_{it}\delta - w_{it}), \quad (6)$$

where, $0 \le TE \le 1$ and the closer the TE score to 1, the higher the efficiency. In this specification, the parameters, β, σ, σ_u, and δ are estimated simultaneously using the maximum likelihood method. Thus, the log-likelihood ratio (LR), which has a chi-square distribution, is used to test the significance of parameter estimates. Version 15 of the Stata software [45] was used for all econometric estimation in this study.

5. Results

The estimation of the level of, and factors affecting, production risk and technical efficiencies of wheat farms by using the stochastic frontier production function with an additive heteroskedastic error structure are reported in Table 3.

Two models, namely, an unrestricted variance model that incorporates the risk function and technical inefficiency and a restricted variance model without the risk function, are estimated. Based on the likelihood ratio test for model specification, the restricted risk function is rejected in favor of the unrestricted risk function at 1% level of significance. Thus, we mainly discuss the results estimated by the unrestricted variance model.

Quantities of inputs (nitrogen fertilizers, total amount of seed used and seeds) are found to have positive and significant effects on yield, which are consistent with theoretical expectations.

The elasticities' signs on seed and nitrogen fertilizer are positive and significant. This implies that, holding all else constant, an increase in seed quantity, and nitrogen fertilizer, would increase wheat output. On average, output is more responsive to a change in seed quantity (0.124) relative to a change in nitrogen fertilizer (0.081). However, the elasticity of labor (−0.054) is negative and significant, phosphorus fertilizer (−0.001) is negative but not significant.

The sum of the elasticities for each farm representing their returns to scale (RTS) is 0.2, indicating that wheat farms are operating under decreasing returns to scale (DRTS). This implies that, holding all else constant, a 1% joint increase for all inputs will bring about more than a 0.2% increase in wheat output.

The negative and significant coefficient for the "Plant date" variable indicates that late planting will decrease the wheat yield relative to early planting. Likewise, the negative and significant coefficient for the "Graze on crop residues" variable indicates that allowing on-site animal grazing on crop residues leads to decreased wheat yield relative to retaining or cutting and carrying away the crop residues.

Table 3. Estimation results.

Variable	Unrestricted Risk Function		Restricted Risk Function	
	Coefficient	Standard Error	Coefficient	Standard Error
Deterministic function				
Seed	0.124 ***	0.047	0.037	0.053
Labor	−0.054 **	0.027	−0.083 ***	0.030
Phosphorus	−0.001	0.009	−0.001	0.010
Nitrogen	0.081 ***	0.011	0.057 ***	0.010
Plant date (0,1)	−0.140 ***	0.047	−0.343 ***	0.061
Graze on crop residues (0,1)	−0.282 ***	0.054	−0.068	0.054
Use ZT (0,1)	0.415 ***	0.034	0.328 ***	0.038
Level of education	−0.033 ***	0.011	−0.042 ***	0.014
Experience (year)	0.000	0.002	0.000	0.002
Constant	6.965 ***	0.268	7.608 ***	0.297
Risk function				
Seed	−0.215	0.362	-	-
Labor	−0.160	0.175	-	-
Phosphorus	−0.160 **	0.074	-	-
Nitrogen	−0.160 **	0.078	-	-
Plant date (0,1)	−0.436 *	0.245	-	-
Graze on crop residues (0,1)	0.532 **	0.279		
Use ZT (0,1)	−0.571 **	0.248	-	-
Soil depth (0,1)	−0.105	0.542	-	-
Soil salinity (0,1)	0.138	0.245	-	-
Constant	−0.418	1.864	-	-
Inefficiency function				
Plant date (0,1)	0.804 ***	0.290	−0.021	0.330
Graze on crop residues (0,1)	−1.310 ***	0.450	0.189	0.320
Level of education	−0.403 ***	0.099	−0.305 ***	0.093
Experience (year)	−0.012	0.010	−0.003	0.014
Soil depth (0,1)	1.095 ***	0.378	0.942 **	0.396
Soil salinity (0,1)	0.155	0.251	0.977 ***	0.226
Constant	−0.306	0.484	−1.257 *	0.735
Sigma-squared	0.176 ***	0.035	0.176 ***	0.035
Gamma	0.906 ***	0.162	0.906 ***	0.162
Log-likelihood function	−212.3		−237.3	

***, **, * represent significance at 0.01%, 0.05% and 0.1%, respectively.

At the current national average adoption level of 40.1%, the adoption of ZT has led to an increase in national wheat production by 0.35 million tons per year, which account for a small (16.6%) portion of the total domestic supply of wheat in the country. If ZT is fully promoted to cover 75% and 100% of the total wheat area in the country, it will be possible to increase wheat supply by at least 31.13% and 41.5%, respectively.

In the risk function, the coefficients on ZT, Nitrogen fertilizer, Phosphorus fertilizer, Plant date, and Graze on crop residues are negative and significant, showing that they contribute to the reduction of production risk. The negative and significant coefficient on ZT is consistent with the theoretical expectation, as yield stability is one of the main benefits of ZT; our results show that the adoption of ZT leads to 95% and 33.3% reductions in the risk of obtaining yield levels below 1000 kg/ha and 1500 kg/ha, respectively.

These results indicate that risk-averse farmers can use ZT, leaving the crop residues without grazing and fertilizers in order to reduce the production risk and, hence, the revenue variability.

Overall, the results suggest that besides adopting the ZT technology, the adoption of the other components of CA, such as early sowing and residue retention or at least prevention of onsite grazing, can lead to higher yields at current levels of inputs.

A closer look at the efficiency figures shows that 6.4% of the farmers who used ZT have efficiency levels of between 90% and 100%. The corresponding figure for farmers who did not use ZT is 2.4%. At the same time while only 0.4% of the farmers who used ZT have efficiency levels of between 0% and 40%, 4% of non-adopters fall in the same category—a clear indication that using ZT leads to improvements in productive efficiency (Figure 1).

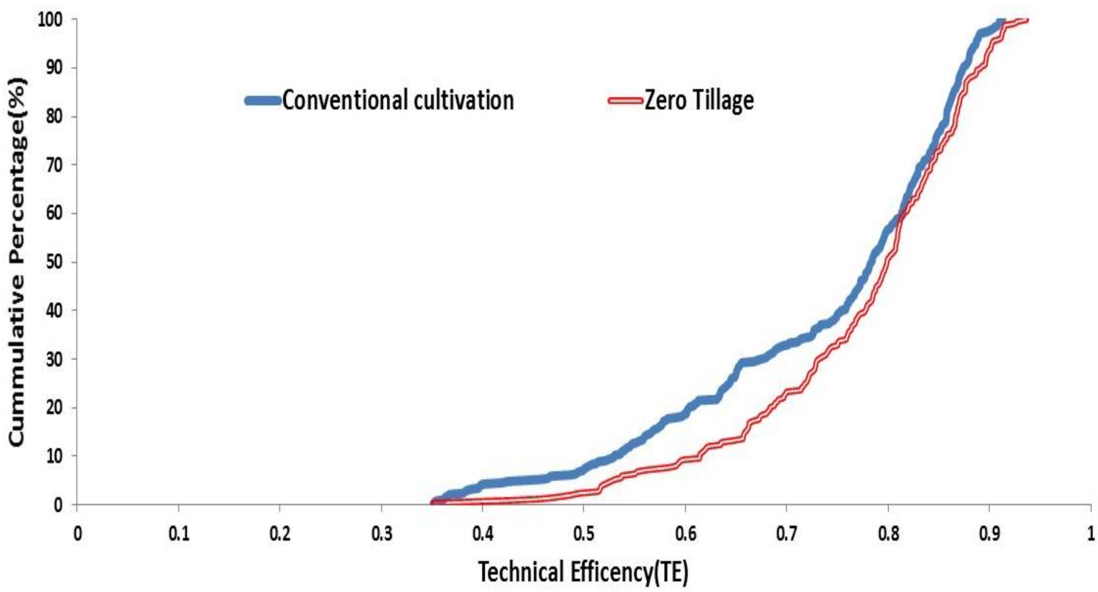

Figure 1. Cumulative Distribution of the Estimated Efficiency by using ZT.

6. Conclusions and Recommendations

Using a sample size of 621 farm households and a stochastic frontier production function model that explicitly and simultaneously accounts for technical inefficiency and production risk, this paper provides empirical evidence that a shift from conventional cultivation to conservation tillage increases technical efficiency, reduces production risk, and increases yield, thereby contributing to national food security.

Analysis of estimates from the inefficiency model show that 6.4% of the farmers who used ZT have efficiency levels of between 90% and 100%. The corresponding figure for farmers who did not use ZT is 2.4%. At the same time 0.4% of the farmers who used ZT have efficiency levels of between 0% and 40%, while the 4% for farmers who did not use ZT is a clear indication that using ZT leads to improvements in productive efficiency.

The stochastic dominance criterion also shows that the adoption of ZT led to 95% and 33.3% reductions in the risk of obtaining yield levels below 1000 kg/ha and 1500 kg/ha, respectively.

It is worth mentioning that risk-averse farmers can use ZT, leaving the crop residues without grazing and fertilizers in order to reduce the production risk and, hence, the revenue variability.

At the current national average adoption level of 40.1%, the adoption of ZT has led to an increase in national wheat production by 0.35 million tons per year, which account for a small (16.6%) portion of the total domestic supply of wheat in the country. If ZT is fully promoted to cover 75% and 100% of the total wheat area in the country, it will be possible to increase the wheat supply by at least 31.13% and 41.5%, respectively.

These results show that along with its biophysical, chemical, economic, and environmental benefits documented elsewhere, ZT can be justified on resource use efficiency and productive risk management grounds. The main implication of our results is that developing world governments can use ZT as a means of enhancing resource use efficiency in their agricultural sector and for minimizing the risk of national food supply during drought seasons.

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