Efficiency of Crop–Livestock Production Systems Under Conservation Agriculture: Scope for sustainable system transformation to Achieving Food Security in Rain-Fed Drylands of Tunisia

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Abstract

The objective of this study is to evaluate the technical efficiency of farmers engaged in mixed crop–livestock systems under conservation agriculture (CLCA) in Tunisian rainfed areas who are using Resource-Conserving Technologies (RCTs) such as forage mixture, minimum and zero tillage, and small machinery. These technology promotions are being carried out under the "*Use of Conservation Agriculture in Crop-Livestock Systems (CLCA) in the Drylands for Enhanced Water Use and Soil Fertility in NEN and LAC Countries*" project interventions. The resource-conserving technologies are being promoted as part of the integrated crop-livestock farming system under conservation agriculture supported by the project. The data used in this study have been derived from the socio-economic surveys conducted in the Tunisian rain fed areas during the 2020-2021cropping season.

Data was collected from a total sample of 118 farmers, 59 farmers who benefited from the interventions of the CLCA project and 59 that did not. A stochastic frontier analysis was carried out to calculate the farm-level technical efficiency and its main driving factors for both adopter and non-adopter farmers. The study has revealed that current efficiency level of farmers' productivity was between 0.43 and 0.99 with an average of 0.9. Inputs such as land and livestock were found to be significant in increasing farm production. This finding suggests that CLCA is livestock friendly. From the estimated coefficients of the inefficiency equation, five major factors were tested: farmer's age, education level, farmer's dependency ratio, farmer's access to credit and access to extension services. Results show that the age and the education level affect positively the level of efficiency. Thus, providing farmers with accurate and reliable extension information through both conventional and non-conventional technologies (ICT, video, mobile phones, etc.) and improving their educational level through farmers field school mechanisms are recommended for policy implications. Finally, combining CLCA practices with improving efficiency of farmers in optimal use of the inputs through providing training programs, extension services, access to credit for small machinery (e.g., livestock feeds) can contribute substantially to productivity, thus enhancing food security in the face of climate change in Tunisian semi-arid areas and other similar contexts.

Key words: Conservation agriculture, Integrated crop–livestock farming, Resource-conserving technology, Technical efficiency, Stochastic frontier, Tunisia.

1. Introduction

Food security, especially of smallholder farmers, depends on socio-economic and environmental factors (Chan et al., 2017). Therefore, improving the food and nutritional security of smallholders requires a transdisciplinary approach that includes improving the income of these vulnerable groups and their agricultural production. This improvement requires suitable and sustainable cropping systems that must be based on principles that limit degradation and conserve natural resources. Conservation agriculture (CA) is one of the sustainable cropping systems available to smallholder farmers limited to rain-fed practices, that can reverse soil degradation, improve agricultural production, and improve the socio-economic condition of smallholder farmers (Debebe et al., 2015).

The debate concerning farm diversification and intensification has lasted several decades (Todaro and Smith, 2012; Kuria et al, 2014). Although the specialization of agricultural systems and the search for economies of scale have contributed to agriculture evolution. However, the intensification of agriculture with limited soil amendments and conservation practices has led to soil erosion and nutrient depletion (IFAD, 2010). More diversified models have emerged to increase household incomes, reduce vulnerability, create employment opportunities, improve land productivity, and water use efficiency (Moraine et al, 2014). The FAO (2010) has recognized the need for productive and remunerative agriculture which, at the same time, conserves natural resources and the environment. Conservation agriculture is based on three principles, namely minimum soil disturbance, permanent cover, and crop diversification in rotations (Kassam et al, 2009).

Given the problems of land degradation by water erosion and the decline in the chemical and biological fertility of the soil which have led to a reduction in yields, conservation agriculture represents an alternative to land degradation and the improvement of her fertility. the usefulness of this technology has been tested through several works (Kassam et al, 2009; Thierfelder et al. 2012; Chan et al., 2017). Among the benefits driving the adoption of CA, the most mentioned are the improved farm economics, the flexible technical possibilities, the increased yields and greater yield stability, the soil protection and the better water saving in arid areas (Kassam et al., 2009a). The problems faced by farmers, in particular erosion and drought have facilitated the adoption of conservation agriculture (CA). Government support has contributed to accelerating the adoption of CA in many countries, leading to relatively rapid adoption rates, for example in Kazakhstan and China, but also in African countries (Friedrich et al., 2012).

In Tunisia, the awareness of farmers about soil and water issues and the progressive application of the principles of conservation agriculture through several national and international projects has enabled the creation of an informal network for the development of land conservation measures. Several farmers have adopted the idea to test conservation agriculture techniques. However, the full adoption in their own plots is a more complicated process depending on many factors (Jendoubi et al., 2019).

Agricultural diversification is one of the pillars of CA. It refers to the shift from the dominance of one crop to the production of several crops with diversified species (Petit and Barghouti, 1992). According to (Vyas, 2006), the process of agricultural diversification includes several stages. the first stage is the shift from monoculture to multiple corps. Usually developing countries are in this stage of diversification. The second stage is characterized by the introduction of different activities such as livestock-crops farming. The third stage represent the mixed farming and finally the incorporation of non-farming activities such as transformation, packaging, etc. (Chaplin, 2000). Sichoongwe et al. (2014) stated that at the farm level the main determinants of crops diversification are the land area, the output value, types of cultivated crops, workforce and family labor, use of technologies, and quantity of used fertilizer. The main diversification influencing factors are the farmers' access to markets, distance to markets, access to extension, access to credit, membership of farmers' associations and proximity to research and extension institutions (Joshi et al., 2007; Kankwamba et al., 2012). Weiss and Briglauer (2000) highlight the fact that smallholders are more oriented towards specialization than large farms. A significantly lower degree of diversification as well as a reduction in diversification over time is also reported for farms managed by older, less educated, and part-time farmers. Diversification is usually estimated as a joint decision-making process employing limited dependent-variable models, basically the logit and probit models, as well as Tobit models (Asante et al., 2018).

Agricultural diversification aims to increase household profits and to diversify smallholders into crop–livestock enterprises to stabilize household incomes (Joshi et al., 2004). Many studies claimed that the benefit of the integrated crop–livestock farming under CA is higher compared to benefits of crop and livestock systems conducted separately. Indeed, the synergies between crop and animal production improve the productivity and the resilience of agricultural production (Liniger et al., 2011; Tarawali et al., 2004). Integrated crop–livestock farming system under CA is advantageous first because of the mulch left on the soil surface that can be used as animal fodder and second because permanent vegetative cover with a high level of nutrients improves animal performance. Besides, this combination offers farmers a more diverse source of food and income (Guesmi et al., 2019). The simultaneous implementation of CA principles such as crop diversification allows enhanced forage production for livestock, which is also a source of organic matter and crop fertilization. Lander (2007) findings show that integrated crop–livestock under CA based on no-tillage presents many benefits such as the increased profit through the reduced production costs, the diseases reduction, and the maintenance of a high average stocking rate on rotated pasture. A similar study confirmed that CA-based systems in Zambia contribute to a better net benefit through the increase of grain yields up to 33% (Komarek et al., 2019).

However, the tradeoffs that farmers face when having to allocate their biomass resources among competing objectives such as feed or mulch may represent an obstacle for a CA system adoption mainly in resource-limited areas (Klapwijk et al., 2014). Some suggestions for successful crop–livestock integration refer to either introducing crops with higher biomass production or adapting herd size to forage production capacity, or the development of alternative feeding options (Ameur et al., 2021). Consequently, measuring and evaluating farm efficiency accounting for inputs, social and environmental differences is important task in order to identify the best-performing farms and for a better implementation of CA practices.

Llewelyn et al., (1996) and Coelli et al., (2002) relate technical efficiency to the conditions under which a farmer produces the maximum achievable output resulting from a given set of inputs or uses the minimum quantity of inputs to produce the optimum level of output. Unlike other indicators such as productivity, yield per hectare or unit cost of production, technical efficiency may explain the differences observed between smallholder farmers practicing the same cropping system. Quantitative survey data can document the amounts of non-land inputs, such as labor, seeds, and fertilizers, used by farms that drive yield differences among smallholders and help understand the differences in inefficiency among smallholder farmers (Chan et al., 2017).

In Tunisia, small mixed farming systems cover 75 to 85% of agricultural land, their production represents more than 80% of certain annual and perennial crops and livestock products (Marzin et al., 2017). Despite the important role of crop-livestock system under CA in improving household food security and reducing poverty, especially among smallholders in Tunisian rainfed agriculture systems, the efficiency of the crop-livestock system has not been adequately explored. No study has compared the technical inefficiency in the integrated crop-livestock and crop-livestock farming under CA farming systems. Therefore, the objectives of this study are to evaluate the technical efficiency of farmers engaged in mixed crop–livestock systems under conservation agriculture (CLCA) in Tunisian rainfed areas who are using Resource-Conserving Technologies. It is important to answer some relevant questions including if the adoption of the integrated livestock-crops farming under CA is more technically efficient than conventional system and which factors influence the adoption of CA by farmers in Tunisian rainfed areas?

In the next section we present the methodological framework. This section addresses the data collection, the analytical framework, and the specification of the empirical model. Section 3 discusses the empirical findings and, finally, section 4 provides the conclusions and the policy implications.

2. Methodological framework and data analysis

The methodology of the paper is based on applying the stochastic frontier model to a sample of smallholders in integrated crop–livestock systems in Tunisian dry areas, to provide empirical evidence on the difference between technical efficiency of crops- livestock farmers adopting the CA practices and non-adopters' farmers (Lachaal et al., 2005; Villano et al., 2010; Asante et al., 2020). The main hypothesis is that the difference between technical efficiency of smallholders in integrated crop–livestock systems under CA and under conventional agricultural system is significant. We also expect to assess inputs (labor, land, crop capital and livestock capital) effects on the efficiency level and to identify the most efficiency influencing factors of adopter and non-adopter farmers. Socio-demographic variables such as age, education, dependency ratios, share of off-farm income (%), credit access and extension access level are expected to be significant.

2.1. Data collection and sampling procedures

This investigation employed a case study research design. The study area involves four governorates which are Kef, Siliana, Zaghouan and Kairouan, located in Tunisian semi-arid areas under a same agroecological system characterized by the mixed crop-livestock farming. Facing a deep erosion problem, the mentioned regions have benefited from programs that integrate the conservation agriculture. In addition, agriculture represents the main activity and income for the majority of the population in these governorates. The data related to the CA adopters has been collected from smallholders' crops–livestock farmers operating under CA systems, who were part of the CL integration under CA project[1] funded by the International Fund for Agricultural Development (IFAD) under the Agreement number # 200116. These farmers were selected randomly from those who benefited from the project programs and innovation packages aiming at crop–livestock integration under CA. Finally, a sample of 118 farmers was included to this study. 50% of the interviewed farmers are adopting the conservation practices.

It is worth to indicate that from the total of 100 farmers (whom had interventions from the CLCA project), we retain only 59 farmers for two reasons: (i) farmers who had interventions from the project and (ii) full data completed with these farmers. The data collection process for both typologies of farmers was conducted during the last quarter of 2021 where the country is still under lock down due to the COVID-19 threats. The farmers sought to improve their farming systems by improving their farming practices through the adoption of a component or package of CA (e.g., no till, residual biomass, forage mixtures, and crop rotation). The data were obtained by using structured questionnaires with pre-identified smallholders. The collected data includes socio-demographic and economic information such as technical information on both crops and livestock activities, types of crops and livestock produced, the value of production for both activities, and other household characteristics.

2.2. Analytical framework

As explained by Farrel (1957) the figure 1 represent the technical efficiency of a firm producing the output (q) using two inputs (x1 and x2). The curve SS′ is the unit isoquant of the full efficiency. The point P illustrate the used quantities of inputs used by a given firm to produce one unit of output. In this case the distance QP represents the technical inefficiency of that firm, which is the amount in which all inputs could be proportionately reduced without a reduction in output. The technical efficiency is expressed in percentage terms which represented the percentage in which all inputs can be optimally reduced to achieve technically efficient production (Farrel, 1957). The technical efficiency (TE) of the firm can be measured by the ratio (1):

$$TE = \frac{OQ}{OP} \qquad \text{(Equation 1)}$$

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[1] See https://mel.cgiar.org/projects/clca2 for more information about the project.

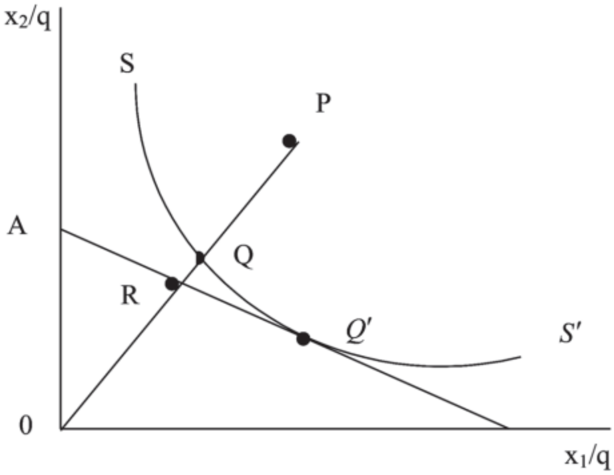

Figure 1. Technical efficiency (Farrell, 1957)

The Technical inefficiency is equal to (1 – TE) and takes a value between zero and one. A value of one implies that the firm is fully technically efficient (Coelli et al., 2005).

2.3. Empirical model

Many empirical studies investigated the role of exogenous variables in explaining inefficiency effects. A two-stage formulation was adopted, and they all used cross-section data (Kumbhakar et al.,1991; Reifschneider and Stevenson, 1991). The stochastic frontier production function was simultaneously and independently suggested by Aigner et al. (1977) and Meeusen and van den Broeck (1977). The original specification involved a production function specified for cross-sectional data which had two components of the error-term, the first one is used to account for random effects and the second to measure the technical inefficiency. In this study the used model is inspired by the work of Battese and Coelli (1996). According to Dung et al. (2011), the model is expressed by the equation (2):

$$Y_i = f(x_i, \beta) + V_i - U_i \qquad \text{(Equation 2)}$$

where,
Y_i represents the possible output level of i^{th} production unit with i ranging from 1, 2, …, N;
$f(x_i ; \beta)$ is a suitable function (Cobb-Douglas or translog form) given the vector of inputs x;
β is a vector of parameters to be estimated;
V is the symmetric error term accounting for random variations in output;
U represents the error-term associated to technical inefficiency relative to the stochastic frontier, which assumes only positive values.

The technical efficiency of unit i, in the context of the stochastic frontier production function is given in the form of Equation (3):

$$TE_i = Y_i / Y_i^* = f(x_i ; \beta) \exp(V_i - U_i) / f(x_i ; \beta) \exp(V_i) = \exp(-U_i) \qquad \text{(Equation 3)}$$

where,
Y_i is an observed output
Y_i^* is the frontier output.
Xi , βs and V_i are as defined earlier.
The translog form is expressed by Equation (4):

$$lnY_i = \beta_0 + \sum_{j=1}^{n} \beta_j \, lnX_{ji} + \frac{1}{2} \sum_{k=1}^{n} \sum_{j=1}^{n} \beta_{kj} lnX_{ki} \, lnX_{ji} + \varepsilon_i \text{ (Equation 4)}$$

where,

- Y_i is the output of the i^{th} farmer;
- X is a vector of n input variables;
- X_k X_j is the pair-wise interaction of two inputs;
- e is the random error-term;
- ln is the natural logarithm;
- i is the number of observations with a total of n samples.

The Cobb-Douglas form is a reduced form of the translog model where the interaction terms between inputs are assumed to be equal to zero, as Expressed in Equation (5):

$$\ln Y_i = \beta_0 + \sum_{j=1}^{n} \beta_j \, lnX_{ji} + \varepsilon_i \quad \text{(Equation 5)}$$

The Likelihood Ratio test is used to determine the appropriate form of the production function. The test verifies the validity of the assumption that the interaction terms are not important and can be dropped. Maddala (2001) used the Likelihood Ratio test to determine whether the Cobb-Douglas or the translog transformation provided the best fit for the data:

$$LR = nln[\frac{RRSS}{URSS}] \qquad \text{(Equation 6)}$$

where,

- RRSS is the residual sum of squares of the restricted model (Cobb-Douglas model),
- URSS is the residual sum of squares of the unrestricted model (translog function),
- n is sample size,

In this study, four inputs were used in the specification of the production function, the labor (Man-day per year), the land (Hectares), the crop capital (TND) and the livestock capital (TND). To establish the socio-economic factors that affect the level of technical efficiency of the farmers. Tested inefficiency variables were the age of household (Years), the education (Yes=1, No=0), the dependency ratio, share of off-farm income (%), the credit access (Yes=1, No=0), and the extension access (Yes=1, No=0). Following Coelli et al. (2005), the technical inefficiency model was specified as per Equation (7):

$$TI_i = \delta_0 + \sum_{j=1}^{5} \delta_j Z_{ji} + \sum_{k=1}^{4} \delta_k D_{kj} \qquad \text{(Equation 7)}$$

Where,

- TI_i is technical inefficiency of the (i) farmer;
- δ are unknown parameters to be estimated to explain the inefficiencies of production of the farm output activities (e.g., cereals, legumes, forage crops, livestock, etc.);
- Dk_j represents the four input variables;
- Z_{ji} represents the five socio-economic variables. The expected signs of these variables with respect to technical inefficiency are summarized in Table 1.

Table 1. The expected signs of the explanatory variables determining the technical inefficiency

Variable	Parameters	Expected sign
Age	δ_1	+/-
Education	δ_2	-
Dependency ratio	δ_3	+
Share of off-farm income	δ_4	-
The credit access	δ_5	-
The extension access	δ_6	-

Source: Own elaboration (2022).

3. Empirical findings and discussions

The characteristics of sample household based on their outputs, inputs and socio-demographic variables used in the empirical model for both adopters and non-adopters' farmers are summarized respectively in Table 2 and Table 3.

3.1. Socio economic characteristics of samples households

Statistical analysis results displayed in the tables below (Table 2 &3) reveals that non adopters Farm household incomes varied from 2682 TND to 33736TND per year. Livestock husbandry included cattle and small ruminants. The higher incomes were associated with small ruminant breeding. Incomes of adopters' farmers varied from 9150 TND and 269686 TND. On average, the adopters' farmers reported a higher education level. The average farm size was 6.9 ha for non-adopters and 81.4 ha for adopters.

Table 2. Characteristics of sample household – socio-demographic variables used in the empirical model (conventional farming system)

Variable	Mean	Max	Min	SD
Outputs				
Cereals[(a)]	698.7	2580	118	507.62
Legumes	654	1056	336	369.64
Forage crops[(b)]	453.31	1800	160	304.66
Livestock 1 (Cattle)	744.35	4400	200	952.65
Livestock 2 (Small ruminants)	6715.83	23900	1878	5323.59
Inputs				
Labour (Man-dDay per year)	1.90	3.75	0.51	0.83
Land (Hectares)	6.92	12	4	2.64
Crop capital (TND) [(c)]	978.46	2319.81	313.09	455.36
Livestock capital (TND) [(d)]	3717.51	17622	670	3288.91
Inefficiency variables				
Age of household (Years)	53.32	87	27	14.40
Education (Yes=1, No=0)	0.67	1	0	0.48
Dependency ratio	0.97	6	0.25	0.96
Share of off-farm income (%)	55.68	99.62	7.58	21.48
Credit access (Yes=1, No=0)	0.02	1	0	0.13
Extension access (Yes=1, No=0)	0.17	1	0	0.38
N		59		

Notes:

- *a Cereals crops are composed of wheat; b Forage crops are composed of barley, oat, and other forage crops; c Crop capital involves all expenses made in the production of crops except expenses on land and labour; d Livestock capital involves all expenses in livestock production except expenses on breeds, labour, feed, and veterinary services*
- *1 TND= US$ 0.33 (Average January – October 2022).*

Source: Own elaboration from field data (2022).

All the interviewees are highly dependent on agriculture to sustain their livelihood. Off-farm employment opportunities are limited. Farmers cultivated cereals followed by legumes and forage crops for livestock feed. The farmers differed in their inputs in the CA cropping systems, livestock and crop capitals are much more important. Labor differed between adopters and non-adopters with adopters' labor higher than non-adopters' labor.

Table 3. characteristics of sample household – socio-demographic variables used in the empirical model (CA farming system)

Variable	Mean	Max	Min	SD
Outputs				
Cereals[(a)]	1806.1	3936	560	812.53
Legumes[(b)]	1216.4	2900	440	584.91
Forage crops[(c)]	1247.1	2750	450	720.30
Livestock 1 (Cattle)	17516.7	69600	2700	25842.48
Livestock 2 (Small ruminants)	47618.3	190500	5000	52403.11
Inputs				
Labour (Man-day per year)	27.2	188	2	38.60
Land (Hectares)	81.4	400	4	87.26
Crop capital (TND) [(d)]	2040.1	4425	214	1102.26
Livestock capital (TND) [(e)]	14722.2	51000	3000	11836.92
Inefficiency variables				
Age of household head (Years)	51.4	70	34	9.9
Education (Yes=1, No=0)	0.9	1	0	0.3
Dependency ratio	0.6	1	0.11	0.2
Share of off-farm income (%)	90.5	100	36.12	28.14
Credit access (Yes=1, No=0)	0.08	1	0	0.22
Extension access (Yes=1, No=0)	0.95	1	0	0.0
N			59	

Notes:

- *a Cereals crops are composed of wheat; b Forage crops are composed of barley, oat, and other forage crops; c Crop capital involves all expenses made in the production of crops except expenses on land and labour; d Livestock capital involves all expenses in livestock production except expenses on breeds, labour, feed and veterinary services*
- *1 TND= US$ 0.33 (Average January – October 2022).*

Source: Own elaboration from field data (2022).

3.2.Empirical results and discussion

Maximum likelihood estimates of the parameters of the translog stochastic frontier production, and the technical inefficiency effects models are obtained using the computer package FRONTIER version 4.1 (Coelli, 1996). Table 4 shows the maximum likelihood estimates of the production function model of CA adopter and non-adopter farmers. The sigma-squared values were statistically significant for both models, which confirms the accuracy of the specified assumptions of the distribution of the error-term. The gamma values were also statistically significant, meaning that variation in outputs could be attributed to technical inefficiency.

For CA non-adopter farmers, the significant variables were land and the crop capital. The estimate sign was negative for the land which implies that the efficiency is positively correlated to the land area. According to Feder et al. (1985), farm size could be a proxy for better access to inputs, information, and technical efficiency. Specifically, the farm size had a statistically significant impact on technical efficiency, mainly on scale efficiency (Latruffe and al., 2005). It is expected that the production increase when the crop capital increase. But this is not the case for non-adopter farmers. The interaction between the land and the crop capital variables are positively significant. However, the interaction between the labor and land variables that was also significant was with negative sign for non-adopter farmers. For CA adopter farmers the livestock capital was statistically significant with a positive sign, which implies that the more the herd size is, the less integration is. Such a result stresses the fact that, in a rainfed agriculture context, crop-livestock integration remains the main challenge facing the CA adoption and dissemination. Additionally, no interaction variables were found to be statistically significant for farmers under CA.

Table 4. Determinants of technical inefficiency model, with- and without CA adoption

Variable	CA Non-Adopters farmers	CA Adopters Farmers
Constant	-0.215 (-0.951)	0.845 (1.316)
Labor	0.637 (0.458)	-0.061 (0.842)
Land	-2.244* (1.454)	0.460 (2.458)
Crop capital	3.202*** (0.864)	-0.410 (0.988)
Livestock capital	-0.011 (0.627)	0.318* (0.206)
Labor^2	0.058 (0.059)	0.089 (0.079)
Land^2	-0.670* (0.426)	-0.119 (1.080)
Crop capital^2	-2.696*** (0.750)	0.203(0.254)
Livestock capital^2	0.950*** (0.168)	-0.259*** (0.082)
Labor*Land	-0.317*** (0.098)	-0.136 (0.555)
Labor*Crop capital	-0.407 (0.588)	0.013 (0.421)
Labor*livestock capital	0.039 (0.860)	0.030 (0.027)
Land*Crop capital	3.664*** (1.212)	0.228 (0.930)
Land*Livestock capital	0.127 (0.299)	-0.110 (0.145)
Crop capital*Livestock capital	-1.015 (0.815)	0.009 (0.099)
Inefficiency effects model		
Constant	0.198* (0.129)	0.828 (0.955)
Age	-0.001 (0.001)	-0.019*** (0.006)
Education	-0.117* (0.065)	-0.354* (0.244)
Dependency ratio	0.002 (0.029)	-0.300 (0.470)
Share of off-farm income	0.054 (0.141)	0.230 (1.457)
Credit access	-0.520 (0.569)	-0.214 (0.395)
Extension access	-0.051 (0.048)	0.089 (0.839)
σ^2	0.006*** (0.001)	0.051** (0.020)
γ	0.448* (0.261)	0.999*** (0.002)
log likelihood function =	68.075	77.71
LR test of the one-sided error	15.322	67.42

*Notes: *, ** and *** are statistically significant at 10 per cent, 5 per cent and 1 per cent levels, respectively*
Values given in parentheses are standard errors
Source: Own elaboration from model data (2022).

Concerning the tested inefficiency factors the variable associated with the education level was significant in the two models for both CA adopter and non-adopter farmers. As expected, the sign was negative, indicating that the technical efficiency is positively correlated to the education. The age variable coefficient was only significant and negative for CA adopters. This means that it is important to consider these variables specially for the promotion of CA practices and in field workshop planning. This study result shows that older household heads are more inefficient. They might be, due to shorter planning horizon, reluctant to adopt new technologies, which improve their level of inefficiency than the younger one. Again, difference in the physical effort exerted on crops-livestock production system i.e., the capacity to work energetically may also be a case for more inefficiency level of older household heads. For both models, the variables dependency ratio, share of off-farm income, credit access and extension access were not statistically significant. Although, according to Mekuria and Mekonnen (2018) these variables are the major factors affecting the extent of farmers' decision on crop-livestock diversity. However, in this study results show that none of these variables influences the technical efficiency in the crop-livestock farming system.

The models demonstrate that the economic attractiveness of CA depends on many factors. In this study the potential efficiency gains from switching to CA are not large and are achieved on better resourced farms. Under a diversified crop-livestock system, technical efficiency is relatively high, switching to the full CA package may result benefic mainly if we take in consideration the age and the education level of farmers, especially on the larger farms.

Technical efficiency in CLI systems under conventional agriculture and under CA

Understanding the source of technical inefficiency and its extent is very important for policy making to address the problem of farmers. The mean values of technical efficiency of CA adopters and non-adopters are presented in the Table 5. For both categories of farmers, the technical efficiency is generally high. The mean values for both cases exceed 90 per cent. The mean technical efficiency value of CA adopter farmers was higher than the mean technical efficiency of non-Adopter farmers. However, the t-test showed that the mean difference of technical efficiency between these two categories was not statistically significant.

Table 5: Technical efficiency levels between CA Adopters and Non-Adopters farmers

Item	CA Adopter Farmers	CA Non-Adopter Farmers	Difference
Mean	0.909 (0.012)	0.905 (0.006)	0.004
Minimum	0.433	0.779	
Maximum	0.999	0.993	
Farm frequency (TE < 60%)	1	0	
Farm frequency (60% < TE < 80%)	5	2	
Farm frequency (TE > 80%)	53	57	

Source: Own elaboration from model data (2022).

The Figure 2 presents the distribution of the mean value of technical efficiency of CA adopter and non-adopter farmers. The mean value of technical efficiency of adopter farmers indicated that they could improve their efficiency by 9.1 per cent. The percentage of adopter farmers having a technical efficiency level higher than the mean value was 72.8 per cent. The mean value of technical efficiency of non-adopter farmers was 90.5 per cent and it ranged between 77.9 per cent and 99.3 per cent efficiency levels. This result also shows that the non-adopter farmers could improve their efficiency by about 9.5 per cent which is not significantly different from adopter ones.

However, if we consider the farmers' distribution, we find that in this case only 61.1 per cent of non-adopter farmers had levels of technical efficiency higher than the mean level. This implies that, in general, CA adopter farmers were more technically efficient than those not adopting the CA.

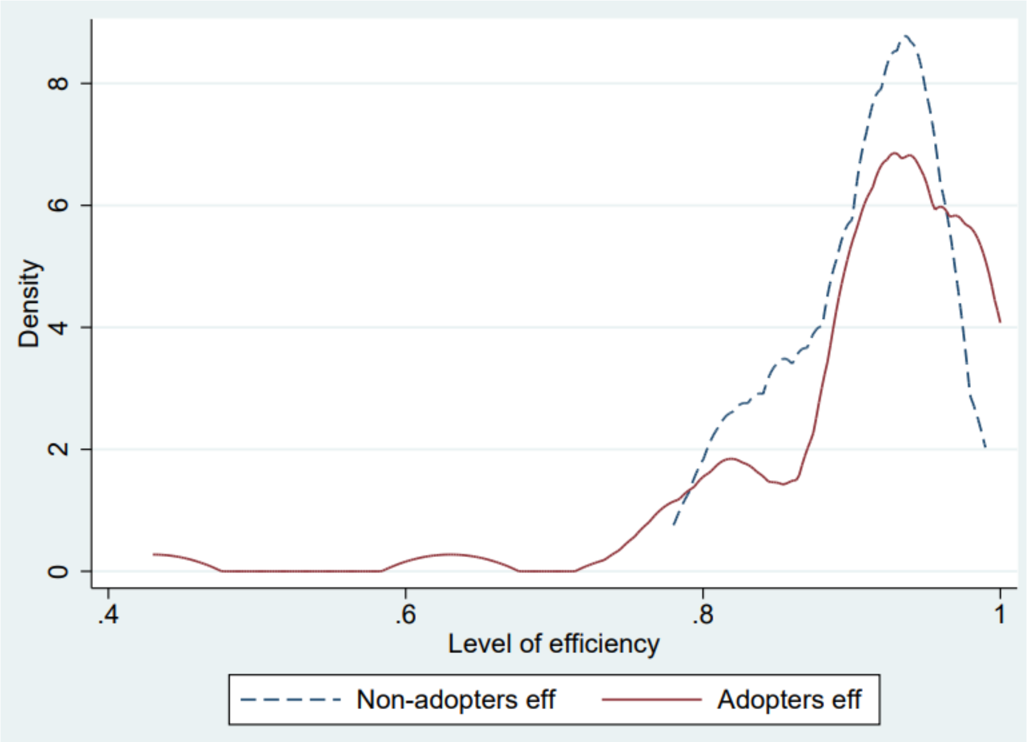

Figure 2. Distribution of technical efficiency level of CA adopter and non-adopter farmers

Source: Own elaboration from model data (2022).

4. Concluding remarks and policy implications

The role of the livestock capital, the crop capital, the land and the labor use in technical efficiency has been revealed in this study. In the CLI system, all farmers who are not adopting CA need to improve inputs use, mainly the interaction between labor and land, and between land and crop capital to be more technically efficient.

The estimated technical efficiency of integrated crop-livestock system production in the sample varies widely especially for the adopter farmers, ranging from 43 per cent to 99 per cent, with a mean value of 90 per cent. This suggests that, on average, the farmers in the integrated crop-livestock system have a high technical efficiency. For both CA adopter and non-adopter farmers, they could increase their production by almost 10 per cent through more efficient use of production inputs, mainly the land and the capital. This result implies that improvement of technical efficiency should be the first logical step for considerably increasing the use of existing technology and investment in conservation agriculture development. We found that technical inefficiencies were significant in crop–livestock systems, suggesting that enhancing crop–livestock integration under CA led to improvements in technical efficiency. The key driving forces that significantly improved technical efficiency were farmer's age and farmer education. These results suggest that actions on these factors would lead to higher technical efficiency in crop–livestock production under CA. This result implies that policies in drylands should consider the improvement in socio-demographic characteristics (e.g., education, extension, and knowledge of CA technology management) and institutional factors (e.g., *Agricultural Development Group* - GDA, *Mutual Agricultural Service Company* SMSA, and cooperatives), for instance in providing subsidies, training, and extension support, and raising awareness of farmers, particularly those who are young and practice agricultural diversification under CA farming systems. Several studies reveal that education enhances farm productivity in the case of adopters of modern technology. The study suggests that farmers’ field school program must be implemented along with a strong extension network in the study region for a wider dissemination of CA technology.

These measures will help raise farmers’ adaptive capacity for adoption of agricultural diversification and enable them to generate tangible benefits by increasing income through adopting sustainable agricultural livelihoods. Findings indicate that encouraging CA as a solution to all the economic and natural resource challenges that farmers face is not realistic. Therefore, the design of Appropriate strategies for enhancing the production of specific output combinations in crop-livestock systems, taking account of the heterogeneity of farming circumstances and identifying the cases where components of CA are adoptable, is more useful for policymakers.

Our empirical findings corroborate earlier assumptions that farmers' characteristics, farm capital structure (Land, crops, and livestock), and preferences toward CA technologies adoption are heterogeneous. Much as opportunities exist to support farmers to bypass some constraints by focusing on drivers with similar influence on both discrete choice (credit access, off-farm income) and efficiency scores. No single driver is consistently associated with the efficiency scores in the two farmers' groups. There are trade-offs in terms of either opposing factor effects on the adopters and nonadopters group. These findings lead researchers, extensionists, and policymakers to adapt, respectively, scientific research, extension methods, and policies to the specific contexts of farmers and farming systems. The methodic fragmentation of CA technology on different packages (SWC techniques, legumes crop integration, and livestock feeding improvement) could make easier the establishment and dissemination of agroecological practices.

Finally, these findings presented in this paper were an attempt to enhance understanding of the role that adopting CA packages can play in sustaining the livelihoods of crop–livestock farming households, especially in dry regions. Combining CA practices with improving efficiency of farmers in optimal use of the inputs through providing training programs, extension services, access to credit for small machinery (e.g., livestock feeds) can contribute substantially to productivity, thus enhancing food security in the face of climate change in Tunisian semi-arid areas and other similar contexts.

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