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Trade-Off between Land Use Pattern and Technical Efficiency Performance: Evidence from Arable Crop Farming in Tunisia

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Abstract: Cereal, oilseed, and protein (COP) production is an important sector contributing to Sustainable Development Goals (SDGs) in Tunisia. COP farms often diversify their production patterns to stabilize their income sources and spread production risk across crops. However, crop diversity may entail an inefficient use and management of resources to achieve the desired output. In addition, the COP sector still shows a low productivity level, depending on weather conditions in Tunisia. In this context, this study aimed to assess the relationship between the land use pattern and efficiency performance of farms. We used data envelopment analysis (DEA) in the presence of uncertainty based on state-contingent techniques. This approach has not previously been used to examine the links between crop pattern and efficiency. We found that specialized COP farms, on average, exhibited higher technical efficiency levels than those adopted mix cropping systems (83% and 60%, respectively), indicating an important margin to reduce inefficiency. Nevertheless, both diversified and specialized farms could reduce their inefficiency levels through more rational input use to attain the current level of production. Some practical implications were derived to target policy interventions to enhance agricultural productivity and resource use efficiency.

Keywords: diversification; data envelopment analysis; production risk; technical efficiency; specialization

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1. Introduction

The economic and social development in Tunisia and particularly in the north-west region strongly depends on the agricultural sector. The cereals, oilseeds, and protein (COP) sector is a vital pillar of local economies through ensuring economic and food security for rural households and contributing to reducing the poverty in the production areas [1]. Despite the importance of this sector, the domestic COP production cannot meet the national demand for these products. Actually, hard wheat representing 70% of the total cereal production meets, on average, 72% of the national demand, while the soft wheat and barley production covers 20% of national needs [2]. The government has resorted to importing main COP products to fill the gap between the demand and the supply. On the other hand, the situation becomes challenging with increasing prices and disrupted production and trade driven by the effect of the Ukraine−Russia war, which has also deepened the food insecurity, especially in developing countries [3–5]. For instance, Tunisia among other many countries heavily rely on wheat imported from Ukraine and Russia, accounting for around half of wheat purchases from these origins during the last five years.

Policymakers encourage farmers to allocate more land to produce COP products in Tunisia to overcome this problem and to satisfy the national demand. However, the sector still suffers several technical and management constraints. COP yield is still low and has not been able to reach the desired potential production level. This could be attributed to many factors, including scarcity of skilled workforce and advanced technologies, indebtedness of farmers, shortage of fertilizer supply during critical COP growing seasons, limited training operations and extension services, and low adoption rates of improved varieties. In addition, the farmland fragmentation due to family heritage is another key issue that reduces the effectiveness of machinery usage given the predominance of small size farms with irregular shapes [6–9]. The COP sector largely depends on climatic conditions, since most farms strongly rely on rain-fed production systems and the irrigated land represents only less than 5% of the total cultivated area [2].

Crop diversification, often known as mixed cropping strategies, is the practice of growing more than one type of crop [10]. In addition, COP farms tend to diversify their production to cope with negative climate change impacts [11,12], among other common problems related to soil fertility, plant diseases, and crop rotation planning which affect the productivity of farms [13]. Using different cropping patterns is one strategy of reducing yield variability, to ensure more stable farm revenues [14,15] and control weed [16]. On the other hand, Chen et al. [17] and Li et al. [18] stressed that only resource-efficient use can boost land productivity. Furthermore, Chavas et al. [19] pointed out that farmers and policymakers use crop diversification strategies to address food issues as well as to spread income risks between crops and over space. Accordingly, Weigel et al. [20] stated that diversified crop portfolios might offer an alternative to stabilizing farm revenue specially to face decreasing financial support measures for agricultural products.

Assessing farmers' technical efficiency could be a relevant measure that helps improving farm yields and profitability. Moreover, previous research studies showed that COP farms are able to increase their productivity gains through an optimal use of productive technologies during specific growing conditions even with moderate precipitations [21]. It is thus relevant to investigate the technical performance of COP farms by taking into account the stochastic nature of COP production to provide more reliable efficiency measures and conclusion regarding technical performance of farmers. To the best of our knowledge, our study constitutes the first study examining the relationship between technical efficiency and crop diversification for the COP sector in Tunisia. Second, our study contributes to the few empirical studies using a state-contingent approach to estimate technical efficiency ratings of farms [22–25]. Third, this analysis allows assessing to what extent a monoculture or mixed cropping pattern affects farmers' performance. Finally, such research is important for both farmers and policymakers to obtain valuable feedback that can guide future policy interventions.

The article is structured as follows. The Section 2 provides an overview of earlier research on efficiency and crop diversification effects. Section 3 describes the methodology employed to answer the research question in this study. The Section 4 presents the data and discusses the main findings obtained from the empirical analysis. Finally, the paper finishes with some concluding remarks.

2. Literature Review

Despite the importance of the COP sector in Tunisia, research studies on the performance of COP production are still thin. Such analyses are often limited to data availability in this country. Nevertheless, there have recently been a few initiatives focusing on the evaluation of technical efficiency of farms using alternative estimation methods. Non-parametric methods, mainly data envelopment analysis (DEA), and parametric models, particularly the stochastic frontier production technique (SFA), have been widely used to derive efficiency scores. Bachta and Chebil [21] used the SFA approach to estimate the TE for a sample of cereals farms in Kef region in Tunisia and found an inverse association between farm the size and efficiency levels of farms. The authors suggested that smallholdings showed a higher efficiency performance (0.81) than large-scale farms (0.68). Another study by Amor and Muller [26], using the same approach, estimated the TE of farms specialized in grain production across different regions in Tunisia and reported an average efficiency level of 0.77. In addition, Dhehibi et al. [27] found similar results for wheat farmers in Beja governorate. Compared to prior findings, the DEA suggested a lower TE rating (71%) for wheat producers in Chebika region (Central Tunisia), relying on irrigated production systems [28]. Another DEA-based study by Abdelhafidh et al. [29] investigated a sample of rain-fed wheat production in Zaghouan region for the growing seasons in 2015–2016. The study indicated a lower mean efficiency estimate of about 0.60. Another recent study revealed that wheat farmers could enhance their potential output by 30% without altering the current production technology [30]. More recently, Rached et al. [31] estimated a stochastic frontier production for a sample of farmers specialized in cereal production located in the north region of Tunisia and found an efficiency level of 0.85, on average.

Determining the association between the land use pattern and efficiency level could be key for policymakers and policy design aiming at improving the performance and competitiveness of COP production in Tunisia. Strong association may reflect that diversifying crop production improves both technical efficiency of farms and economic security of farmers. Mzyece and Ng'ombe [10] stressed that crop diversification may also result in resource competition between different crops and may have negative impact on farm productivity. Furthermore, while some prior studies indicated an adverse effect of crop diversity on efficiency, others suggested contrasting findings. Manjunatha et al. [32] assessed the effects of crop diversification on farm profit and efficiency for a sample of irrigated farms in South India and found a negative correlation between mix cropping and inefficiency. Similar findings have been obtained by Ogundari [33], who looked at the impact of crop diversity in Nigeria. Consistently, Ajibefun [34] advocated that technical efficiency increases with the increase in crop variety by taking advantage of soil fertility and lower pests and diseases effects on productivity. In the same line, Rahman [35] showed a significant positive relationship between efficiency and crop diversification for Bangladeshi agricultural firms. In addition, another study by Coelli and Fleming [36] clearly revealed that adopting multiple cropping production systems in Papua New Guinea significantly improves efficiency performance of farmers.

In contrast to previous findings, Llewelyn and Williams [37] concluded that the technical efficiency of a sample of Indonesian farms decreases with the crop diversification system. In the same vein, Haji [38] demonstrated an adverse effect of multiple cropping production on economic efficiency of farms in Ethiopia. This overview allows concluding that the previous literature provides evidence for mixed results on the effects of crop diversification on technical efficiency levels of farms, depending on the regional context and specificities of each study [10]. While few attempts have examined this relationship in other parts of the world, this issue has not been investigated in Tunisia so far. Thus, our study contributes to filling this gap and to the ongoing debate on the effect of crop variety on efficiency.

Traditional efficiency measures are focused on the effective use of inputs to produce outputs. However, state-contingent analysis has recently gained specific attention to appropriately account for the stochastic nature of production and provide sound estimates [39,40]. An important feature of using this approach lies on modeling the production under different states of nature and providing nonbiased inefficiency estimates [41]. Chambers and Quiggin [40] and Rasmussen [42] emphasized that farmers can allocate their input use ex-ante to obtain ex-ante outputs under different growing conditions (bad, normal, and ideal), especially linked to weather, control of pests and diseases, and expected yields under such situations. Nevertheless, its use has been limited to few empirical implementations mainly due to data availability [43]. Therefore, our empirical application relies on this estimation technique contributing to the scarce literature on the use of the DEA method through considering production risk. Furthermore, we attempted to answer the research question: Does the crop diversification strategy effectively improve the technical efficiency of COP farms in Tunisia?

3. The Cereal Sector in Tunisia

COP production displays a relevant role in the Tunisian's economy and is a key driver to reduce food insecurity [44]. In 2019, the total COP value was about 2000 million TND (note: 1 TND ≈ 0.32 US Dollar) representing 12% of the total agricultural value added [2]. Moreover, this sector directly or indirectly employs around 50% of the agricultural labor. Thus, it engages about 240 thousand farmers and generates over 7 million working days every year, which helps to support the rural population. In addition, the COP output increased at an annual rate of 8% between 2009 and 2019, contributing to improve the agro−food trade balance.

The COP land is extended over one-third of the total utilized agricultural area (1.609 million hectares), of which almost 73% concentrates in the north region of the country. This region provides better and favorable climatic and edaphic conditions to COP production [45], possessing 80% of available water resources in this country. Wheat accounts for 46% (534 thousand hectares) of the cereal area. Barley is the second most significant grain crop (45%), followed by soft wheat (7%). The production is unevenly distributed across different regions where the north and the center of the country account for 87% and 10% of the total COP production, respectively. The average annual production was almost 1.7 million tons during the last decade. During this period, COP production achieved the highest volume in 2009 with 2.5 million tons, while the lowest level (1.1 million tons) was recorded in 2010 primarily affected by drought and water scarcity problems. However, the COP productivity remains low in comparison to both the world average (3.9 tons per hectare) and its potential (two tons per hectare) [45,46].

Since most farms rely on rain-fed production systems, weather fluctuation has a significant impact on COP production and yield. Further, the proportion of irrigated land is still low, representing only less than 5% of the total COP area. Nonetheless, the irrigated COP contributes to 13% of the total production. At the political level, different policies have been conceived to use alternative practices that improve productivity and efficiency levels. For instance, farmers are encouraged to adopt certified and improved varieties, sustainable agricultural practices, and new irrigation and fertilization techniques and be supported with production costs (well, capital, and building investments) [27,28]. In this context, assessing the performance of farms would provide valuable information for policymakers and stakeholders involved in the COP supply chain. Furthermore, the importance of the COP sector in the agricultural economy makes this research interesting and supports our decision to assess the technical efficiency of arable crop farming in Tunisia.

4. Methodological Framework

Conventional efficiency measures have been extended to consider the production uncertainty and stochastic nature of the agricultural sector. The model specification is built upon state-contingent methods proposed by Chambers and Quiggin [39,40]. The production function is defined through differentiating outputs, depending on various growing conditions.

Let $\Omega = \{1, 2, \ldots, C\}$ represents the set of natural states. Consider a firm that uses N inputs $x = (x_1, \ldots, x_n)' \in R_+^N$, to produce M outputs, $\tilde{y} = (\tilde{y}_1, \ldots, \tilde{y}_m)'$ under states of nature c. The following set defines the production technology:

$$T^Y = \left\{ (y,\ x)\ |x \text{ can produce } y;\ x \in\ R_+^N\ ,\ y\ \in\ R_+^C \right\} \tag{1}$$

Data envelopment analysis (DEA) is a non-parametric technique, which allows estimating the technology set specified by Equation (1). One attractive feature of the DEA approach is its ability to overcome multi-collinearity problems that may lead to biased estimates when applying a state-contingent approach to parametric production models [47]. The empirical application relies upon three possible crop-growing conditions: bad (c = 1), normal (c = 2), and ideal (c = 3). For a given set of observations on inputs and ex-ante production $\left(x^i, \tilde{y}_1^i, \ldots, \tilde{y}_M^i\right)$, $i = 1, 2, \ldots, I$, where I indicates the number of farms. We estimated the production technology set T^Y assuming constant returns to scale and free disposability of both inputs and outputs. Therefore, T^Y is approximated using the following linear program:

$$T^Y(I) = \left\{ \begin{array}{l} (x, \widetilde{y}_1, \ldots, \widetilde{y}_M) : \\ x \geq \sum_i \varphi^i x^i, \\ \sum_i \varphi^i \widetilde{y}^i_m \geq \widetilde{y}_m,\ m = 1, \ldots, M,\ \varphi \in R^I_+ \end{array} \right\} \quad (2)$$

Technical efficiency scores are derived by solving the DEA linear programming model [48]:

$$TE(\widetilde{y}, x) = \min_\theta \{\theta | \langle \theta x, \widetilde{y} \rangle \in T^y\} \quad (3)$$

where θ represents a scalar value that varies between zero and one indicating technical efficiency scores of farms.

The second key variable in this analysis was related to the crop diversity at the farm level. We used the Simpson index of diversification (*SID*) to calculate the degree of farm diversification, which is defined as follows:

$$SID = 1 - \sum_{i=1}^{J} \left(\frac{L_i}{\sum_{i=1}^{J} L_i} \right)^2 \quad (4)$$

where L_i represents the land area devoted to each crop type *i*. *SID* is an index taking values limited between zero and one, where zero indicates no diversification strategy and one implies that farmers adopt total diversification production systems.

In addition, a Tobit model was estimated to determine the factors affecting the technical efficiency of farmers. Previous research studies have widely used Tobit estimation to model efficiency ratings as a censored variable with values bounded between zero and one [30,43,49]. The Tobit model is defined by the following expression:

$$TE_i = \beta_0 + \sum_{k=1}^{K} \beta_k Z_{ki} + \varepsilon_i \quad (5)$$

where TE_i represents technical efficiency scores of farmers, Z_k is a vector of explanatory variables that could affect efficiency, β_k denotes the parameters to be estimated, and ε_i is the error term assumed to follow a normal distribution.

Following existing studies on efficiency, the DEA efficiency scores can be expressed as a function of key socioeconomic characteristics of farms and farmers. Z_1 represents the farm manager's age as a proxy to farming experience and expected to have a positive impact on efficiency [33,50,51]. Z_2 identifies the gender of farmers to capture the difference in farm management between men and women [10,51–53], taking a value of one if the farmer is male and zero otherwise. Further, the framer's education level is included in Z_3 and defined as a dummy variable that equals to one if the farmer has completed at least an elementary degree and zero otherwise. We expect that better educated farmers tend to be more technically efficient [33,50,51]. We also considered the agricultural household size reflected in Z_4, which could have positive impact on efficiency since it ensures a continuous availability of the workforce for different framing activities [43,50–53]. Moreover, the model includes the crop diversification index (*SID*) (Z_5), our key variable in this study, to investigate its effect on efficiency. Additionally, Z_6 includes off-farm income expressed in TND, which may ensure extra economic resources to support farming activities [10,53]. The literature has shown mixed results regarding its effect on the efficiency. We considered land tenure regime and property rights (Z_7) in the model as another variable that could affect efficiency performance of farmers. It takes the values of one and zero if a farmer owned or rented the cultivated land, respectively. It has been shown a positive impact of landownership on technical efficiency levels [54,55], while other groups of studies reported negative relationships [56,57]. Finally, farm size measured in hectares is reflected in Z_8.

Existing studies suggested an inverse relationship between farm size and productivity of farmers [10,58,59].

5. Data

The empirical application uses a sample of farms that produce arable crops. Primary data were collected using structured questionnaire from 200 farmers. Our sample farms are mainly distributed across four production regions (namely, Jendouba, Beja, Siliana, and Bizerte). These regions account for 40% of the total COP area and provide around 40% of the total COP output in Tunisia. The importance of these production areas as leading producers of arable crops in Tunisia justifies the decision to select this study area.

We collected detailed data on the farm's input use including details on the total area in hectares (ha) of the land allocated to COP production (x_1). Labor force (x_2), defined in hours, represents both salaried work and family labor. In addition, capital input (x_3), expressed in Tunisian currency unit (TND), measures the depreciation value of machinery, equipment, and buildings investments. Besides, crop-specific inputs encompass seeds expenses (x_4), fertilizers (x_5), and pesticides, herbicides, and fungicides products (x_6) measured in currency units. Energy (x_7) represents expenditures in fuels, electricity, and lubricants and is measured in TND. Farming overheads (x_8) cover water, contract work, and other inputs expenditures. Furthermore, as mentioned earlier, we assumed three possible ex-ante COP outputs that could be obtained under bad, normal, and ideal growing conditions ($y = (y_1, y_2, y_3)$) expressed in TND. Following previous studies [22,23,43], collecting ex-ante output data were chiefly drawn on the experience and opinions of farmers regarding crop yield under different growing conditions over a long period.

Table 1 presents the main statistics for key variables used for deriving efficiency scores and its determinant factors. The results indicated that our sample farms managed 32 hectares, on average. Consistent with the national COP farming statistics, 76% of the COP land was allocated to cereals crops (wheat, barley and triticale), 9% was allocated to forage, and 15% was allocated to leguminous production. Our sample farmers used on average, 1316 h with a high relevance of unpaid family labor (about 70% of the total labor force) to produce COP during the growing season.

Table 1. Summary statistics for key variables used for efficiency models.

Variable	Variable Description	Mean	Standard Deviation
y_1	Ex-ante bad output (TND)	35,425.99	57,864.91
y_2	Ex-ante normal output (TND)	56,793.17	87,491.33
y_3	Ex-ante ideal output (TND)	85,252.99	130,382.70
x_1	Land (hectares)	32.07	43.62
x_2	Labor (hours)	1316.07	2717.56
x_3	Capital (TND)	76,645.30	95,970.43
x_4	Seeds (TND)	21,193.03	121,401.20
x_5	Fertilizers (TND)	9966.89	22,712.44
x_6	Crop protection products (TND)	4486.77	7445.53
x_7	Energy (TND)	2648.88	4891.10
x_8	Farming overheads (TND)	3655.03	7279.79
	Efficiency Effect model		
Z_1	Age (year)	56.05	11.42
Z_2	Gender (1 = male, 0 = female)	0.94	0.24
Z_3	Education level (1 = primary school and above, 0 = no formal education)	0.92	0.26
Z_4	Family size (number of people in the household)	4.16	2.32
Z_5	Crop diversification index (*SID*)	0.42	0.26
Z_6	Off-farm income (TND)	7859.51	3934.00
Z_7	Land tenure status (1 = ownership, 0 = tenancy)	0.82	0.38
Z_8	Farm size (hectares)	32.07	43.62

Source: Own elaboration based on the survey data.

COP's yield varied across crop growing states and farmer's expectations. Farmers would expect an output of 36 thousand TND under bad conditions, whereas an average output of 85 thousand TND would be obtained for ideal growing conditions. The value of COP output that farmers used to generate under normal conditions was about 57 thousand TND. The statistics show increasing output standard deviations according to the growing conditions of COP production, indicating a high output variability among farms. Farmers invested about 76 thousand TND in machinery and buildings. Expenses in crop protection products (pesticides, insecticides, and herbicides) was approximately 4.5 thousand TND to prevent COP production against pest infestations and diseases. Farmers spent much higher expenses in seeds compared to energy and farming overheads costs, about 21 thousand TND, on average. Annual expenditures in fertilizers applied to COP production averages around 10 thousand TND.

6. Empirical Results and Discussion

Table 2 reports the statistics for technical efficiency scores. The results showed to what extent our sample COP farms used effectively their inputs to achieve their potential output. The global efficiency mean score was around 65%, suggesting that farmers had the opportunity to reduce their input use by 35%, on average, without changing the current production level. Consistent with previous findings, we found relatively close TE indicators, which fell in the range of existing estimates with slight differences that could be attributed to different estimation techniques, databases, and the period of analysis used across studies. Bachta and Chebil [21] and Amor and Muller [26] using the SFA method and Chebil et al. [28] using the non-parametric technique reported slightly higher averages of TE scores among a sample of cereal farms located in other production zones in Tunisia, which are 74%, 77%, and 71%, respectively. Dhehibi et al. [27] found a similar TE performance for a sample specialized in wheat production in the governorate of Beja, whereas Abdelhafidh et al. [29] found a lower TE performance of 58% for rainfed wheat production in Zaghouan during 2015–2016. More recent studies [30,31] suggested that farmers specialized in wheat production could improve their performance levels by 28% and 15% by keeping their actual production technology process.

Table 2. Summary statistics for technical efficiency scores.

Region	Mean	Standard Deviation	Minimum	Maximum
Béja	0.70	0.25	0.27	1.00
Bizerte	0.39	0.22	0.07	1.00
Jendouba	0.85	0.13	0.52	1.00
Siliana	0.62	0.21	0.29	1.00
Total sample	0.65	0.27	0.07	1.00

Source: Own elaboration based on the survey data.

Moreover, TE ratings suggest important room to improve the input use without altering the current production level, especially for farmers located in Bizerte region. In contrast, our empirical findings suggest that farmers located in Jendouba show better technical performance. On average, farmers in this region show higher TE levels (85%) compared to their neighbor counterparts. This finding may reflect that this group of farmers show better management skills and experience in COP production. Furthermore, it is worth noting that this group of farms adopt an irrigation technique to improve their productivity. Better allocation of available resources may help farmers improve their technical efficiency and reduce their production costs, leading to more economic and technical sustainable agricultural activities without implementing any new technological innovations at the farm level.

The average index of crop diversification for our COP farmers was 0.42, suggesting a moderate level of diversification within our sample farms (Table 3). The second objective of this study was to examine how these indicators are related to each other. For this purpose, we computed the Spearman's rank correlation coefficient. The latter is a nonparametric statistical measure that examines the strength and the direction of the relationship between two or many variables. It is widely used in the literature on efficiency measurement. In contrast to the Pearson's correlation, this test does not require the normality assumption. Results reported in Table 3 show a significant negative association (−0.26) at the 1% level of significant supporting evidence of an inverse relationship between technical efficiency and crop diversification within our sample. Hence, we can conclude that technical efficiency decreases with farmers producing multiple crops and are likely to diversify their income sources.

Table 3. Relationship between the crop diversity index (*SID*) and the technical efficiency level.

***SID* Index**	**Technical Efficiency Level**
0–0.20	0.83
0.21–0.40	0.60
0.41–0.60	0.59
0.61–0.80	0.58
Mean	
0.42	0.65
Spearman's rank correlation coefficient between the efficiency score and the *SID*	
Spearman's test −0.264 (*p*-value = 0.000)	

Source: Own calculations from the survey data.

Figure 1 illustrates the kernel distributions of efficiency ratings and crop diversification index confirming the negative association between the degrees of diversification and technical efficiency levels of farms. Farmers that were more specialized tend to be more technically efficient than farmers who sought to diversify their income sources through cultivating several crops during the production season. In line with previous research [10,37,38], we found evidence that an increase in the crop diversification index will lead to a greater inefficiency performance of COP farmers. However, our findings contrast with those obtained by other groups of studies [53,60], who reported inverse relationships, suggesting that diversified farms showed slightly higher technical efficiency than their specialized counterparts.

One possible explanation of this behavior is that using different crops would need optimal allocation of resources which is not straightforward for framers and may need more qualified skills to use resources more efficiently. On the other hand, farmers often use crop diversification as a resilient and risk-coping strategy to ensure income stability, especially for limited farmers' income. Policymakers would pay more attention to bundle crop diversification with promoting agricultural practices management (soil, water, and energy [12,61–63] that rationalizes the use of productive factors in the COP production process, along with strategy based on cost reduction. Another strategy could rely on incentives that encourage farmers to uptake innovative production technologies that help stabilize and reduce revenue variability [10].

The Tobit model results for the TE measures are reported in Table 4. The likelihood ratio test suggests that the model is globally significant and all variables considered jointly fit the data at the 1% level of significance, meeting the expected signs. In line with previous findings [10,37,38,64], crop diversification showed a negative and significant influence on efficiency at the 10% level of significance, supporting the evidence of findings reported in Table 3 and Figure 1. Thus, results indicated that a one-unit increase in the crop diversity index would reduce efficiency performance by 0.32 unit. Consistently, off-farm income had also negative and marginal effects on efficiency, indicating that farmers who diversify their sources of income are likely to exhibit lower levels of efficiency [53,64]. Therefore, farms that are more specialized are likely to be more efficient.

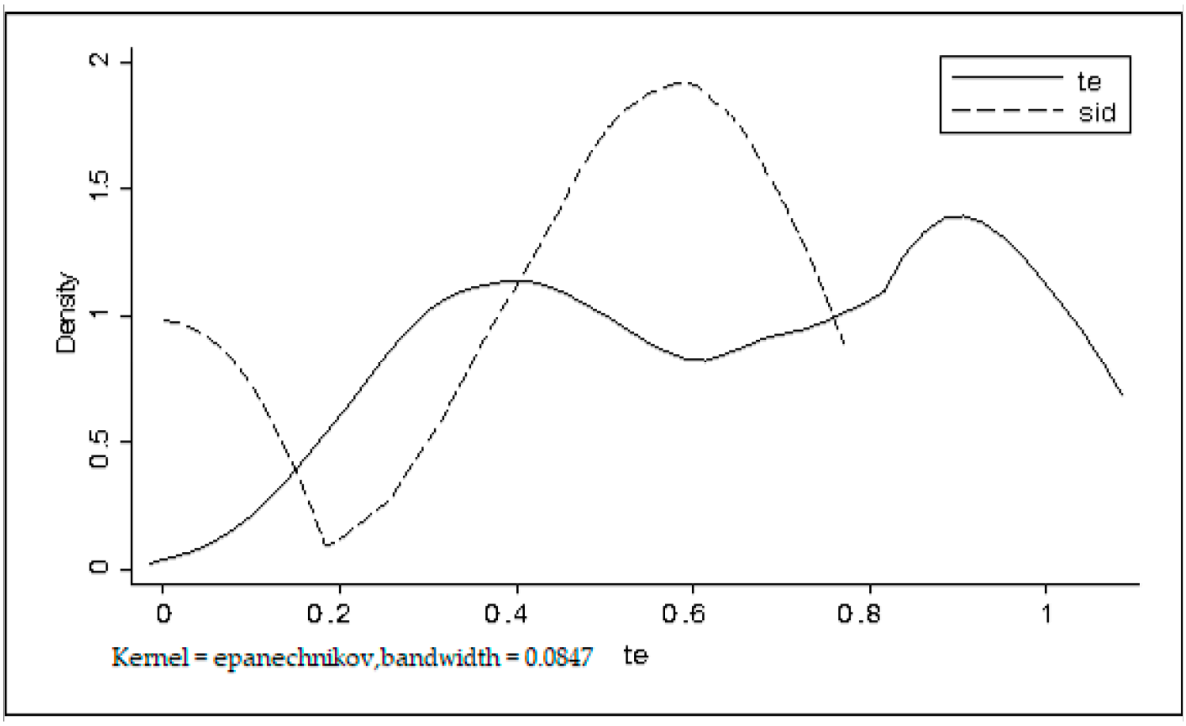

Figure 1. Kernel distributions of the efficiency level and the crop diversification index.

Table 4. Technical efficiency effect model.

Variable	Coefficient	*p*-Value
Constant	0.966	0.000 ***
Age	0.023×10^{-3}	0.993
Gender	0.287	0.066 *
Education level	0.159	0.200
Family size	0.022	0.081 *
Crop diversification index (*SID*)	−0.321	0.016 **
Off-farm income	-0.017×10^{-3}	0.012 **
Land Tenure	0.014	0.872
Farm size	-0.035×10^{-3}	0.955
PseudoR^2	0.161	
LR χ^2	18.600	
Prob > χ^2	0.017 **	
Log likelihood	−48.544	

***, **, and * denote statistical significance at the 1%, 5%, and 10%, respectively.

In addition, the results revealed a significant effect of family size on farm productivity. Consistent with previous findings [50,51], larger households tended to be more efficient, indicating a rationale use of an available family workforce for the production activities throughout the growing season. Our results further support earlier research showing male farmers are more efficient than female farmers [51–53]. This finding suggest that male farmers may exhibit better farm management skills to improve their efficiency levels than their female counterparts. This could be attributed to more engagement of women in operating activities than their participation in production choices and decisions in the farming system in Tunisia.

Finally, empirical findings might provide some policy implications and recommendations to improve efficiency performance of COP farms which may entail some actions at both the farm and policy levels. Financial support received by farmers could play a key role, as long as they are drawn on more economically and environmentally sustainable practices and efficiency performance. In this way, framers would be more motivated to comply with such rules to maintain their livelihood, on the one hand, and to increase the economic viability of farms, on the other hand [65]. Furthermore, improving farmers' managerial capacity would increase farm competitiveness and productivity, which in turn boosts the COP supply to meet the society needs and alleviate the food security issue in the country. This should rely on more informative campaigns, advisory service contact, and training activities [57] on adopting innovative and sustainable management practices in COP farming.

7. Concluding Remarks

The COP sector still has an important contribution to the agricultural economy and livelihood of rural households in Tunisia. Research studies on the performance of COP production are still thin. Nevertheless, there have recently been a few initiatives focusing on the evaluation of technical efficiency of farms using alternative estimation methods to derive efficiency scores. Determining the association between the land use pattern and efficiency level could be of strategic importance for policymakers aiming at improving the performance and competitiveness of the COP production and promoting mixed cropping as a resilient farming strategy in this country. However, the previous literature provides evidence for mixed effects of crop diversity on farms productivity that varies across regional context and specificities of the country [10,19]. While few attempts have examined this relationship in other parts of the world, this issue has not been investigated in Tunisia so far. Thus, this work contributes to filling this gap and to the ongoing debate on the effect of multiple cropping system on efficiency performance of farmers. Moreover, state-contingent analysis has gained specific attention to appropriately account for the stochastic nature of production. In this context, this study relied on this estimation technique, contributing to the scarce literature on the use of the DEA method through considering production risk.

We attempted to provide valuable information for both farmers and policymakers regarding the tradeoff between efficiency performance and income stability. The empirical analysis relies on state-contingent techniques to derive technical efficiency estimates and the crop diversification index to determine the land use pattern using a sample of farms producing COP products. Our results provide evidence that specialized farmers were more efficient (83%), on average, than farmers who adopted crop diversification strategies (60%), suggesting significant room to reduce inefficiency. In this context, this finding implies that public policies may support resilient techniques that reduce both inefficiency and income variability of farms through more productive interaction between farmers and local services and administration. Improving technical efficiency of COP farmers would enhance the farm's economic sustainability through better allocation of farmland and other inputs use between crops cultivated to become more productive and profitable. At the academic level, further research may investigate the factors affecting farmers' risk attitudes and risk perception to better understand farm production, investment, and management decisions and to improve efficiency performance of farmers.

Last but not least, we acknowledge the fact that our study might reveal some limitations. First, using a larger sample size through by either increasing the number of farmers or extending the data to cover several years of panel data would provide more reliable findings and conclusions about the variability of efficiency estimates and income. Secondly, future research might consider the integration of environmental and social efficiency to understand the tradeoff between technical, social, economic, and environmental viability of COP farms in Tunisia.

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References

1. Dhraief, M.Z.; Dhehibi, B.; Albouchi, L.; Oueslati, M. Decomposition analysis of income difference between recommended and traditional method in cultivation of Durum Wheat in Northwest of Tunisia. *Ann. De L'inrat* **2021**, *94*, 127–139.
2. Observatoire National de L'agriculture Annuaire de Statistique Agricole. 2019. Available online: http://www.onagri.nat.tn/uploads/statistiques/2019/Annuaire-statistique-2019.pdf (accessed on 20 September 2022).
3. Food and Agriculture Organization of the United Nations. Impact of the Ukraine-Russia Conflict on Global Food Security and Related Matters under the Mandate of the Food and Agriculture Organization of the United Nations. 2020. Available online: https://www.fao.org/3/nj164en/nj164en.pdf (accessed on 20 September 2022).
4. Jagtap, S.; Trollman, H.; Trollman, F.; Garcia-Garcia, G.; Parra-López, C.; Duong, L.; Martindale, W.; Munekata, P.E.S.; Lorenzo, J.M.; Hdaifeh, A.; et al. The Russia-Ukraine conflict: Its implications for the global food supply chains. *Foods* **2022**, *11*, 2098. [CrossRef]
5. Von Cramon-Taubadel, S. Russia's invasion of Ukraine–implications for grain markets and food security. *Ger. J. Agric. Econ.* **2022**, *71*, 1–13. [CrossRef]
6. Mekki, I.; Bailly, J.S.; Jacob, F.; Chebbi, H.; Ajmi, T.; Blanca, Y.; Zairi, A.; Biarnès, A. Impact of farmland fragmentation on rainfed crop allocation in Mediterranean landscapes: A case study of the Lebna watershed in Cap Bon, Tunisia. *Land Use Policy* **2018**, *75*, 772–783. [CrossRef]
7. Ferchichi, I.; Mekki, I.; Elloumi, M.; Arfa, L.; Lardon, S. Actors, scales and spaces dynamics linked to groundwater resources use for agriculture production in Haouaria plain, Tunisia. A territory game approach. *Land* **2020**, *9*, 74. [CrossRef]
8. Taghouti, I.; Elloumi, M.; Hinojosa, L.; Napoléone, C. Planification nationale en Tunisie: Une analyse diachronique. *Maghreb-Machrek* **2020**, *246247*, 25–42. [CrossRef]
9. Gharbi, I.; Elloumi, M.; Jamin, J.Y. Influence of land practices on the sustainability of irrigated farms in Tunisia: An analysis using the IDEA method. *J. New Sci. Agric. Biotechnol.* **2022**, *88*, 4972–4983.
10. Mzyece, A.; Ng'ombe, J.N. Does crop diversification involve a trade-off between technical efficiency and income stability for rural farmers? Evidence from Zambia. *Agronomy* **2020**, *10*, 1875. [CrossRef]
11. Kassie, M.; Pender, J.; Yesuf, M.; Kohlin, G.; Bluffstone, R.; Mulugeta, E. Estimating returns to soil conservation adoption in the northern Ethiopian highlands. *Agric. Econ.* **2008**, *38*, 213–232. [CrossRef]
12. Kalinda, T.H.; Tembo, G.; Ng'ombe, J.N. Does adoption of conservation farming practices result in increased crop revenue? Evidence from Zambia. *Agrekon* **2017**, *56*, 205–221.
13. Lin, B.B. Resilience in agriculture through crop diversification: Adaptive management for environmental change. *BioScience* **2011**, *61*, 183–193. [CrossRef]
14. Sasmita, I.; Supriyono, S.; Nyoto, S. Pengaruh berbagai varietas jagung secara tumpangsari additive series pada pertanaman kacang tanah terhadap pertumbuhan dan hasil. *Caraka Tani J. Sustain. Agric.* **2014**, *29*, 45–52. [CrossRef]
15. Makate, C.; Wang, R.; Makate, M.; Mango, N. Crop diversification and livelihoods of smallholder farmers in Zimbabwe: Adaptive management for environmental change. *SpringerPlus* **2016**, *5*, 1135. [CrossRef]
16. Amosun, J.O.; Aduramigha-Modupe, V. Influence of groundnut populations on weed suppression in cassava-groundnut systems. *J. Agric. Sci.* **2016**, *8*, 72–78. [CrossRef]
17. Chen, P.; Song, C.; Liu, X.M.; Zhou, L.; Yang, H.; Zhang, X.; Zhou, Y.; Du, Q.; Pang, T.; Fu, Z.-D.; et al. Yield advantage and nitrogen fate in an additive maize-soybean relay intercropping system. *Sci. Total Environ.* **2019**, *657*, 987–999. [CrossRef]
18. Li, Y.H.; Shi, D.Y.; Li, G.H.; Zhao, B.; Zhang, J.W.; Liu, P.; Ren, B.; Dong, S.T. Maize/peanut intercropping increases photosynthetic characteristics, 13cphotosynthate distribution, and grain yield of summer maize. *J. Integr. Agric.* **2019**, *18*, 2219–2229. [CrossRef]
19. Chavas, J.P.; Rivieccio, G.; Di Falco, S.; De Luca, G.; Capitanio, F. Agricultural diversification, productivity, and food security across time and space. *Agric. Econ.* **2022**, *53*, 41–58. [CrossRef]

20. Weigel, R.; Koellner, T.; Poppenborg, P.; Bogner, C. Crop diversity and stability of revenue on farms in Central Europe: An analysis of big data from a comprehensive agricultural census in Bavaria. *PloS ONE* **2018**, *13*, e0207454. [CrossRef]
21. Bachta, M.S.; Chebil, A. Efficacité technique des exploitations céréalières de la plaine du Sers-Tunisie. *New Medit* **2002**, *3*, 4–13.
22. Serra, T.; Lansink, A.O. Measuring the impacts of production risk on technical efficiency: A state-contingent conditional order-m approach. *Eur. J. Oper. Res.* **2014**, *239*, 237–242. [CrossRef]
23. Chambers, R.G.; Serra, T.; Stefanou, S.E. Using ex ante output elicitation to model state-contingent technologies. *J. Product. Anal.* **2015**, *43*, 75–83. [CrossRef]
24. Ait Sidhoum, A.; Serra, T.; Latruffe, L. Measuring sustainability efficiency at farm level: A data envelopment analysis approach. *Eur. Rev. Agric. Econ.* **2020**, *47*, 200–225. [CrossRef]
25. Guesmi, B.; Taghouti, I.; Abdelhafidh, H.; Selmi, S.; Arfa, L. Assessment of the environmental sustainability of family farming: The case of cereal sector in Tunisia. In *Agriculture Productivity in Tunisia under Stressed Environment*; Khebour Allouche, F., Abu-hashim, M., Negm, A.M., Eds.; Springer Water: Cham, Switzerland, 2021; pp. 13–26.
26. Amor, T.B.; Muller, C. Application of stochastic production frontier in the estimation of technical efficiency of irrigated agriculture in Tunisia. *Agric. J.* **2010**, *5*, 50–56.
27. Dhehibi, B.; Bahri, H.; Annabi, M. Input and output technical efficiency and total factor productivity of wheat production in Tunisia. *Afr. J. Agric. Resour. Econ.* **2012**, *7*, 70–87.
28. Chebil, A.; Frija, A.; Thabet, C. Economic efficiency measures and its determinants for irrigated wheat farms in Tunisia: A DEA approach. *New Medit* **2015**, *14*, 32–38.
29. Abdelhafidh, H.; Ben Brahim, M.; Abed, H.; Mekki, A. Analysis of the technical efficiency, pure and scale efficiency of rained cereal farms: Case of the upper semi-arid. *J. Exp. Biol. Agric. Sci.* **2017**, *5*, S116–S125.
30. Chemak, F.; Mazhoud, H.; Abdelhafidh, H.; Albouchi, L.; Snoussi, Y. Technical performance and water productivity analysis of the irrigated durum wheat activity. *NJAS-Wagening. J. Life Sci.* **2018**, *50*, 3106–3116.
31. Rached, Z.; Chebil, A.; Khaldi, R. Economic, allocative and technical efficiency of cereals farms in Tunisia case of durum wheat in sub-humid region. *J. New Sci.* **2020**, *71*, 4300–4310.
32. Manjunatha, A.V.; Anik, A.R.; Speelman, S.; Nuppenau, E.A. Impact of land fragmentation, farm size, land ownership and crop diversity on profit and efficiency of irrigated farms in India. *Land Use Policy* **2013**, *31*, 397–405. [CrossRef]
33. Ogundari, K. Crop diversification and technical efficiency in food crop production: A study of peasant farmers in Nigeria. *Int. J. Soc. Econ.* **2013**, *40*, 267–287. [CrossRef]
34. Ajibefun, I.A. Cropping system, technical efficiency and policy options: A stochastic frontier analysis of Nigerian small-scale farmers. *Q. J. Int. Agric.* **2006**, *45*, 145–170.
35. Rahman, S. Whether crop diversification is a desired strategy for agricultural growth in Bangladesh? *Food Policy* **2009**, *34*, 340–349. [CrossRef]
36. Coelli, T.; Fleming, E. Diversification economies and specialisation efficiencies in a mixed food and coffee smallholder farming system in Papua New Guinea. *Agric. Econ.* **2004**, *31*, 229–239. [CrossRef]
37. Llewelyn, R.V.; Williams, J.R. Nonparametric analysis of technical, pure technical, and scale efficiencies for food crop production in East Java, Indonesia. *Agric. Econ.* **1996**, *15*, 113–126. [CrossRef]
38. Haji, J. Production efficiency of smallholders' vegetable-dominated mixed farming system in eastern Ethiopia: A non-parametric approach. *J. Afr. Econ.* **2007**, *16*, 1–27. [CrossRef]
39. Chambers, R.G.; Quiggin, J. Cost functions and duality for stochastic technologies. *Am. J. Agric. Econ.* **1998**, *80*, 288–295. [CrossRef]
40. Chambers, R.G.; Quiggin, J. *Uncertainty, Production, Choice, and Agency: The State-Contingent Approach*; Cambridge University Press: Cambridge, UK, 2000; pp. 1–390.
41. O'Donnell, C.J.; Chambers, R.G.; Quiggin, J. Efficiency analysis in the presence of uncertainty. *J. Product. Anal.* **2010**, *33*, 1–17. [CrossRef]
42. Rasmussen, S. Criteria for optimal production under uncertainty. The state-contingent approach. *Aust. J. Agric. Resour. Econ.* **2003**, *47*, 447–476. [CrossRef]
43. Guesmi, B.; Serra, T. Can we improve farm performance? The determinants of farm technical and environmental efficiency. *Appl. Econ. Perspect. Policy* **2015**, *37*, 692–717. [CrossRef]
44. Bonjean, A.C.; Simonet, C. Are grain markets in Niger driven by speculation? *Oxf. Econ. Pap.* **2016**, *68*, 714–735. [CrossRef]
45. The Ministry of Agriculture. Statistical Yearbook of Agriculture: Tunisia. 2015. Available online: http://www.onagri.nat.tn/uploads/statistiques/annuaire-statistique-2014.pdf (accessed on 1 October 2022).
46. The World Bank Group. Cereal Yield. 2017. Available online: https://data.worldbank.org/indicator/AG.YLD.CREL.KG (accessed on 1 November 2022).
47. Chavas, J.-P. A cost approach to economic analysis under state-contingent production uncertainty. *Am. J. Agric. Econ.* **2008**, *90*, 435–466. [CrossRef]
48. Färe, R.; Grosskopf, S.; Lovell, C.A.K. *Production Frontiers*; Cambridge University Press: Cambridge, UK, 1994; pp. 1–296.
49. Tovar, B.; Wall, A. Specialisation, diversification, size and technical efficiency in ports: An empirical analysis using frontier techniques. *Eur. J. Transp. Infrastruct. Res.* **2017**, *17*, 279–303.

50. Ouko, K.O.; Hillary, K.B.; Bandiougou, D. Technical efficiency of sugarcane monoculture and sugarcane-soybean integration among smallholder farmers in Awendo Sub-County, Kenya. *J. Econ. Sustain. Dev.* **2018**, *9*, 157–169.
51. Zhou, W.B.; WANG, H.Y.; Xi, H.U.; DUAN, F.Y. Spatial variation of technical efficiency of cereal production in China at the farm level. *J. Integr. Agric.* **2021**, *20*, 470–481. [CrossRef]
52. Sienso, G.; Asuming-Brempong, S.; Amegashie, D.P. Estimating the efficiency of maize farmers in Ghana. *Asian J. Agric.Ext. Econ. Sociol.* **2014**, *3*, 705–720. [CrossRef]
53. Kansiime, M.K.; van Asten, P.; Sneyers, K. Farm diversity and resource use efficiency: Targeting agricultural policy interventions in East Africa farming systems. *NJAS-Wagening. J. Life Sci.* **2018**, *85*, 32–41. [CrossRef]
54. Michler, J.D.; Shively, G.E. Land tenure, tenure security and farm efficiency: Panel evidence from the Philippines. *J. Agric. Econ.* **2015**, *66*, 155–169. [CrossRef]
55. Ngango, J.; Hong, S. Impacts of land tenure security on yield and technical efficiency of maize farmers in Rwanda. *Land Use Policy* **2021**, *107*, 105488. [CrossRef]
56. Bradfield, T.; Butler, R.; Dillon, E.J.; Hennessy, T. The factors influencing the profitability of leased land on dairy farms in Ireland. *Land Use Policy* **2020**, *95*, 104649. [CrossRef]
57. Bradfield, T.; Butler, R.; Dillon, E.; Hennessy, T.; Kilgarriff, P. The effect of land fragmentation on the technical inefficiency of dairy farms. *J. Agric. Econ.* **2021**, *72*, 486–499. [CrossRef]
58. Julien, J.C.; Bravo-Ureta, B.E.; Rada, N.E. Assessing farm performance by size in Malawi, Tanzania, and Uganda. *Food Policy* **2019**, *84*, 153–164. [CrossRef]
59. Benmehaia, M.A. Farm size and productivity in Algerian agriculture: A contingent relationship. *New Medit* **2022**, *21*, 3–15. [CrossRef]
60. Lanamana, W.; Supardi, P.N. A Comparison of economic efficiency of monoculture and multiple cropping patterns: The case of cassava farming in Ende, Indonesia. *Caraka Tani J. Sustain. Agric.* **2020**, *36*, 69. [CrossRef]
61. Solís, D.; Bravo-Ureta, B.E.; Quiroga, R.E. Soil conservation and technical efficiency among hillside farmers in Central America: A switching regression model. *Aust. J. Agric. Resour. Econ.* **2007**, *51*, 491–510. [CrossRef]
62. Abdulai, A.N.; Abdulai, A. Examining the impact of conservation agriculture on environmental efficiency among maize farmers in Zambia. *Environ. Dev. Econ.* **2017**, *22*, 177–201. [CrossRef]
63. Chan, C.; Sipes, B.; Ayman, A.; Zhang, X.; LaPorte, P.; Fernandes, F.; Pradhan, A.; Chan-Dentoni, J.; Roul, P. Efficiency of conservation agriculture production systems for smallholders in rain-fed uplands of India: A transformative approach to food security. *Land* **2017**, *6*, 58. [CrossRef]
64. Guesmi, B.; Serra, T.; Kallas, Z.; Roig, J.M.G. The productive efficiency of organic farming: The case of grape sector in Catalonia. *Span. J. Agric. Res.* **2012**, *3*, 552–566. [CrossRef]
65. Serra, T.; Zilberman, D.; Goodwin, B.K.; Hyvonen, K. Replacement of agricultural price supports by area payments in the European Union and the effects on pesticide use. *Am. J. Agric. Econ.* **2005**, *87*, 870–884. [CrossRef]