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Socio-economic impacts of zero and reduced tillage in wheat fields of the Moroccan drylands

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Abstract

Zero tillage (ZT) is recommended for dryland farming because it enhances retention of residual soil moisture. However, it is not always clear whether this translates to an economic advantage over conventional tillage, which helps in controlling weeds. Using a nationally representative sample of 1901 wheat fields in Morocco as a case study, we provide comparative analysis on different tillage intensities. Results from an endogenous switching regression model showed that fields that were not tilled gave 298.6 kg/ha (23%) higher yields, US$89/ha (27%) more income and more stable yields than those tilled once or more. Fields that were not tilled also had 87% lower yield variance with 100% and 65.6% less risk of giving yield levels below 500 and 1000 kg/ha, respectively. The highest yield losses occurred during the first and third tillage passes, but the second had negligible effect. Labor saving from avoiding tillage under ZT was undermined by higher labor needed for weeding. Along with biophysical benefits documented elsewhere, our results show that, if constraints for its wider diffusion are removed, zero or reduced tillage has the potential to sustainably improve the economic and biophysical viability of dryland agriculture in Morocco and other similar countries in North Africa and West Asia.

KEYWORDS

dryland, endogenous switching regression, impact, intensity of tillage, Morocco, zero tillage

JEL CLASSIFICATION

O33, Q12, Q55

1 | INTRODUCTION

In the last two decades, the global area under zero tillage (ZT) has expanded at an average rate of 6 million ha per year - from 45 million ha in 1999 (Derpsch, 2001) to 73 million ha in 2003 (Benites et al., 2003), 116 million ha in 2008/2009 and 155 million ha in 2017 (FAO, 2017). The annual growth rate has, however, declined from 7 million ha during 1999–2003 to 5.8 million ha during 2003–2017 - raising concerns on the biophysical and socio-economic viability of the technology in places other than the large farms of North and South America and Australia, where it has been widely adopted. Derpsch and Friedrich (2010) argue that the documented global expansion of ZT technology is due to its benefits, including improvement of soil biology, reduction of soil erosion risk, biochemical properties and reduction of energy inputs. There are also food security and economic justifications for ZT apart from the fuel saving; for example, Brazil increased its grain production by 67.2 million tons in 15 years by adopting the ZT system, with additional revenue of US$10 billion (Derpsch, 2005).

ZT is often promoted as one of three important pillars of conservation agriculture (CA) and, as a result, yield differences have been reported in the range of 20–120% between CA and tillage systems in Latin America, Africa and Asia (Erenstein et al., 2008; FAO, 2008; Hengxin et al., 2008; Landers, 2007; Pretty et al., 2006; Rockstrom et al., 2009). However, adoption of ZT alone is still reported to be associated with grain yield gains relative to conventional tillage and this is especially so in drylands (Aravindakshan et al., 2018; Bouzza, 1990; El-Shater et al., 2016; Jaleta et al., 2016; Kacemi et al., 1995). Several studies including meta-analyses, reviews, syntheses and case studies from around the world (Erenstein et al., 2012; Knowler & Bradshaw, 2007; Palm et al., 2014; Pannell et al., 2013; Powlson et al., 2014; Rusinamhodzi et al., 2011) have shown that the farm-level impacts of ZT on yield, labor and other impact indicators are either mixed or inconclusive. For instance, where ZT is combined with mulching, a commonly described pattern is for yields to fall at least in the initial few years (Baudron et al., 2011; Fowler & Rockstrom, 2001; Giller et al., 2009). All the studies cited above conclude that lack of economic incentives, agronomic challenges and agro-ecological conditions play major roles in determining the benefits of CA and its components including ZT.

In Morocco, the National Institute of Agricultural Research (INRA) started a CA project in 1982 with the aim of revising needs for tillage systems in ensuring simultaneous amelioration of crop production and soil quality under drought and water shortage in dry areas. This project was reinforced by other CA research activities led by other national partners. Over the last three decades, several CA experimental trials and on-farm studies have been conducted in different agro-ecosystems of Morocco and the results documented (Mrabet, 2011). Promotion of CA in Morocco started in the 1990s when INRA and development organizations successfully demonstrated that the introduction of CA would bring more stable yields and reduce production costs and erosion, enhance soil water conservation, improve soil quality and lead to higher and stable crop yields (Boughlala & Dahan, 2011; Moussadek et al., 2011; Mrabet et al., 2012). Using a simple cost–benefit analysis and bivariate comparison of adopters and non-adopters, Boughlala and Dahan (2011) estimate a net gain of about 60% for large farmers and 200% for small farmers in central Morocco.

Mrabet et al. (2012) argue that reduction of costs in machinery and fuel, timesaving in the operations (which permits the development of other agricultural and non-agricultural complementary activities), yield gains and greater yield stability are the main drivers for adoption of CA in dry areas of Morocco. Lower risk is also an important advantage, especially for small landholders (Magnan et al., 2011). Use of ZT can also reduce drudgery and permit the release of labor, leading to other economic and social benefits including leisure as it creates more spare time. Therefore, CA technologies in general and ZT in particular stand out as the best immediate solutions to satisfy food requirements of the Moroccan population over the next few decades (Badraoui & Dahan, 2010).

Despite the credible evidence of biophysical benefits, successful demonstrations in research stations and four decades of advocacy, CA has found limited adoption in Moroccan farm communities (Acevedo et al., 2014; Giller et al., 2011). Different sources estimate the adoption of CA in central Morocco at a meager 1% or 4000 ha (FAO, 2017; WB, 2014). The situation in neighboring Algeria and Tunisia is similar. El-Shater et al. (2016) found that ZT has clear livelihood benefits for wheat farmers in the rainfed areas of Syria where it was expanding rapidly until the instability in the country started in 2011. Akroush et al. (2015) also found that adopters of ZT among wheat and barley growers in Jordan obtained higher net margins. Given the strong similarities between the agro-ecological conditions within and across the Middle East and North Africa (MENA) region, we argue that the results of the Moroccan study are generalizable to all dryland areas in MENA. With this background, there are at least two hypotheses for the low adoption in the North African region: (1) farmers are not yet convinced of the benefits of the CA technology package and (2) there are barriers to adoption even if farmers are willing. Due to lack of data, this article focuses only on the first hypothesis.

Given that ZT is an important component of CA and is often cited as the main hurdle for its wider adoption, this article attempts to provide credible estimates on the level of adoption and farm-level benefits of ZT on some livelihood indicators (yield, gross margins, wheat consumption, labor demand and risk management). Given some farmers' desire to reduce and not completely eliminate tillage, this article also provides comparative analysis of the benefits of different intensities of tillage. By doing so, this article tests the first of the two hypotheses given above and helps in the decision concerning whether it is worth promoting the ZT technology or if reducing the intensity of tillage is a better option in Morocco and similar countries in MENA. The results of this study will be useful for researchers, development agencies, policy makers and donors.

2 | THE CHALLENGES OF PROMOTING CONSERVATION AGRICULTURE

The literature documents many benefits to CA in general and ZT in particular. For example, ZT conserves soil moisture and organic matter and reduces fuel, labor and machinery costs (Ribera et al., 2004). In addition, a reduction in erosion by wind and water and an increase in soil organic matter and carbon provide significant environmental benefits (Liu et al., 2006; Reicosky, 2003). With its capacity for moisture conservation and cost savings, ZT can often lead to higher yields and increased gross margins with reduced variability of yield and income, which is particularly important in dryland farming. ZT can also lead to benefits for smallholder farmers and consumers in low- and middle-income countries in Asia and Africa (El-Shater et al., 2016).

A shift from tillage, plow-based to CA-based agriculture is also not a simple matter of technical change (Gonzalez-Sanchez et al., 2015; Kassam et al., 2014). The adoption of CA requires learning new practices, introducing long-term changes in the production system and changing machinery. Moreover, the specific climate and pedologic conditions, farm management settings, market contexts, technical conditions, frequency of extension contacts and socio-economic drivers, including social networks and labor constraints, may affect a farmer's decision to adopt soil and water conservation technologies (Abdulai & Huffman, 2014; Lahmar, 2010; Wall, 2007). In addition, many studies indicate that intensive tillage practices have many benefits, including suppressing weeds and helping crops to use available soil nutrients without competition; tillage suppresses already germinated weeds but initiates new weed germination (Boomsma et al., 2010; Erkossa et al., 2006; Guan et al., 2015; Sime et al., 2015; Temesgen et al., 2008).

Intensive tillage can also increase soil moisture by increasing the water infiltration rate (Blevins & Frye, 1993; Guan et al., 2015; Sime et al., 2015; Temesgen et al., 2008; Wang et al., 2002). The purpose of tillage is to prepare a fine seedbed and to soften the soil so that it facilitates uniform seed germination. Uniform seed germination in turn increases the density of the plants and suppresses weeds (Hobbs et al., 2008; Weiner et al., 2001)—all excellent justifications in favor of tillage and for farmers not to abandon it and adopt ZT. The literature also provides mixed pictures on the effects of ZT on yield (El-Shater et al., 2016; Giller et al., 2015; Jaleta et al., 2016; Zheng et al., 2014) and environmental considerations, particularly concerning ecology and herbicide use and labor demand for weeding in the smallholder farmers' context (Bajwa, 2014; Christoffoleti et al., 2007; Norsworthy, 2008; Reicosky, 2003; Samson et al., 1996; Sims et al., 2018). These mixed results also make it challenging for development practitioners and policy makers to promote CA and for farmers to make adoption decisions. Even worse, in some parts of the world including North Africa, the literature on the pros and cons of CA—particularly on socio-economic considerations—is scant, posing a major challenge for its promotion.

3 | MATERIALS AND METHODS

3.1 | Sampling and data

Data for this study came from a large household survey conducted in 2013 covering 21 major wheat producing provinces in Morocco. These provinces account for about 79% of the total number of wheat-growing farmers and 74% of the total wheat area in the country. They also span four agro-ecological zones in the country where wheat is currently produced: favorable, intermediate, unfavorable south and mountainous zones. Provinces in the remaining two agro-ecological zones in Morocco, the Saharan and Unfavorable Oriental zones, are excluded from the survey as wheat production in these zones is either non-existent or minimal.

Using power analysis, the minimum sample size required to ensure 95% confidence and at least 2.5% precision levels for capturing the adoption of up to 75% (the ex-ante estimate by experts) from among a total of 632,263 households was determined to be 1151. To buffer the effects of possible higher adoption levels, missing values, non-response and erroneous entries, the sample was inflated upwards by about 7%. Therefore, a sample of 1230 farm households (cultivating a total of 2292 wheat fields) was drawn for this study using a stratified sampling approach in which provinces, districts and villages were used as strata. The total sample was distributed proportionally across 292 villages distributed across 56 districts that were randomly drawn from the 21 study provinces. Because ZT was not practiced in any of the irrigated wheat fields, all 391 irrigated wheat fields in the sample were dropped from this analysis, leaving a total of 995 households and their 1901 wheat fields in the sample. Structured survey questionnaires were used to collect demographic, economic, social and consumption data. Detailed production-related data were also collected for each of the 1901 wheat fields.

We analyzed the data 7 years after its collection in 2013. However, the results are still relevant to the present-day conditions in Morocco for the three following reasons. (1) The only policy change that might affect the study results was after 2016 when the government increased subsidies for the purchase of ZT seeders from Moroccan Dirhams (MAD) 48,000 (the same amount as that for a conventional

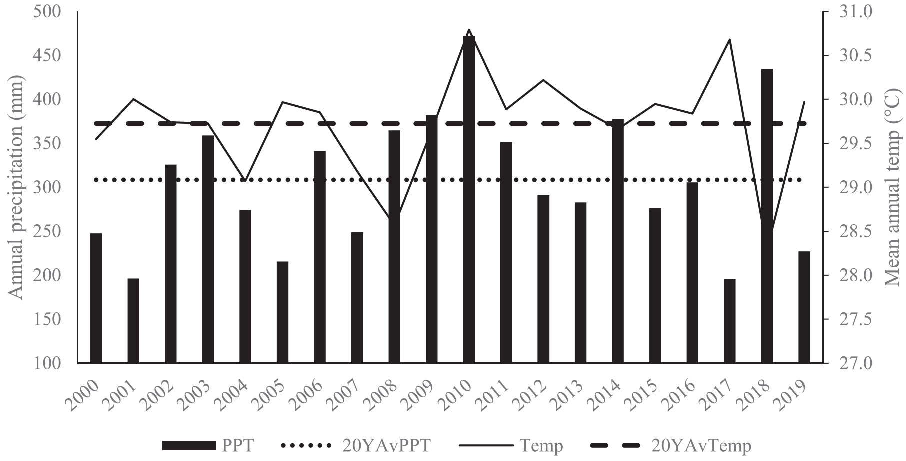

FIGURE 1 National average annual precipitation (PPT) and temperature (Temp), and 20-year average precipitation (20YAvPPT) and temperature (20YAvTemp) for Morocco

seeder) to MAD 90,000. However, even almost doubling the subsidy size for the ZT seeders did not increase the number of ZT seeder purchases. This phenomenon shows that even though almost doubling the size of the subsidy was a great move on the government's side, the lack of change in the trend shows that the subsidies should have been accompanied by intensive extension education and demonstration of the benefits of ZT as well as improved access for agricultural credit. (2) Because there has been no major change in the seed sector over the last 7 years (Bishaw et al., 2019), varietal adoption has not changed much. (3) With some exceptions related to implementation of projects (such as the project Enhancing Food Security in Arab Countries) that were implemented in specific locations, no major change has taken place in the types and timing of agronomic practices including input use and land management over the course of the last 7 years. Therefore, despite the old data, we are confident that the results of this study will still be useful to policy makers, development practitioners and extension personnel in Morocco and similar other countries with dryland agriculture in the MENA region.

As described above, this study was based on a cross-sectional data, which limited our ability to analyze the effects of variation of weather conditions across years. The impact of ZT is likely to vary across different weather conditions, with higher benefits expected during years of moisture stress because ZT helps retain much-needed residual moisture in the soil. The national average rainfall and temperature during the survey year were 282 mm and 29.89°C, respectively, which make it safe for us to consider the weather conditions in 2013 as average because these were close to the corresponding 20-year averages of about 308 mm and 29.72°C (Figure 1). Therefore, the impacts reported in this study can be considered to be the average benefit that a typical farmer in Morocco can expect in a typical year.

3.2 | Methods

Estimation of local average treatment effects (Imbens & Angrist, 1994) has been the focus of the program evaluation literature. One of the main challenges in this pursuit is related to establishing counterfactuals because selection bias is often inherent in program participation. Several econometric approaches can be used to address the problem of selection bias in program evaluation using quasi-experimental and observational data. Imbens and Wooldridge (2009) provide a good review of the literature and the developments in causal inference and impact assessment. Propensity score matching (PSM) due to Rosenbaum and Robin (1983) is by far the most widely used for improving causal inference and estimation of local average treatment effects (El-Shater et al., 2016; Henderson & Chatfield, 2011; Jalan & Ravallion, 2003; Morgan & Winship, 2014;). PSM helps in correcting biases introduced only by observable covariates (Heckman & Vytlacil, 2007). Therefore, PSM results can sometimes be misleading because unobservable factors such as skills and motivation can influence not only the outcome but also the program participation decision, thereby leading to confounding errors - see Austin (2008) for a critical review of PMS. To overcome this problem, two other methods have been proposed: endogenous switching regression (ESR) (Maddala & Nelson, 1975) and instrumental variable (Angrist & Pischke, 2009) methods. Both methods account for the endogeneity of the participation decision and are potent to correct for selection bias introduced by both observable and unobservable factors. In this article, we employ the ESR approach for estimating treatment effects for the different intensities of tillage including ZT among Moroccan farmers. The rationale for choosing ESR is that even with an instrument that may not be very strong, the model can be identified with the assumed non-linearities in the distribution of the error terms (Clougherty et al., 2016).

3.3 | Endogenous switching regression

The difference in the outcomes of interest between adopters and non-adopters may not only be due to observable heterogeneity but also to unobserved heterogeneity (Bidzakin et al., 2019; Khonje et al., 2015; Malikov & Kumbhakar, 2014; Paltasingh & Goyari, 2018). Therefore, we use an ESR to account for both observable and unobservable endogeneity of the adoption decision by simultaneously estimating the adoption function (equation 1) and the outcome equation of interest for each group.

Theoretically, farmers decide to adopt a technology when the expected utility received from adoption (D_1^*) is greater than that from non-adoption (D_0^*). Although utility is not observable, adoption is observable and is treated as a dichotomous choice: D = 1 if $D_1^* > D_0^*$ and D = 0 if $D_1^* < D_0^*$. Following Bidzakin et al. (2019), Shiferaw et al. (2014) and Lokshin and Sajaia (2011), the ESR can be formulated as follows with the adoption decision (selection equation) modeled as:

$$D_i^* = Z_i \beta + \varepsilon_i \text{ with } D_i = 1 \, if \, D_i^* > D_0^*; \text{ otherwise } D_i = 0 \tag{1}$$

where Z represents a matrix of the explanatory variables, β is a vector of parameters to be estimated and ε a vector representing a normally distributed error term with mean zero and variance σ_ε^2.

The outcome equations can also be formulated as:

$$y_1 = X_1 \omega_1 + \epsilon_1 \, if \, D = 1 \tag{2}$$

$$y_0 = X_0 \omega_0 + \epsilon_0 \, if \, D = 0 \tag{3}$$

where y_i is a vector of dependent variables representing outcomes for adopters (y_1) and non-adopters (y_0), X_i is a matrix of explanatory variables, ω_i is a vector of parameters to be estimated, and ϵ_1 and ϵ_0 are error terms.

The error terms from the three equations ε ,ϵ_1 and ϵ_0 are assumed to have a trivariate normal distribution with mean vector zero and a symmetric covariance matrix as shown in Lokshin and Sajaia (2011).

If ε is correlated with ϵ_1 and ϵ_0, the expected values of ϵ_1 and ϵ_0 conditional on the sample selection are non-zero.

If $\sigma_{\epsilon 1 \varepsilon}$ and $\sigma_{\epsilon 0 \varepsilon}$ are statistically significant, this indicates that the decision to adopt and the outcome variable of interest are correlated, suggesting evidence of sample selection bias. Therefore, estimating the outcome equations using ordinary least square (OLS) would lead to biased and inconsistent results, and Heckman procedures (Heckman, 1979) are normally used. In the face of heteroscedastic error terms, the full information maximum likelihood (FIML) estimator can be used to fit an ESR that simultaneously estimates the selection and outcome equations to yield consistent estimates. The ESR can be estimated in which the actual expected outcomes of adopters (7) and non-adopters (8), and the counterfactual hypothetical cases that the non-adopters do adopt (9) and the adopters do not adopt (10) can be analyzed as follows:

$$E\left(y_1 | D = 1\right) = X_1 \omega_1 + \sigma_{\epsilon 1 \varepsilon} \lambda_1 \tag{4}$$

$$E\left(y_0 | D = 0\right) = X_0 \omega_0 + \sigma_{\epsilon 0 \varepsilon} \lambda_0 \tag{5}$$

$$E\left(y_0 | D = 1\right) = X_1 \omega_0 + \sigma_{\epsilon 0 \varepsilon} \lambda_1 \tag{6}$$

$$E\left(y_1 | D = 0\right) = X_0 \omega_1 + \sigma_{\epsilon 1 \varepsilon} \lambda_0. \tag{7}$$

Finally, we calculate the average treatment effect on the treated (ATET) as the difference between (4) and (7) and the average treatment effect on the untreated as the difference between (6) and (5) (Carter & Milon, 2005; Di Falco et al., 2011; Lokshin & Glinskaya, 2009; Lokshin & Sajaia, 2011; Miranda & Rabe-Hesketh, 2006). We also compute the effect of base heterogeneity for the group of adopters as the difference between (4) and (6), and for the group of non-adopters as the difference between (7) and (5).

A number of factors such as types of varieties used and the amounts of fertilizers, seed, labor, herbicides and pesticides are important in determining yield, which in turn will affect income and consumption. Moreover, for farmers to adopt ZT, it is necessary that they have access to rented or privately owned ZT seeders. One of the keys to success in CA is the ZT seeding machine and its accessories, which allow farmers to seed under optimum conditions on different types of soils and with different cover crops. Therefore, we use availability of ZT seeders as an instrument in the estimation of the ESR. Descriptive statistics for selected variables including those included in the modes is provided in Table 1.

To create a more homogeneous dataset, all continuous variables (such as yield, income, consumption, farmer age, experience, area and all quantities of inputs) are converted into their natural logarithm equivalents. To avoid problems associated with zero values, a constant value of 1 was added to all values before the logarithmic transformation.

TABLE 1 Summary statistics for variables included in the models

Variable name	Variable	ZT = 1		ZT = 0		Entire sample		
		Mean values or count	Std. dev.	Mean values or count	Std. dev.	N^	Mean value	Std. dev.
Variables derived from household-level data (N = 995)								
Age	Age of household head (years)	58.97	14.18	59.5	13.62		59.48	13.65
Educ	Education of household head (years)	2.04***	0.93	1.88	0.87		1.89	0.87
WArea	Wheat area (ha)	4.36	6.16	3.82	12.10		3.86	11.82
TArea	Total cropped area (ha)	14.18	40.66	12.37	28.40		12.49	29.32
WDist	Walking distance from home to seed sources (km)	15.11***	11.26	16.99	13.43		16.87	13.32
Cons	Household consumption of wheat from own production (kg/capita/year)	71.09***	34.11	57.23	31.39		58.11	31.74
Sex	Household head is female (0 = No, 1 = Yes)	***8***		***72***		80	0.04	0.20
Credit	Household has access to credit (0 = No, 1 = Yes)	***63***		***833***		896	0.47	0.49
Livestock	Household owns livestock (0 = No, 1 = Yes)	***38***		***532***		570	0.30	0.46
Variables derived from field-level data (N = 1901)								
Labor	Total amount of labor used (person days/ha)	56.38***	39.79	44.18	27.69		44.95	28.75
LWeeding	Amount of labor used for weeding (person days/ha)	6.34***	1.67	4.26	1.49		4.59	1.57
RF	Rainfall (mm)	434.21***	76.49	340.86	94.32		346.75	96.01
QN	Quantity of nitrogen fertilizer used (kg/ha)	27.32***	20.32	20.05	17.90		20.50	18.15
QDAP	Quantity of DAP fertilizer used (kg/ha)	26.53***	10.48	18.78	12.13		19.27	12.17
QSeed	Quantity of seed used (kg/ha)	150.10***	40.92	157.57	44.41		157.10	44.51
QPesti	Quantity of pesticides (kg/ha)	0.35***	0.48	0.21	0.41		0.22	0.41
QHerbi	Quantity of herbicides (kg/ha)	0.96	0.63	0.91	0.60		0.91	0.60
Yield	Yield (kg/ha)	1253.63***	225.71	836.13	258.60		896.59	274.71
GM	Gross margins (MAD/ha)#	3034.20***	926.41	2100.62	769.10		2390.61	814.41
ZTseeder	Number of ZT seeders per 10,000 ha of wheat area in each province	0.01	0.01	0.01	0.01		0.01	0.01
Ntill	Number of times the field was tilled	0.00***	0.00	2.26	0.01		2.13	0.82
ZT	Is field planted to ZT? (0 = No, 1 = Yes)	***120***		***1781***		120	0.06	0.24
ImpVar	Is field planted to improved wheat varieties? (0 = No, 1 = Yes)	***49***		***577***		626	0.33	0.47
Off-farm	Household head has off-farm employment (0 = No, 1 = Yes)	***21***		***298***		319	0.17	0.37

(Continues)

TABLE 1 (Continued)

Variable name	Variable	ZT = 1		ZT = 0		Entire sample		
		Mean values or count	Std. dev.	Mean values or count	Std. dev.	N^	Mean value	Std. dev.
SoilFertile	Soil in this field/plot is fertile (0 = No, 1 = Yes)	***80***		***1131***		1211	0.64	0.48
Favorable	Farm is in favorable zone (0 = No, 1 = Yes)	***46***		***655***		701	0.37	0.48
Intermediate	Farm is in intermediate zone (0 = No, 1 = Yes)	***39***		***535***		574	0.3	0.46
Herbi	Herbicide was applied on the field (0 = No, 1 = Yes)	***88***		***1321***		1409	0.741	0.438
Rot	Was legume-based rotation practiced on this field? (0 = No, 1 = Yes)	***74***		***549***		623	0.33	0.47***
Ftill	Was there a first round of tillage operation on the field? (0 = No, 1 = Yes)	***0***		***1781***		1781	0.94	0.29
Still	Was there a second round of tillage operation on the field? (0 = No, 1 = Yes)	***0***		***1601***		1601	0.84	0.50
Ttill	Was there a third round of tillage operation on the field? (0 = No, 1 = Yes)	***0***		***660***		660	0.35	0.48

^N indicates the number of cases with a "Yes" answer and ***bold-italic*** figures represent count values.
#The exchange rate in 2012 was 1US$ = 8.62 Moroccan Dirhams.
~235 farm households and their 395 wheat fields were excluded from this analysis because they lived in the irrigated areas of Morocco where ZT is not practiced.
***, **, * represent significant difference between adopters and non-adopters of ZT at 0.01, 0.05 and 0.1 levels, respectively.

TABLE 2 Full information maximum likelihood estimates of the endogenous switching regression model for yields and gross margin

Independent variables	Adoption of ZT (No = 0, Yes = 1)		Yield equation for adopters		Yield equation for non-adopters		Gross margin equation for adopters		Gross margin equation for non-adopters	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Age	0.034	0.214	−0.053	0.038	0.008	0.018	0.051	0.114	−0.005	0.041
Sex	0.068	0.230	0.023	0.035	0.017	0.021	−0.042	0.108	0.092	0.049*
Educ	0.144	0.158	0.019	0.028	0.001	0.013	0.001	0.084	0.029	0.029
ImpvVar (0 = No, 1 = Yes)	−0.077	0.143	0.288	0.025*	0.384	0.012*	0.411	0.076*	0.450	0.028*
WArea	−0.020	0.075								
QN			0.000	0.039	−0.003	0.006	0.107	0.117	−0.014	0.013
QDAP			0.087	0.018*	0.050	0.004*	0.017	0.054	0.058	0.009*
QSeed			0.023	0.032	0.071	0.012*	0.238	0.097*	0.049	0.027*
Labor			−0.006	0.042	0.054	0.012*	−0.160	0.128	0.038	0.027
QHerbi			0.012	0.023	−0.008	0.011	−0.027	0.069	−0.160	0.026*
QPesti			0.004	0.022	0.012	0.013	0.067	0.068	−0.074	0.029*
NZTseeders	0.102	0.022*								
RF	2.202	0.267*	0.585	0.090*	0.112	0.015*	0.677	0.301*	0.128	0.036*
Rot	0.561	0.111*	0.021	0.025	0.073	0.010*	0.182	0.085*	0.184	0.022*
Livestock			−0.003	0.019	−0.056	0.009*	0.020	0.058	−0.059	0.021*
Constant	−15.15	1.872*	3.267	0.662*	5.248	0.131*	2.413	2.216	6.330	0.307*
Rho			0.129	0.423	−0.238	0.094*	−0.008	0.442	−0.276	0.096*
Sigma			0.091	0.007*	0.174	0.003*	0.275	0.018*	0.400	0.007*
Wald test chi−square			2781.3*				896.77*			
LR test of indep. eqns			380.86				−1262.24			

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

4 | RESULTS AND DISCUSSION

The likelihood ratio test for the joint independence of the three equations (Table 2) shows that they are interdependent with each other. The significant correlation coefficients (rho) for both adopters and not adopters also suggest the existence of endogeneity and the problem of self-selection. In other words, the decision to adopt and the impact of ZT on yield, given the adoption decision, are influenced by both observed and unobserved factors. The correlation coefficient estimates are also negative for both adopters and non-adopters, indicating positive selection bias such that farmers with above average yield tend to decide to adopt ZT.

The instrument used in this article is the number of ZT seeders in each of the 21 provinces included in the study. Given that the analysis is at plot-level, we were not sure that the instrument was valid. Therefore, we followed Di Falco et al. (2011) and carried out a falsification test, which showed that the instrument has a positive and significant effect on the adoption decision but has no significant effect on yield and net returns of the non-adopters—thereby giving us confidence in validity of the instrument.

4.1 | Impacts on yield

Because the main objective of this study is to measure impact, results of the ESR are discussed only briefly. Coefficients of the key explanatory variables in the ESR model return important information. The difference in the coefficients of the explanatory variables in the outcome equations of ZT for adopter and non-adopter households illustrates the presence of heterogeneity in the sample (Di Falco et al. 2011).

Consistent with agronomic science, inputs such as DAP fertilizer, seed and labor have strong associations with productivity of the fields on which ZT is not adopted. Likewise, DAP fertilizer significantly affects crop productivity of the fields on which ZT is adopted.

The use of improved varieties and certified seeds also leads to higher yields relative to the use of local (and old improved) varieties and uncertified seeds for both fields on which ZT is adopted and not adopted—showing clear advantages to the use of both improved varieties and certified seeds, consistent with the findings of Yigezu et al. (2019).

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TABLE 3 Average expected treatment and heterogeneity effects of adoption of zero tillage on yield and gross margin from endogenous switching regression

Subsample effects	Decision stage and outcome: To adopt (n = 120)	Decision stage and outcome: Not to adopt (n = 1781)	Treatment effects	Percentage change
Yield (kg/ha)				
Farm households that adopted	1253.87 (a) (18.75)	955.31 (c) (18.01)	298.56* (11.08)	+31.25
Farm households that did not adopt	962.90 (d) (6.37)	837.11 (b) (4.78)	125.79* (3.47)	+15.03
Heterogeneity effects	290.97* (25.02)	118.20* (19.00)	172.797* (13.69)	+146.19
Gross margin (MAD/ha)				
Farm households that adopted	3032.11 (66.61)	2253 (58.01)	779.11* (32.08)	+34.58
Farm households that did not adopt	2208.32 (19.64)	2100.57 (16.43)	107.75* (11.04)	+5.12
Heterogeneity effects	823.79* (77.61)	152.43* (65.05)	671.36* (43.33)	+440.43

*, **, *** represent significance at 0.1, 0.05 and 0.01 levels, respectively.
Figures in parentheses are standard errors

Ownership of livestock has a negative effect on yield, which seems counterintuitive because manure from livestock is expected to increase yield. However, the results are indicative of the existence of overgrazing where the extraction of biomass is higher than what is returned to the soil as manure. Rotation results in a positive and significantly higher yield from the subsequent wheat crop, consistent with the ecological benefits of the faba-bean–wheat rotation and the findings of Yigezu et al. (2019).

Table 3 presents estimates of the expected wheat yield under actual and counterfactual conditions from the ESR model. Simple comparison of observed outcomes of adopters and non-adopters alone can be misleading because it suggests that on average the adopting households' wheat yield of 1254 kg/ha is 50% higher than that of the non-adopters. However, the correct comparison is between the observed outcomes for adopters (a) and the counterfactual case (c) (both in Table 3). This shows that by adopting the technology, the adopter farm households produce on average 298.6 kg/ha (23%) more than they would if they had not adopted. Similarly, comparing the expected wheat productivity in the counterfactual case (d) and observed outcome (b), by not adopting ZT technology, non-adopters forgo 125.8 kg/ha (13.06%) of wheat productivity. These results imply that ZT adoption significantly increases wheat productivity. In addition to the falsification test discussed above, we also estimate the treatment effect using inverse probability weights (*ipw*) as we wanted additional assurance on the validity of the instrument and hence the results. The results of the *ipw* estimation show that ATET is 291.8 kg/ha, which is comparable to the ATET from ESR of 298.6 kg/ha. Because some of the input quantities and other variables such as rotation that require farmers' decisions might still be endogenous, we carried out a robustness check using the *checkrob* command in Stata (Barslund, 2007) in which 256 variations of the model specification are analyzed. The results show that of all the 13 explanatory variables included into the selection and outcome equations, only education shows high variation in terms of significance and the other 12 variables are stable. Simulations for the treatment effects under several specifications show that ZT adoption indeed has significant positive effects. However, the treatment effects range, for example for yield, within 298.6–1027 kg/ha for adopters and 125.8–725 kg/ha for non-adopters. In view of the distribution of these results and results from other similar agro-ecologies (El-Shater et al., 2016), we argue that the results obtained using our choice specification can be considered the minimum gains to be realistically expected.

The results of the adjusted potential heterogeneity in the sample show that farm households who adopt would have a wheat productivity significantly higher than the farm households that do not adopt under both decision stages (i.e., under adoption and non-adoption scenarios). This highlights the existence of important sources of heterogeneity—i.e., adopters would obtain higher wheat yields than non-adopters irrespective of their adoption status. Nevertheless, farm households are still better off adopting than not adopting. This result is consistent with many studies that found that the introduction of zero or reduced tillage is associated with significant productivity and income gains (Erenstein et al., 2008; Jaleta et al., 2016; Krishna & Veettil, 2014; Krishna et al., 2016; Teklewold et al., 2013). The gains, however, seem to be higher in Morocco, possibly associated with the additional advantage of ZT in retaining residual moisture—most important in drylands.

At the current average adoption level of 0.3 ha/family, each adopter farm household produces about 89.53 kg more wheat per year. The total wheat area in the country (average for 2002–2011) is 2.91 million hectares. At the current national average adoption level of 7.13%, the adoption of ZT (regardless of whether it is proper ZT or skipping tillage by using conventional drills for that particular season) increases national wheat production by 0.09 million tons per year, accounting for only a small proportion (2.3%) of the total domestic supply of wheat in Morocco. If 75% and 100% of total wheat area in the country were not tilled, this should increase wheat supply by at least 24.19% and 32.25%, respectively.

4.2 | Impacts on gross margins

From the results of the FIML estimation of the ESR model, the Wald test is highly significant and indicates the goodness of fit of our ESR model. This implies there is an endogeneity problem justifying our use of the ESR model.

Because the main objective of this study is to measure impact, the ESR results are discussed only briefly. Rotation leads to significantly higher gross margins for the subsequent wheat crop. The adoption of improved varieties has a significant positive effect on net wheat income.

The estimates of treatment effects from ESR show that adopters of ZT obtain on average 779.1 MAD/ha or US$89.65/ha (25.7%)[1] higher net wheat income than they would for not adopting (Table 3). Were non-adopters to adopt ZT, they would earn 107.7 MAD/ha or US$12.52/ha (4.88%) more gross margin, showing that the benefit to those who adopted is higher, which may explain why they adopted while the non-adopters did not - showing a positive heterogeneity effect.

Given that 7.3% of wheat fields in the country are not tilled, this translates to a total national gain of about US$19.53 million dollars per year. Although the gain per unit area from adoption of ZT is high, the low adoption of ZT has undermined the country's ability to fully tap into the benefits of the technology.

4.3 | Impacts on risk and variability of yields

In moisture-stressed areas, ZT is believed to have the added advantage of retaining soil moisture and hence not only reducing the risk of low yields (especially in drought conditions) but also enhancing yield stability. Therefore, we generated the second central moment as an indicator of the variance of yield and the third moment as an indicator of downside risk exposure. The ESR results for both yield variance and downside risk are reported in Table 4. In the interest of space, discussion of the ESR results is omitted here. The treatment effects from ESR show that non-adopters of ZT face 730% higher risk of obtaining below-average yield levels than those who adopted (Table 5). This is consistent with the results of the stochastic dominance criterion, which also shows that the fields that are not tilled are associated with 100% and 65.6% reductions in the risk of obtaining yield levels below 500 and 1000 kg/ha, respectively. The ESR results also show that adoption of ZT leads to an 87% reduction in variance of yield, i.e., ZT helps obtain stable yields. Therefore, together these results show that adoption of ZT leads to higher and more stable yields with lower risk of obtaining below-average yields—all desirable outcomes, especially in drylands.

4.4 | Impacts on consumption

As the test of endogeneity fails to reject the null hypothesis of existence of endogeneity, we conclude that endogeneity is not an issue and hence we use OLS. Total wheat area, number of years of education, improved varieties and rotation have significant positive effects on wheat consumption compared to age of farmers, quantity of nitrogen, amount of labor used and ownership of livestock with significant negative effects (Table 6). The results show that, at household level, adopters of ZT consume on average about 6 kg/capita/year (10.1%) more wheat from their own production than the counterfactuals. Available estimates show that average food energy consumption for Morocco was 3260 kilocalories per capita per day for 2006–2008 (FAOStat, 2010). Assuming that the energy consumption did not change until 2012 and taking the average energy per kilogram of wheat as 3390 kilocalories, the additional 6 kg/capita/year of wheat consumed by adopters of ZT in Morocco translates to 55.7 kilocalories/capita/day, representing about 1.72% of total daily caloric intake.

4.5 | Impacts on labor use

Apart from the ecological benefits, the main socio-economic rationale for adoption of ZT is reduction of costs of production due to reduced tillage operations and hence reduced fuel and labor costs. Although the reduction in fuel cost is obvious, reduction in the amount and cost of labor inputs may not be straightforward. In this article, we check if adoption of ZT indeed leads to overall reduction in the amount of labor used. Our results show that ZT adoption has no significant effect on the total amount of agricultural labor used.

Exploring for possible reasons for this result shows that the literature presents problems of weeds as one of the greatest challenges associated with efforts to achieve wider diffusion of ZT, especially in the early years of its adoption. This is because intensive tillage has been historically used

[1] The exchange rate in 2012 was 1US$ = 8.62 Moroccan Dirhams

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TABLE 4 Full information maximum likelihood estimates of the endogenous switching regression model: Downside risk and variability of yield

Independent variables	OLS				ESR									
	Dependent variable (downside risk exposure)		Dependent Variable (variance)		Adoption of ZT (0 = No, 1 = Yes)		Downside risk exposure of yield for:				Variance of yield for:			
							Adopter households		Non-adopter households		Adopter households		Non-adopter households	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Adoption zero tillage (0 = No, 1 = Yes)	0.039	0.005***	−0.126	0.015***										
Age	−0.018	0.005***	0.029	0.015**	0.047	0.218	−0.043	0.012***	−0.018	0.005***	0.002	0.014	0.029	0.016*
Sex	−0.023	0.005***	0.071	0.017***	0.114	0.236	−0.039	0.012***	−0.023	0.006***	0.001	0.013	0.069	0.019***
Educ	−0.038	0.003***	0.130	0.010***	0.132	0.163	−0.050	0.009***	−0.038	0.003	0.005	0.011	0.129	0.011***
ImpvVar (0 = No, 1 = Yes)	0.065	0.003***	−0.229	0.010***	−0.055	0.147	0.081	0.008***	0.066	0.003***	−0.018	0.014	−0.233	0.011***
WArea					−0.017	0.073								
QN	−0.001	0.001	0.007	0.005			0.017	0.013	−0.001	0.001	0.041	0.014***	0.006	0.004
QDAP	−0.008	0.001***	0.037	0.003***			−0.016	0.006***	−0.008	0.001***	−0.017	0.006***	0.028	0.003***
QSeed	0.023	0.003***	−0.083	0.010***			0.021	0.011**	0.024	0.003***	0.000	0.012	−0.060	0.005***
Labor	0.012	0.003***	−0.046	0.010***			−0.012	0.014	0.014	0.003***	−0.035	0.015**	−0.038	0.005***
QHerbi	0.004	0.003	−0.024	0.009***			0.011	0.007	0.005	0.003	−0.001	0.008	−0.011	0.003***
QPesti	−0.013	0.003***	0.027	0.010***			−0.011	0.007	−0.013	0.003***	−0.009	0.008	0.008	0.003***
NZTseeders					0.102	0.022***								
RF	0.025	0.004***	−0.056	0.012***	2.299	0.281***	0.151	0.033***	0.020	0.004***	−0.037	0.023*	−0.106	0.013***
Rot	0.017	0.002***	−0.038	0.008***	0.569	0.113***	0.013	0.006**	0.016	0.002***	0.010	0.007	−0.050	0.004***
Livestock	−0.007	0.002***	0.054	0.008***			0.003	0.006	−0.008	0.002***	0.003	0.007	0.030	0.002***
Constant	−0.213	0.033***	0.854	0.108***	−16.61	1.970***	−0.762	0.233***	−0.199	0.035***	0.303	0.173*	1.020	0.103***
Adj R-squared	0.3		0.38											
Rho							−0.255	0.467	−0.229	0.083***	−0.214	0.310	0.072	0.151
Sigma							0.031	0.004***	0.046	0.001***	0.034	0.003***	0.151	0.003***
Wald chi-square							840.87***				1054***			
LR test of independence of equations							2841***				756.9***			

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

TABLE 5 Average expected treatment and heterogeneity effects on average expected downside risk exposure and variance of yield—ESR results

Subsample effects	Decision stage and outcome: To adopt (n = 120)	Decision stage and outcome: Not to adopt (n = 1781)	Treatment effects	Percentage change
Downside risk exposure				
Farm households that adopted	0.045 (0.003)	−0.008 (0.002)	0.053* (0.003)	+730
Farm households that did not adopt	0.026 (0.001)	−0.004 (0.001)	0.031* (0.001)	+410
Heterogeneity effects	0.070* (0.010)	0.004 (0.003)	0.066* (0.004)	+1650
Variance				
Subsample effects	To adopt (n = 120)	Not to adopt (n = 1781)	Treatment	
Farm households that adopted	0.021 (0.001)	0.166 (0.001)	−0.145* (0.013)	− 87
Farm households that did not adopt	0.043 (0.001)	0.171 (0.002)	−0.128* (0.002)	− 75
Heterogeneity effects	−0.022 (0.003)	−0.005* (0.010)	−0.017 (0.010)	− 240

*, **, *** represent significance at 0.1, 0.05 and 0.01 levels, respectively.
Figures in parentheses are standard errors.

TABLE 6 OLS regression on impact of zero tillage on consumption from own production, total labor used, and labor used for weeding

Independent variables	Consumption from own production (kg/capita/year): Coef.	Std. Err.	Total labor used: Coef.	Std. Err.	Weeding labor used: Coef.	Std. Err.
Zero tillage	0.101	0.022*	0.029	0.035	0.293	0.022*
Age	−0.043	0.022*	0.006	0.035	0.015	0.022
Sex	−0.032	0.026	0.081	0.040*	0.019	0.026
Educ	0.044	0.016*	0.003	0.024	−0.004	0.016
ImpvVar (0 = No, 1 = Yes)	0.419	0.015*	0.030	0.023	0.066	0.015*
WArea	0.453	0.008*	0.114	0.012*	0.079	0.008*
QN	−0.017	0.007*	0.320	0.008*	0.143	0.005*
QDAP	−0.002	0.005	−0.068	0.008*	−0.029	0.005*
QSeed	−0.004	0.015	0.038	0.023*	0.018	0.015
Labor	−0.040	0.015*	−0.018	0.022	−0.015	0.014
QHerbi	−0.014	0.014				
QPesti	0.015	0.016	0.046	0.024*	0.007	0.016
RF	−0.009	0.018	0.003	0.028	0.056	0.018*
Rot	0.146	0.013*	−0.023	0.019	−0.020	0.013
Livestock	−0.024	0.011*	0.014	0.018	0.012	0.012
Constant	3.639	0.163*	2.628	0.245*	0.583	0.159*

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

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TABLE 7 OLS regression on impact of different numbers of tillage on yield

Independent Variables	Impacts of different intensities of tillage (counterfactual is ZT)		Impact of frequency of tillage	
	Coef.	Std. Err.	Std. Err.	Std. Err.
Land was tilled only once (0 = No, 1 = Yes)	−0.224	0.018*		
Land was tilled only twice (0 = No, 1 = Yes)	−0.227	0.015*		
Land was tilled three times (0 = No, 1 = Yes)	−0.448	0.016*		
Number of times the field was tilled (tillage number)			−0.034	0.014*
Square of tillage number			−0.031	0.004*
Age	0.004	0.014	−0.003	0.015
Sex	0.022	0.017	0.020	0.017
Educ	−0.002	0.010	−0.005	0.011
ImpvVar	0.335	0.010*	0.324	0.010*
WArea	0.004	0.005	0.000	0.006
QN	0.006	0.005	0.004	0.005
QDAP	0.028	0.004*	0.033	0.004*
QSeed	0.047	0.010*	0.051	0.010*
Labor	0.023	0.010*	0.031	0.010*
QHerbi	−0.008	0.009	−0.007	0.009
QPesti	−0.003	0.010	0.002	0.010
RF	0.071	0.012*	0.076	0.012*
Rot	0.052	0.008*	0.061	0.008*
Livestock	−0.015	0.008*	−0.022	0.008*
Constant	6.091	0.111*	5.986	0.115*
Number of wheat fields	1901		1901	
Adjusted R-square	0.7395		0.7544	

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

as a weed control mechanism (Chauhan et al., 2012; Giller et al., 2009). To see if this is indeed the case in Morocco, we estimate another model to measure the impacts of adoption of ZT on the amount of labor used for weeding. Our results show that adopters of ZT on average use about (29.3%) more labor for weeding than the counterfactual (Table 6). This result is consistent with many studies that found that time and labor demands can increase by up to 50% under CA as a result of increased weed pressure (Haggblade & Tembo, 2003; Nyamangara et al., 2013).

4.6 | Reducing or illuminating tillage?

Given the challenges of weed control discussed above, which are potentially the main reasons for the low adoption of ZT, we considered whether reducing tillage can be an option in drylands. To shed light on this, we measure the impacts of each additional tillage on yield and other socio-economic outcomes. The data collected from the farmers concern the number of times the field was tilled. To measure the impact of each successive tillage relative to ZT and keeping in mind that the maximum number of tillage in the data is three, we systematically generate dummy variables for the first till as Ftill = 1 if number of tillage = 1, 2 or 3 and zero otherwise; for the second till as Still = 1 if number of tillage = 2 or 3 and zero otherwise; and the third till as Ttill = 1 if number of tillage = 3 and zero otherwise. Then, we run an OLS regression of yield on Firsttill, Still, Ttill and all other explanatory variables included in the previous regressions. We also run an OLS regression of yield on the number of tillage and its quadratic term. The results show that intensive tillage practices have significant negative effects on yield (Table 7).

A closer look into tillage intensity also shows that tillage has significant negative effects on all the socio-economic indicators considered, with the value of each indicator declining as the tillage frequency increases. For example, the first tillage reduces yield by 22.4%, while the cumulative effects of the second and third tillage are yield losses of 22.7% and 44.8%, respectively, showing that the effect of the second tillage has negligible effect but that of the third tillage (which takes place along with planting) has almost the same effect as the first tillage.

We also perform an ESR estimation to measure the impacts of different intensities of tillage. There is a clear

TABLE 8 FIML estimates of the endogenous switching regression model for yield when the land is tilled at different intensities

Independent variables	Adoption of only one or zero tillage (0 = No, 1 = Yes)		Yield equation for adopters of only one or zero tillage		Yield equation for non-adopters of only one or zero tillage		Adoption of two or less tillage (0 = No, 1 = Yes)		Yield equation for adopters of two or less tillage (including ZT)		Yield equation for non-adopters of two or less tillage (including ZT)	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Age	0.323	0.164*	−0.002	0.019	−0.030	0.041	−0.044	0.135	−0.004	0.019	0.001	0.019
Sex	0.110	0.168	0.014	0.023	0.040	0.036	0.185	0.177	0.014	0.021	0.042	0.028
Educ	0.250	0.118*	−0.007	0.013	0.000	0.030	0.059	0.094	0.000	0.014	−0.001	0.013
ImpvVar (0 = No, 1 = Yes = 1)	0.464	0.103*	0.392	0.013*	0.251	0.031*	0.575	0.094*	0.332	0.016*	0.340	0.020*
WArea	0.161	0.053*					0.168	0.051*				
QN			−0.005	0.006	0.036	0.014*			0.026	0.007*	0.003	0.005
QDAP			0.049	0.004*	0.048	0.011*			0.046	0.006*	−0.002	0.004
QSeed			0.063	0.012*	0.089	0.030*			0.076	0.013*	−0.005	0.012
Labor			0.057	0.012*	−0.008	0.024			0.009	0.013	−0.010	0.014
QHerbi			−0.006	0.012	−0.002	0.024			−0.008	0.012	−0.009	0.012
QPesti			−0.002	0.013	0.107	0.025*			0.041	0.013*	−0.095	0.014*
NZTseeders	0.025	0.010*					0.000	0.000				
RF	1.428	0.156*	0.084	0.017*	0.438	0.066*	0.938	0.108*	0.207	0.023*	−0.062	0.027*
Rot	0.181	0.082*	0.074	0.010*	0.056	0.020*	0.281	0.077*	0.091	0.011*	0.006	0.014
Livestock			−0.064	0.009*	0.009	0.020	0.01	0.01	−0.017	0.011	−0.019	0.009*
Constant	−11.35	1.172*	5.480	0.146*	3.603	0.556*	−5.327	0.829*	4.884	0.189*	6.862	0.174*
Rho			0.377	0.228	−0.195	0.100*			0.386	0.122*	−0.202	0.270
Sigma			0.159	0.013*	0.172	0.003*			0.162	0.005*	0.111	0.005*
Wald chi-square	705.71*						705.71*					
LR test of indep. eqns	−16.66						−38.68					

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

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TABLE 9 Average expected treatment and heterogeneity effects of different tillage intensities on yield from endogenous switching regression

Subsample effects	Decision stage and outcome: To adopt (n = 120)	Decision stage and outcome: Not to adopt (n = 1781)	Treatment effects	Percentage change
Only one or zero tillage (counterfactual two or more tillage)				
Farm households that adopted	1123.27 (14.74)	897.85 (17.82)	225.42* (9.25)	+25.11
Farm households that did not adopt	897.85 (4.71)	812.41 (4.74)	85.44* (2.79)	+10.51
Heterogeneity effects	225.42* (4.84)	85.44* (18.84)	139.98* (11.04)	+163.83
Two or less (including zero) tillage (counterfactual is three tillage)				
Subsample effects	To adopt (n = 120)	Not to adopt (n = 1781)	Treatment effects	
Farm households that adopted	979.46 (17.42)	698.44 (15.82)	281.02* (8.23)	+40.24
Farm households that did not adopt	735.10 (5.19)	665.14 (5.21)	69.95* (2.56)	+10.52
Heterogeneity effects	244.36* (20.51)	33.3* (20.52)	211.07* (10.12)	+633.84

*, **, *** represent significance at 0.1, 0.05 and 0.01 levels, respectively.
Figures in parentheses are standard errors.

grain yield difference between soil tillage treatments when using fields tilled three times as counterfactual (Table 8). The corresponding figures of treatment effects from ESR estimation of the model (Table 9) show that tilling a field two or less (including zero) times will increase yield by 41.5% compared with tilling three times, but tilling only once or not tilling at all will increase it 23.8% compared with tilling the field two or more times. This result is consistent with other studies that found that tilling the soil, even once, may reduce the benefits of CA (Anderson, 2015).

5 | CONCLUSIONS

This article used a nationally representative sample of 1901 wheat fields cultivated by 1230 farm households drawn using a multi-stage sampling procedure from the wheat-based production systems in Morocco to provide estimates of adoption and impacts of ZT. Using wheat areas on farms and the different administrative levels as weights for upward aggregation, we found that 7.13% of the Moroccan wheat fields were not tilled during the 2012/2013 production season. Results from an ESR model showed that farm households that actually adopted would have obtained about 298.6 kg/ha (23%) higher yields, US$89/ha (27%) higher net wheat income, more stable yields and 10% lower downside risk with 100% and 65.6% less risks of giving yield levels below 500 and 1000 kg/ha, respectively, compared to not adopting. Likewise, if they adopted ZT, farm households that did not adopt would have obtained about 125.8 kg/ha (13.06%) more yield and US$12.52/ha (4.88%) more income. We also found a positive TH effect, implying that the impact of ZT on wheat productivity was significantly higher for those who already adopted ZT than those who did not adopt.

Given that 7.13% of wheat fields in Morocco were not tilled during the survey year, our estimates showed that the country benefited from an additional annual wheat production of only 0.09 million tons, representing only a small proportion (2.3%) of the total domestic supply of wheat. It also led to an increase in total national gain of about US$19.53 million dollars per year. Adopters of ZT were found to consume 6 kg (10.1%) more wheat per capita per year compared to continuing with conventional tillage.

The estimates of labor for weeding showed that adopters of ZT on average used about (29.3%) more labor for weeding than the counterfactual. Given that Moroccan farmers currently use herbicides and manual weeding, these results indicate the importance of introducing more effective alternatives for weed control to replace these methods if CA in general and ZT in particular are to be options for smallholder farmers in North Africa.

A closer look into tillage intensity showed that tillage had significant negative effects on grain yield, with each economic indicator declining as the frequency of tillage increased. For example, the first tillage reduced yield by 22.4% but the second had negligible effects on yield. The third tillage carried at the time of planting, however, led to almost the same yield loss as for the first tillage.

Along with the biophysical benefits documented in the literature, all these results provide economic justifications for the efficacy of ZT, and that its wider adoption has potential to improve productivity, profitability and sustainability of agricultural production in Morocco and other similar countries with dryland agriculture. From a policy perspective, our results suggest that Morocco and other similar countries would benefit if they embrace ZT as one of the cropping technology-packages in their national extension programs priorities for dry areas and develop policies which overcome limitations to its adoption.

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