Soil & Tillage Research 212 (2021) 105067

Contents lists available at ScienceDirect

Soil & Tillage Research

journal homepage: www.elsevier.com/locate/still

Can an incremental approach be a better option in the dissemination of conservation agriculture? Some socioeconomic justifications from the drylands of Morocco

Yigezu A. Yigezu [a,*], Tamer El-Shater [b], Mohamed Boughlala [c], Mina Devkota [d], Rachid Mrabet [c], Rachid Moussadek [d]

[a] *International Centre for Agricultural Research in the Dry Areas (ICARDA), Egypt*
[b] *International Centre for Agricultural Research in the Dry Areas (ICARDA), Syria*
[c] *Institut National de la Recherche Agronomique, (INRA), Morocco*
[d] *International Centre for Agricultural Research in the Dry Areas (ICARDA), Morocco*

ARTICLE INFO

Keywords:
Conservation agriculture
Incremental approach
Impact
Ordered probit
Endogenous switching regression
Morocco

ABSTRACT

Despite several efforts for its dissemination, adoption of conservation agriculture (CA) in the Middle East and North Africa (MENA) region is low – causing some to wonder if an incremental approach for adoption of its three components would prove more effective. In this paper, we apply the endogenous switching regression model to a nationally representative sample of 1901 wheat fields in Morocco to analyze the impacts of partial or full adoption of all three components of the CA system. We also employ an ordered probit model to identify the determinants of partial and full adoption of CA. Model results show that adoption of the complete CA system leads to 307 kg/ha (35 %) higher yields, US$99/ha (44 %) higher gross margins, and 23 kg/capita/year (38 %) more consumption of wheat relative to the conventional system. Our results also show that adoption of only two principles of the CA system leads to higher benefits in all the livelihood indicators listed above compared to adoption of only one or none of the principles. Likewise, adoption of only one principle is more beneficial than the conventional system. Along with biophysical and environmental benefits documented elsewhere, our results demonstrate that the CA system can provide large economic, social, and food security benefits both at individual household and national levels. Therefore, wider diffusion of the full CA system involving zero tillage (ZT), crop rotation, and crop residue retention has potential to sustainably improve the viability of agriculture in the drylands of Morocco and other similar countries in the MENA region. Given that the CA system is complex and knowledge-intensive, transition from the conventional system to CA requires the following: (1) flexibility to let farmers incrementally adopt one or more of the CA components, learn at their own pace, use some of the benefits, and improve it over time to exploit the full potential of the CA system with close follow-up and technical support from experts and extension specialists; and (2) sustained policy and institutional supports that provide incentives for farmers to adopt and for the private sector to be actively involved, especially in service provision.

1. Introduction

Conservation agriculture (CA) is a sustainable agricultural production system based on three interlinked principles applied in a mutually reinforcing manner: (i) continuous non-disturbance of soil, (ii) maintenance of permanent soil cover (mulch), and (iii) crop diversification in space and time (Dumanski et al., 2006; Hobbs et al., 2008; Kassam et al., 2020). Recently, CA has received considerable attention as a form of regenerative agriculture as well as climate-smart and adaptive agricultural system (Kassam and Kassam, 2020). In the last two to three decades, there have been several national and international efforts to promote CA throughout Africa and Asia under the assumption that it could revert soil degradation (Giller et al., 2011; Mrabet et al., 2012; Ngwira et al., 2013; Thierfelder et al., 2014). Despite all these efforts, adoption of CA in Asia and Africa is quite low compared to North and South America and Australia (Kassam et al., 2017).

The low adoption of CA in the developing world is partly attributed to its complexity, coupled with insufficient knowledge and capacity of

* Corresponding author at: 2 Port Said, Victoria Sq, Ismail El-Shaaer Building, Maadi, P.O. Box 11711, Cairo, Egypt.
E-mail address: y.yigezu@cgiar.org (Y.A. Yigezu).

https://doi.org/10.1016/j.still.2021.105067
Received 23 December 2020; Received in revised form 29 April 2021; Accepted 3 May 2021
Available online 13 May 2021
0167-1987/

farmers (Bonzanigo et al., 2016; Lahmar, 2010; Li et al., 2011). In this paper, we argue that although the ultimate goal should be full adoption of the CA system, an incremental approach where the "must-have" component(s) of the CA system is(are) defined and recommended but not imposed, at least for the first few years, will be more effective in promoting CA. Such an approach, we argue, will allow farmers to gradually learn, adapt to, gain experience, and incrementally use the benefits of the system – ultimately motivating them to adopt additional components one at a time toward full adoption. A good example is a project funded by the Australian Government which made zero tillage (ZT) the only mandatory component while allowing Syrian and Iraqi farmers to choose the other components they wanted to add. As a result, unlike prior efforts, the project succeeded in increasing adoption of ZT in Syria to 15 000 ha in three years (until the country was destabilized) with similar success stories in Iraq (Loss et al., 2014; Yigezu et al., 2018a). It is important to note that given the high initial investment requirement for a ZT seeder, the project's innovative approach to create a mechanism that allowed farmers to try ZT at low cost and minimum risk also contributed to the enhanced adoption (Yigezu et al., 2018a).

Both supply and demand side factors contribute to the low adoption of CA. These include the following: lack of appropriate targeting in the face of heterogeneity of farmers; lack of adequate demand for some or all components of the innovation; ineffective policy and institutional incentives for active participation of the private sector; lack of capacity of the private sector to manufacture affordable and locally adapted ZT seeders; socioeconomic, cultural and biophysical barriers such as lack of economic incentives to rotation; trade-offs between the use of residue for mulch and feed; challenges related to pest, disease, and weed control; unfavorable farmer perceptions; and poorly developed markets (Andersson and D'Souza, 2014; Darnhofer et al., 2005; Dessart et al., 2019; Kieninger et al., 2018; Knowler and Bradshaw, 2007; Kutter et al., 2011; Mrabet, 2011a; Mrabet et al., 2012; Thierfelder et al., 2015). Particularly in drylands, livestock play a central role in livelihoods of society; hence the trade-offs between the use of crop residues as animal feed and mulch for soil quality improvement may be one major constraint to promotion of CA (Bonzanigo et al., 2016; Valbuena et al., 2012). Ill-conceived cereal intensification policies driven by the food security agenda also inadvertently promoted monocropping in the Middle East and North Africa region (MENA) thereby reducing the incentive for legume-based rotations (Yigezu et al., 2019b).

The low adoption of multi-component technologies and the challenges involved in their promotion has led experts (e.g., Pannell and Claassen, 2020) to suggest that piecemeal or ladder approaches, which involve starting with one component and gradually adding the others, would be appropriate. However, some studies have documented that such approaches may not be applicable. For example, Thierfelder et al. (2018) provided evidence from Southern Africa that a ladder approach would not be beneficial for promoting CA because adoption of only one of the components of CA may be detrimental. Following the adoption model of Rogers (2003), Thierfelder et al. (2018) recommend starting on a small area with the full CA package and gradually increasing this to cover the whole farm as a viable approach.

In this paper, we define a new approach called "an incremental approach," in which farmers are encouraged not only to follow the ladder approach in which they start with only one component and gradually add other components, but also to adopt any of the technology components at a level at which they are comfortable. In the context of CA, this could mean that farmers can start by reducing tillage passages from three to two, or to one, or if they feel comfortable, to jumpstart ZT; and/or breaking cereal monocropping by including other cereals and ultimately legumes into the rotation once every 5 to 2 years; and/or start leaving some portion of crop residues (10 %, 20 %, …, 100 %) in the field. We argue that such an incremental approach may prove effective for promoting CA in MENA.

In this paper, we use data from Morocco to explore the availability of sufficient justifications supporting the argument that the incremental approach can be effectively used for the dissemination of CA in the drylands of MENA. This will however have to be done with expert guidance to avoid experiments that are known to be detrimental. Although this might be a viable strategy in terms of enhancing adoption, given the interlinked and complementary nature of the three components of CA, such an approach might involve some trade-offs in the socioeconomic and biophysical outcomes. Therefore, analysis comparing the impacts of adopting varying levels and intensities of the different combinations of the three CA principles is warranted.

Most previous studies ignore the fact that the three pillars of CA are interrelated and interdependent and can be influenced by factors relating to their possible complementarity and substitutability (Aryal et al., 2018). What farmers practice may therefore be quite different from the ideal CA developed in on-station trials, thus it is less certain what benefits are being realized by farmers (Bolliger et al., 2006). 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, and socioeconomic drivers may affect a farmer's decision to adopt CA (Lahmar, 2010; Wall, 2007).

Although CA systems mostly lead to yield increases, a meta-analysis by Zheng et al. (2014) showed large variations in yield outcomes with some cases of yield losses. For example, Pittelkow et al. (2015) argue that the initial tillage mobilizes nutrients from organic matter which does not happen under no-tillage giving an advantage to tillage. There is also some evidence for the benefits of adopting only some of the CA components relative to the conventional system. The adoption of ZT without rotation and mulching is generally associated with grain yield advantage relative to conventional tillage, especially in drylands (El-Shater et al., 2016; Jaleta et al., 2016). Some studies have also established that rotation has socioeconomic benefits even without adopting the other components of CA (Abawi and Widmer, 2000; Kirkegaard et al., 2008; Yigezu et al., 2019b). Particularly, rotation using grain legumes in cereal-based systems has great ecological benefits. The legumes are used as break crops for cereals (Amanuel et al., 2000; Lopez-Bellido et al., 2006) and have the potential to enhance soil nitrogen (N) for the subsequent crop (Habtemichial et al., 2007; Nuruzzaman et al., 2005). Rotation also increases the bioavailability of phosphorus (Ben Zekri et al., 2018; Jemo et al., 2006; Nuruzzaman et al., 2005; Pypers et al., 2007), enhances favorable biomes in the rhizosphere (Marschner et al., 2004; Yusuf et al., 2009), and breaks soil-borne disease cycles (Jensen et al., 2010; Peoples et al., 2009). Legumes can also improve the economic value of subsequent cereal crops by enhancing their yields and protein contents (Ruisi et al., 2017; Yigezu et al., 2019b). Residue retention reduces surface run-off, improves rainwater infiltration, and suppresses and controls weed growth (Giller et al., 2009; Hobbs, 2007; Moussadek et al., 2011; Mupangwa et al., 2007; Thierfelder and Wall, 2009).

The economic benefits of adoption of the full CA system have been widely documented (Kassam, 2020; Mrabet et al., 2012). It however remains unanswered if partial adoption of different combinations of only one or two of the three components of CA would also lead to higher socioeconomic benefits than the conventional system. This paper provides an analysis of the grain yield, gross margin, wheat consumption, and downside risk impacts of the adoption of only one, two, and all three components of CA relative to the conventional systems among wheat producers in Morocco. By doing so, the paper tries to provide empirical evidence that supports the idea of potential advantages of an incremental approach for promoting CA in Morocco. The findings will be useful in drawing important lessons, guiding future research, informing development agents and agencies that aim to promote CA as sustainable agricultural system, and to provide credible evidence for national priority setting and policy decisions on extension service delivery systems in Morocco and other similar countries in the MENA region with drylands.

2. Status of CA in Morocco

In Morocco, the National Institute of Agricultural Research (INRA) started a research project on CA in 1982 with the aim of revising tillage systems to ensure simultaneous amelioration of crop production, water conservation and use efficiency, and soil quality in rainfed dry areas. This project was reinforced by other CA research activities led by other national partners. Over the last three decades, several on-station and on-farm experiments on CA were conducted in different agroecosystems of Morocco, with the results documented in Mrabet et al. (2012). Promotion of CA in Morocco started in the 1990s when INRA and other research and development organizations started demonstrating to farmers that the introduction of CA would bring more stable yield, reduce production costs, reduce soil erosion, increase soil water conservation, improve soil quality, and reduce CO_2 emission (Moussadek et al., 2011, 2014; Mrabet, 2011b; Mrabet et al., 2012).

Mrabet et al. (2012) argue that reduction of costs in machinery and fuel, timesaving in operations, yield gains, and greater yield stability are the main drivers of CA adoption in dry areas of Morocco. Although adoption of CA is often associated with lower yields, especially in regions with high precipitation, several studies in dry areas have consistently shown that adoption of one or more of the CA components leads to higher and more stable yields. The main explanations are that in the moisture-stressed dry areas, ZT and residue retention enhance soil moisture retention and rotation enhances soil N – both leading to higher and more stable yields (Loss et al., 2014). Therefore, CA stands out as a viable solution to sustainably satisfy food requirements of the Moroccan population over the coming decades (Badraoui and Dahan, 2010). Lower risks are also an important advantage, especially for small landholders (Magnan et al., 2011). Adoption of CA can also reduce drudgery and permit the release of labor, leading to other economic and social benefits including leisure because it creates more spare time, especially for smallholder farmers.

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 (Bonzanigo et al., 2016; El Gharras et al., 2017; Mrabet et al., 2012). Different sources estimate the adoption of CA in Central Morocco at a meager 1% (less than 20,000 ha) (FAO, 2017; World Bank, 2014), with similar situations in neighboring Algeria and Tunisia (Kassam et al., 2017). There are several hypotheses for such low adoption: (1) farmers are not yet convinced about the benefits of the CA system due to high risk of reduced yields in initial years; (2) existence of biophysical disadvantages due to mismanagement of CA principles; (3) presence of social, economic, and mindset barriers; (4) insufficient capacity development, communication, and outreach; and (5) lack of incentives for adoption even when farmers are willing.

Because Moroccan wheat farmers have adopted various combinations of the three components of CA, this paper attempts to provide credible estimates on the level of adoption and the farm-level benefits associated with partial and full adoption of CA. The paper also tries to analyze the determinants of partial or full adoption of CA, thereby generating the information necessary for developing an effective strategy and an inclusive adoption roadmap to overcome the challenges of disseminating CA.

3. Data

Data for this study come 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 agroecological zones in the country where wheat is currently produced: the favorable, intermediate, unfavorable south, and mountainous zones.

We disclose that the data used were collected for determining the extent of adoption and impacts of improved wheat varieties in Morocco. Therefore, some potentially useful information for analysis of impacts of CA such as reasons for not adopting or abandoning ZT, despite its benefits, was not collected.

Using power analysis, the minimum sample size required to ensure 95 % confidence and at least 2.5 % precision levels for capturing the adoption of improved wheat varieties of up to 75 % (the ex-ante estimate by experts) is determined to be 1151 households. 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) is drawn for this study using a stratified sampling approach in which provinces, districts, and villages represent strata. The total sample is distributed proportionally across 292 villages distributed across 56 districts randomly drawn from the 21 study provinces. As ZT was not promoted and hence not practiced in any of the irrigated wheat fields, all 391 irrigated wheat fields in the sample are dropped from this analysis because the lack of variation in adoption in the irrigated regions would not allow any useful lesson to be drawn. Therefore, this analysis is based on data from 995 households and their 1901 wheat fields, all in rainfed areas (Table 1).

Structured survey questionnaires were used to collect demographic, economic, social, and consumption data. The first part of the questionnaire comprised several household-level questions including demography, different forms of capital (human, social, financial, physical, and natural resources), the farmer's knowledge of the different wheat varieties and recommended agricultural practices, and location. The second part of the questionnaire contained detailed field-level questions including field size, soil type, previous crop, wheat variety used in the current year, number of tillage passages before seeding, seed source, seed rate, access to irrigation, quantities and prices of inputs used (labor, fertilizers, pesticides, and herbicides), and prices received for the outputs (grain and straw).

There are two major caveats with the data. (1) Inadvertently, we only asked farmers whether they tilled the field during the survey year or not. After completion of the survey, we learned that in Morocco, some farmers skip tillage for only one crop season by using conventional drills under dry conditions. As a result, we do not know whether those who answered "yes" to ZT during the survey are true adopters of ZT or if they are simply skipping tillage only for this season. (2) In the sample, we found only 120 fields that were not tilled during the survey year. A closer look at the data revealed that rotation and crop residue were practiced in only 26 of them, leaving us with little statistical power to make econometric analysis using the conventional definition of ZT and CA. However, there were 180 fields in the sample that were tilled only once during the season. Out of the 180 fields on which one tillage pass was practiced, 49 also practiced rotation and residue retention. Owing to the data problem associated with the presence of only a small number of adopters of the full CA package in the strict sense of the term, we define "reduced tillage (RT)" as a practice of not tilling the land or practicing only one tillage passage using conventional drills during the survey year. For the purpose of this study, the loose definition of RT (instead of ZT) is used to analyze its potential benefits during the transition phase toward complete adoption of CA. Therefore, in the rest of this paper, adopters of RT are treated as adopters of a CA tillage principle and adoption of the full CA package is understood as the adoption of RT along with rotation and crop residue retention. Partial adoption is understood as the adoption of one or two of the three main principles of CA. By doing so, we increase the number of fields in the sample on which all three components are practiced from 26 to 65. It is important to note that some of the fields classified as RT may not have been tilled for a long period, thereby qualifying as "proper" ZT; the majority are more likely fields on which tillage was skipped only for the year in reference. The results of this analysis related to tillage will therefore have to be understood as being the minimum benefits to be expected from the full (long-term) or partial (including skipping tillage only for one or more

Table 1
Statistics on wheat area and number of farmers and distribution of sample households across the 21 Provinces in Morocco.

Region	Province	Wheat area (in 1000 ha), average for 2002–2011	Total number of wheat growers in 2011 (in 1000)	Sample statistics			
				No. of districts	No of villages	Number of Households	Number of fields (or plots)
Chaouia-Ouardigha	Benslimane	80.37	13.92	3	10	22	35
	Berrechid	90.39	20.70	2	13	43	92
	Settat	175.47	40.19	3	33	80	148
Doukkala-Abda	El Jadida	92.98	64.08	3	16	45	99
	Sidi Bennour	82.46	56.82	2	17	14	31
	Safi	148.33	63.25	3	19	98	170
Fes-Boulemane	Fes	12.94	3.64	1	1	8	12
	Moulay Yacoub	86.57	24.34	2	7	69	150
Gharb-Chrarda-Bni	Kenitra	85.97	30.66	3	17	21	40
	Sidi Slimane	21.42	7.67	1	8	7	9
	Sidi Kacem	177.53	44.40	5	22	42	74
Marrakech-Tensift-Alhaouz	El Kelaa	73.68	20.33	2	12	24	52
	Rehamna	149.59	41.27	2	12	63	168
Meknès-Tafilalet	El Hajeb	58.83	9.02	3	7	16	32
	Khenifra	104.34	28.05	2	11	57	115
	Meknes	76.27	13.73	1	11	20	43
Rabat-Salé	Khemisset	157.2	32.67	3	22	27	56
Tadla-Azilal	Beni Mellal	190.68	46.06	3	7	64	125
Taza-Alhoceima-Taounate	Taounate	183.26	61.16	1	22	155	270
	Taza	82.54	39.24	1	12	107	144
	Guercif	20.63	9.81	2	6	13	36
Total Sample		2,151.45	671.01	48	285	995	1901
Total National		2,909.97	Not available				
Sample as % National Total		73.9%					

seasons, reducing tillage passes from three to two or one for one or more seasons) adoption of ZT. Descriptive statistics generated using the data from the sample survey show that the characteristics of the Moroccan wheat farmers vary substantially. In the sample, the youngest household head is 24 years old while the oldest is 85 with a mean age of 59 and standard deviation of 13. In terms of land holding, the smallest farm cultivates only 0.2 ha while the largest cultivates over 600 ha, with an average of 12.5 ha. Similarly, the range of area under wheat is 0.1–404 ha, averaging 3.86 ha. The typical farmer has only 2 years of education and 17 % of the households have income from off-farm employment. About 32 % of the farm households own livestock and out of the 995 sample households, only 50 (5%) are female headed. The average N and diammonium phosphate (DAP) fertilizer application rates for wheat are only 20 kg/ha, with most fields cultivated without N and DAP fertilizers and maximum application rates are 100 and 45 kg/ha, respectively. The descriptive statistics on selected farm, farmer, and household variables are provided in Table 2.

4. Methodology

4.1. Explaining farmers' propensity for adoption

Conservation agriculture is a complex system that involves the application of different mutually reinforcing biophysical and socioeconomic components. Hence, when analyzing CA adoption, researchers face the problem of defining criteria that can be accepted by all experts for the classification of farmers into the adopter and non-adopter groups. In practice, many farmers will adopt only part of the package, applying some components of CA practices on their farms, while leaving out the others. To circumvent this problem, we chose the number of CA practices adopted as the dependent variable in our model. Therefore, with slight modification, we follow Namuyiga and Bashaasha (2019), and Wollni et al. (2010) to classify the sample farmers into four categories: the benchmark or base category which represents farmers who do not use any of the CA principles; partial adopters type 1 comprising farmers who use only one component of CA, i.e., RT, rotation, or residue retention; partial adopters type 2 comprising farmers using only two of the three CA components; and finally full adopters of CA which is the set of farmers adopting all three CA components, i.e., RT, residue retention, and crop rotation.

When the possible outcomes of the dependent variable, such as the use of a variety, are only two (e.g., yes or no), the probit model (Bliss, 1934) is widely used to identify the determinants of the decision to use. In this paper, we try to explain the adoption of CA which involves more than two components. Given that the dependent variable, the number of CA components adopted, is an ordinal variable (a dependent variable for which the potential values have a natural ordering, as 1, 2, 3, …) where, theoretically, the benefits are expected to increase with the number of components adopted, the ordered probit (OP) is appropriate to model the differential adoption of CA and identify the determinants (Bogdan and Bilken, 2007; Greene, 2008; Namuyiga and Bashaasha, 2019). In statistics, OP is a generalization of the probit model to the case of more than two possible outcomes of an ordinal dependent variable. In the interest of space and to spare non-economist readers from discussions of the complex mathematical model, a detailed discussion of the OP model is provided as supplementary material in Section 1.1 of Annex I.

4.2. Measuring impacts of adoption

Economic benefits of new agricultural technologies come from higher yields and/or lower costs, both of which contribute to lower per-unit cost of production. Statistical identification of the effect of an adopted technology using observational data collected from farmers is a known challenge because adoption is a choice and the evaluation must consider multiple sources of confounding. To overcome this problem, we employ a multivariate analysis in which any of the outcome variables Y (yield, gross margins, wheat consumption, or downside risk exposure) are regressed on a binary variable T (taking a value of 1 if the farmer adopted CA and 0 otherwise) and other household, farm, and farmer characteristics X including input quantities as follow:

$$Y = \theta + \alpha T + \gamma X + \varepsilon \tag{1}$$

Because the adoption decision T is a binary variable, it can be estimated as a function of explanatory variables Z (including some or all of the variables X in Eq. 1) using a probit model as follows:

Table 2
Summary statistics for selected variables.

Variable name	Variable	CA[v] = 1		CA = 0		Entire sample		
		Mean values or count	Std. dev.	Mean values or count	Std. dev.	N[ˆ]	Mean value	Std. dev.
	Variables derived from household-level data (N = 995)							
Age	Age of household head (years)	59.52	13.43	59.36	13.59		59.37	13.58
Educ	Education of household head (years)	2.42***	0.96	1.85	0.85		1.87	0.86
Sex	Household head is female (0 = No, 1 = Yes)	***2***	***0.25***	***48***	***0.22***	50	(0.05)	0.22
TArea	Total cropped area including all wheat fields and fields under other crops (ha)	9.30	10.32	13.51	13.36		13.38	32.89
WArea	Total area in all wheat fields cultivated by the farm in the study year (ha)	5.32	8.12	3.02	14.08		3.85	11.81
Cons	Household consumption of wheat from own production (kg/capita/year)	87.30***	27.70	57.24	31.07		58.18	31.40
Livestock	Household owns livestock (0 = No, 1 = Yes)	***2***	***0.25***	***318***	***0.47***	320	0.32	0.47
	Variables derived from field-level data (N = 1901)							
Fieldsize	Area of the wheat field (or plot) under consideration (ha)	11.08	22.13	12.54	29.55		12.49	29.32
Labor	Total amount of labor used (person days/ha)	49.05	34.16	44.81	28.54		44.96	28.75
RF	Rainfall (mm)	397.67***	89.94	344.95	95.74		346.75	96.01
QN	Quantity of nitrogen fertilizer used (kg/ha)	24.39	19.91	21.40	18.08		21.50	18.15
QP	Quantity of phosphorus fertilizer used (kg/ha)	19.67	9.56	20.29	12.26		20.27	12.18
QSeed	Quantity of seed used (kg/ha)	168.89**	34.72	156.76	44.77		157.17	44.51
QPesti	Quantity of pesticides applied (kg/ha)	0.35*	0.61	0.27	0.52		0.27	0.53
QHerbi	Quantity of herbicides applied (kg/ha)	0.89	0.60	0.91	0.60		0.91	0.60
Yield	Grain yield (kg/ha)	1200.65***	283.25	885.79	268.24		896.56	274.72
GM	Gross margins (MAD/ha)[#]	3132.86***	1004.69	2364.35	794.52		2390.63	814.36
ZTseeder	Number of ZT seeders per 10,000 ha of wheat area in each province	0.10	0.07	0.06	0.10		0.06	0.10
Ntill	Number of times the field was tilled	0.15	0.36	2.16	0.79		2.12	0.82
ImpVar	Is field planted with improved wheat varieties? (0 = No, 1 = Yes)	***41***		***585***		626	0.33	0.47
NoCAcomponent	No component of the CA package (including one tillage) was practiced on the field	***0***		***628***		628	0.33	0.47
OnlyOne	Only one component was practiced on the field (including one tillage)	***0***		***815***		815	0.43	0.50
OnlyTwo	Only two components were practiced on the field (including one tillage)	***0***		***393***		393	0.21	0.38
All Three	All three components (full CA package) were practiced	***65***		***0***		65	0.03	0.18
NoCAcomptArea	Average Area (ha) of fields on which none of the components of CA was practiced	*0*		*1.98*	2.54		*1.98*	2.54
OnlyOneArea	Average Area (ha) of fields on which only one component of CA was practiced	*0*		*3.71*	8.19		*3.71*	8.19
OnlyTwoArea	Average area (ha) of fields on which only two components of CA were practiced	*0*		*6.63*	22.35		*6.63*	22.35
AllThreeArea	Average area (ha) of fields on which all three components were practiced	*6.88*	*8.78*	*0*			*6.88*	*8.78*

***, **, * represent significant difference between adopters and non-adopters of CA at 0.01, 0.05 and 0.1 levels, respectively.
[v] In this study, adoption the full CA package is defined as the simultaneous use of zero or one tillage, rotation and retention of at least 30 % of crop residues on the field.
[ˆ] N indicates the number of cases with a "Yes" answer and ***bold-italic*** figures represent count values; [#] The currency exchange rate in 2012 was 1US$ = 8.62 Moroccan Dirhams.

$$T = \gamma + \gamma Z + \upsilon \quad (2)$$

In both Eqs. (1) and (2), there are always important explanatory variables (such as differences in land quality, topography, and slope, and in farmer motivation, skills, and IQ) which are omitted because they are not measured, observed, or their data not collected. These omitted variables can affect both the adoption decision (T) and the outcome variable (Y), causing correlation between the error term ε and T in Eq. (1) and between ε in Eq. (1) and υ in Eq. (2). These violate two of the fundamental assumptions of ordinary least squares (OLS) regression. This means, if we ignore them and proceed into the estimation of impact using Eq. (1) only, then the estimates will not be correct. This is because the difference in the outcome variables of interest between adopters and non-adopters may not be only due to the variables included in the regression (also called observable heterogeneity) but also due to the variables that are not included in the regression, i.e., unobserved heterogeneity (Bidzakin et al., 2019; Clougherty et al., 2016; Malikov and Kumbhakar, 2014; Paltasingh and Goyari, 2018). To correct for this problem, we employ the endogenous switching regression (ESR) model (Maddala and Nelson, 1975) which is widely used to account for both observable and unobservable heterogeneity of the adoption decision. The model achieves this by simultaneously estimating the adoption function (Eq. 2) and the yield, gross margin, consumption of wheat, or risk exposure function, also called the outcome equation (Eq. 1) for each of the adopter and non-adopter groups. By doing so, ESR filters the effect of unobserved heterogeneity and controls for all other confounding factors and helps us to estimate the true impact of CA adoption on the outcomes of our interest (yield, gross margins, wheat consumption, and downside risk exposure). Once again, in the interest of space and to spare non-economist readers from discussions of the formulation of the complex mathematical model, a detailed discussion of the ESR model is provided as supplementary material in Section 1.2 of Annex I.

Proper estimation of the ESR requires a variable *IV* that is correlated with *T but* not correlated with the error term ε in Eq. (1). In econometrics, variables like *IV* are termed instrumental variables and are useful for correctly estimating impacts by filtering, among other things, the effects of variables that are not included in the regression but that can affect both the adoption decision and the outcome variables. Several factors *X* (e.g., agronomic practices, quantities of inputs, varieties used, and weather conditions) are important in determining grain yield (Devkota and Yigezu, 2020), which in turn will affect farm income and consumption. Moreover, one of the keys to successful dissemination of CA is the timely availability of a suitable ZT seeder and its accessories, which allows farmers to seed under optimum conditions on different types of soils and residue management. In the Moroccan drylands, farmers with livestock are less likely to be interested in adopting the whole CA package as they heavily depend on crop residues for animal feed. Therefore, we use the number of ZT seeders available for every 10, 000 ha in the total provincial wheat area and ownership of livestock per household as instrumental variables in the estimation of ESR.

Given that the analysis is at plot-level, we were unsure that availability of ZT seeders at provincial level is a valid instrument. Therefore, we followed Di Falco et al. (2011) and carried out a falsification test, which showed that both instruments have positive significant effects on the adoption decision but no significant effect on yields and gross margins of the non-adopters – thereby giving us confidence in validity of the instrument.

In this paper, because survey (not experimental) data are used, Eq. (1) is estimated as a variant of the commonly known Cobb–Douglas production function. The variation is mainly related to the inclusion not only of the usual input quantities, but also binary and continuous variables that capture the differences in farm and farmer characteristics across all fields. Therefore, to fit the specification of the Cobb–Douglas production function, all continuous variables (such as yield, income, consumption, farmer age, area, and all quantities of inputs) are converted into their logarithmic equivalents. The list and descriptive statistics for the dependent and independent variables in the regression equations are provided in Table 2. Version 15 of the Stata software (StataCorp, 2017) is used for all econometric estimations in this study.

5. Results

5.1. Factors affecting farmers' decision on adoption of CA components

Estimates of the OP model to identify factors that influence farmers' decisions on adoption of CA practices in Morocco are shown in Table 3. The marginal effects of changes in the regressors on the response probabilities are also presented. The likelihood ratio statistics (χ^2) are highly significant ($P = 0.000$), suggesting that the model has strong explanatory power.

Our results show that female farmers have positive and significantly higher propensities for adoption of one (+1.4 %), two (+6.2 %), or all three (+2.0 %) components of CA than male farmers. The use of improved wheat varieties released after 1993 has a positive and significant effect on the decision to adopt CA practices. Results of the marginal effects show that farmers who use improved wheat varieties are 2.9 % more likely to adopt all three practices, 9% more likely to adopt any two components of CA practices, and 2.1 % more likely to adopt any one of the components on their wheat fields.

As expected, ownership of livestock negatively and significantly ($P = 0.01$) affects the decision on whether to adopt CA. If a farmer owns livestock, the probability of applying one or more of the CA components decreases by 2.9 %.

The amount of rainfall received in the year positively and significantly ($P = 0.01$) influences the decision to adopt one or more of the CA practices. This result shows that there is higher probability for farmers in higher rainfall areas adopting CA than the lower rainfall areas. Similar results have been previously reported (Aryal et al., 2018; Oumer and Burton, 2018; Yigezu et al., 2019a; Yigezu and El-Shater, forthcoming).

Size of the wheat field has a positive and significant ($P = 0.01$) effect on adoption of one or more of the CA practices; increasing the size by 1 ha above the current average area would increase the probability of applying one or more CA practices by 14 %. The ZT seeder availability in the area (measured by the number of ZT seeders per 10,000 ha) has a positive and significant ($P = 0.05$) effect on the decision whether or not to adopt CA. An increase in availability of a ZT seeder per 10,000 ha of provincial total wheat area increases the propensity of the farmers in the province to adopt one, two, and three CA practices by 0.4 %, 0.2 %, and 0.1 %, respectively.

5.2. Impact analysis

5.2.1. Model diagnostics

Before estimating the ESR, model diagnostics is used to see if endogeneity is a problem and thus making the OLS estimation inefficient. With a significant coefficient on the predicted error term from the selection equation that was included in the outcome equation, the Durbin–Wu–Hausman test shows that endogeneity indeed is a problem (showing some omitted variables do affect both the decision to adopt and the outcome variables). The likelihood ratio test (a post-estimation result) for the joint independence of the three equations also shows that the three equations are all interdependent (Table 4). Other post-estimation results are that the correlation coefficients (rho_1 and rho_2) are significant for both adopters and non-adopters, indicating the existence of self-selection. The estimate is also negative for both adopters and non-adopters, indicating positive selection bias such that farmers with above average farm income tend to decide to adopt CA. All these results show that endogeneity is indeed a problem and hence there is a need for a model such as ESR that corrects for it.

Coefficients of the key explanatory variables in the ESR model for the adoption of the three major components of the CA package provide important information (Table 4). The difference in the coefficients of the explanatory variables in the outcome equations of CA adopter and non-adopter households illustrate the presence of heterogeneity in the sample (Di Falco et al., 2011), which is also evident from the descriptive statistics of our sample (Table 2).

5.2.2. Impacts on yield

Quantities of some inputs such as DAP fertilizer, seed, and labor have strong and positive effects on yield. This result shows that even with rotation (as a CA principle), the average farmer in Morocco will still gain from increasing their DAP fertilizer inputs. This is because the current DAP application levels in Morocco are below the marginal product-maximizing level (Yigezu et al., 2019b). The use of improved varieties and certified seeds also leads to higher yields relative to the use of local (and old improved) varieties and non-certified seeds in both CA and conventional fields. Thus, for best results, CA practices need to be accompanied by best available varieties and seeds.

Simple comparison of the mean observed yields in Table 2 shows that on average 409 kg/ha (52.5 %) higher yields are obtained from fields on which CA is adopted than those with conventional practices. However, this is misleading because such a bivariate comparison masks a lot of confounding errors because yield differences may be associated with differences in application levels of inputs or many other factors. The correct comparison should be between the observed outcomes for fields on which the full CA package is practiced and the counterfactual case which mimics the yield that would be obtained if the fields are under conventional tillage – this is exactly what the ESR model does. Table 5 presents the expected treatment effects for wheat yield under actual and counterfactual conditions from the ESR model. The ESR model results show that by adopting all three main practices of CA on these fields, farm households are producing on average 307 kg/ha (34.8 %) more than if they continue using conventional agricultural practices. Similarly, if CA is applied on fields now under conventional practices, the owners of those fields would produce 151 kg/ha (+19.3 %) more wheat. These results imply that CA adoption has significant yield gains not only for those who have already adopted but showing great potential for those who are yet to adopt.

There is a clear grain yield advantage from adoption of the complete

Table 3
Results of the ordered probit model for adoption of only one, only two or all three components of the CA system.

Variable	Ordered probit model results									
	Adoption of all three components		Marginal effects							
			Prob (y = 0|x)^		Prob (y = 1|x)^		Prob (y = 2|x)^		Prob (y = 3|x)^	
	Coef.	Std.Er	dy/dx	Std.Er	dy/dx	Std.Er	dy/dx	Std.Er	dy/dx	Std.Er
Age (Years)	−0.005	0.112	0.001	0.035	−0.0002	0.005	−0.001	0.023	−0.0003	0.007
Number of years of education	0.111	0.080	−0.035	0.025	0.005	0.004	0.023	0.016	0.007	0.005
Sex (0=Male,1=Female)	0.303	0.126**	−0.096	0.040**	0.014	0.007**	0.062	0.026***	0.020	0.009**
ImpvVar (No = 0, Yes = 1)	0.437	0.073***	−0.139	0.023***	0.021	0.005***	0.090	0.015***	0.029	0.006***
Wheat area (ha)	0.470	0.036***	−0.149	0.011***	0.022	0.004***	0.096	0.007***	0.031	0.004***
ZT seeder availability	0.012	0.006**	−0.004	0.002**	0.001	0.000*	0.002	0.001**	0.001	0.000**
Total cropped area (ha)	−0.110	0.030**	0.035	0.009***	−0.005	0.002***	−0.023	0.006***	−0.007	0.002***
Annual rainfall (mm)	0.552	0.090***	−0.175	0.027***	0.026	0.006***	0.113	0.018***	0.036	0.007***
Ownership of livestock	−0.096	0.011***	0.030	0.003***	−0.005	0.001***	−0.020	0.002***	−0.006	0.001***
/cut1	3.223	0.691**								
/cut2	4.540	0.693***								
/cut3	5.825	0.698***								

Notes:
^ y represents the number of CA components adopted.
***, **, * represent significant difference between adopters and non-adopters of ZT at 0.01, 0.05 and 0.1 levels, respectively.

CA package compared to partial adoption of any one or two of the three components. The ESR model results show that adopters of the full CA package obtain on average 29.0 % and 18.4 % higher yields than those who adopt any one or any two of the three CA components, respectively (Table 5). Likewise, adoption of any two out of all three CA components leads on average to 23.2 % and 17.7 % higher yields relative to conventional agricultural practices and adoption of any one of the three components, respectively.

The total wheat area in the country (average for 2002–2011) is 2.91 million hectares. The area-wise adoption levels of only one, only two, and all three CA components are estimated at 41.3 %, 35.6 %, and 6.1 %. Given the corresponding average yield gains of 218, 251, and 307 kg/ha relative to the conventional practices, at the national average adoption level in 2013 of 6.1 %[1], the adoption of the full CA package leads to an increase in national wheat production by 0.58 million tons per year and represents 28 % higher total domestic supply of wheat in the country (a total value of about US$172 million) compared to what would be produced without use of any of the three components of CA. If the full CA package is well promoted to cover 75 % and 100 % of total wheat area in the country, it will be possible to increase wheat supply by at least 33 % and 44 %, respectively.

5.2.3. Impacts on gross margins

Table 6 presents estimates of treatment effects from the ESR model. The results show that adoption of CA leads on average to a gain in gross margins of MAD[2] 956.94/ha or US$111.01/ha (43.33 %) for those who have adopted the full CA package. Were non-adopters to adopt the full CA package, they would earn US$ 44.33/ha (+20.93 %) higher gross margins – showing that the benefit to those who already adopted is higher, which may explain why they adopted while the others have not. This is also reflected in the positive transitional heterogeneity (TH) effect, which implies that the potential benefits that can be obtained if current non-users of CA were to adopt it is less than that which his being enjoyed by those who already adopted. Given that the adopters of CA are mostly larger farms, a possible explanation for the difference in the gains in gross margins realized by adopters and the potential gains by non-adopters is that there could be scale economies in which the average cost decreases with size of land. This is especially true in the face of the high cost of purchasing a ZT seeder. If ZT-seeder rental is also on a daily basis instead of per hectare, this might also disadvantage those with smaller farm sizes. Moreover, even in the absence of CA, the average cost per unit quantities of the different inputs may be lower for larger farmers and they may have better bargaining power to obtain higher prices for their wheat outputs – thereby leading to disproportionately higher gross margins per hectare for larger farmers.

When we use only one and only two of the three components of CA as counterfactuals, the corresponding treatment effects from ESR (Table 5) show that adopters of the full CA package earn 37.5 % and 23.2 % higher gross margins than that which they would if they adopt only one and only two components, respectively. These results show clear economic advantages of the adoption of the three major components of CA. Likewise, adoption of any two components leads to 28.7 % and 24.6 % higher gross margins than conventional agricultural practices and adoption of any one component, respectively.

5.2.4. Impacts on wheat consumption

In Morocco, rural households often prefer making their own flour and bread. Therefore, it is of interest to see if adoption of CA leads to higher consumption of own production. Our model results show that adopters of the full CA package on average consume 23.22 kg/capita/year (37.7 %) more wheat from their own production relative to what they would consume in the absence of CA. Were non-adopters to adopt CA, they would consume 17.28 kg/capita/year (35 %) more wheat (Table 7). Moreover, adopters of the full CA package have 31 % and 25.9 % higher per capita wheat consumption than they would if they adopt only one and two of the three CA components, respectively. Similarly, adoption of any two components leads to 20.8 % and 15.8 % higher per capita wheat consumption than adoption of none and only one component, respectively.

The 2006–2008 average energy consumption for Morocco was 3260 kcal/capita/day (FAOSTAT, 2010). The projection for the average energy consumption in 2015 in the MENA is about 3090 kcal/capita/day. Considering the regional estimate as a reference, the additional 23.2 kg/capita/year of wheat consumed by CA adopters in Morocco translates to 218.5 kcal/capita/day, which is about 7% of total daily caloric intake.

[1] As explained in the Data section, this figure represents the percentage of total wheat area on which tillage was skipped in the survey year. This figure contains some fields which are under long-term zero or minimum tillage but it is highly likely that most are fields on which tillage was skipped for only one year (during the survey year) by using conventional drills.

[2] The currency exchange rate in 2012 was 1US$ = 8.62 Moroccan Dirhams (MAD).

Table 4
Results of the endogenous switching regression for measuring impacts of the adoption of the complete conservation agriculture package (low intensity tillage, crop rotation, and retaining residue) on wheat yield (kg/ha).

Independent Variables	Adoption of all three components (CA) (No = 0, Yes = 1)		Yield Equation for adopters of CA (counterfactual – those who used none of the three components)		Yield Equation for those who did not use any of the components)		Yield Equation for adopters of CA (counterfactual- those who used only one of the three components)		Yield Equation for those who used only one of the three components)		Yield Equation for non-adopters of CA (counterfactual -those who used any two of the three components)		Yield Equation for those who used any two of the three components)	
	Coef.	Std.Er	Coef.	Std.Er	Coef.	Std.Er	Coef.	Std.Er	Coef.	Std.Er	Coef.	Std.Er	Coef.	Std.Er
Age (Years)	0.133	0.373	−0.051	0.072	0.043	0.031	−0.057	0.073	−0.036	0.027	−0.076	0.089	0.013	0.043
Number of years of education	0.700	0.301**	0.074	0.062	0.0003	0.021	0.074	0.062	−0.011	0.020	0.069	0.064	−0.002	0.031
Sex (0=Male,1=Female)	0.587	0.462	0.091	0.074	0.066	0.048	0.086	0.075	0.003	0.031	0.092	0.076	0.025	0.041
ImpvVar (No = 0, Yes = 1)	0.534	0.242**	0.194	0.059***	0.358	0.023***	0.183	0.061***	0.419	0.018***	0.173	0.071**	0.316	0.027***
Quantity of nitrogen fertilizer used (kg/ha)			0.072	0.030**	−0.006	0.009	0.071	0.029**	0.004	0.008	0.074	0.031**	0.003	0.015
Quantity of DAP fertilizer used (kg/ha)			0.057	0.031*	0.052	0.007***	0.060	0.031**	0.051	0.006***	0.061	0.029**	0.064	0.010***
Quantity of seed used (kg/ha)			0.203	0.083**	0.075	0.019***	0.201	0.083**	0.077	0.018***	0.207	0.083***	0.045	0.031
Amount of labor used (person days/ha)			−0.072	0.049	0.063	0.021***	−0.074	0.050	0.041	0.017**	−0.078	0.052	0.041	0.027
Quantity of herbicide (kg/ha)			−0.114	0.051**	0.010	0.020	−0.114	0.051**	0.009	0.016	−0.122	0.052**	−0.030	0.027
Quantity of pesticide (kg/ha)			0.143	0.052***	−0.009	0.021	0.138	0.052***	0.025	0.019	0.128	0.065**	0.036	0.030
Rainfall	0.807	0.433*	0.404	0.084***	0.077	0.025***	0.397	0.078***	0.146	0.021***	0.376	0.094***	0.299	0.036***
ZT seeder availability	0.038	0.020**												
Wheat area (Ha)	0.880	0.154***												
Total cropped area (Ha)	−0.206	0.098**												
Ownership of livestock	−0.281	0.094***												
Constant	−7.989	2.983***	3.586	0.756***	5.222	0.225***	3.708	0.766***	5.217	0.195***	3.996	1.093***	4.386	0.313***
Rho			−0.276	0.005***	−0.358	0.122***	−0.152	0.446	−0.348	0.126***	−0.534	0.163***	−0.264	0.079***
Sigma			0.144	0.013***	0.174	0.006***	0.145	0.015***	0.176	0.005***	0.162	0.075***	0.195	0.009***
Wald test x2	509.4***						1115***				410.4***			
Log likelihood	111.5						101.7				−53.9			

***, **, * represent significant difference between adopters and non-adopters of ZT at 0.01, 0.05 and 0.1 levels, respectively.

6. Discussion

6.1. Determinants of adoption

The significantly higher propensities of adoption by female over male farmers makes good intuitive sense because, in Morocco, tillage is generally considered a male job and hence female-headed households often rely on male relatives or hired labor for this task. Therefore, female farmers are likely to be more open to adopting ZT, which eases their dependence on others for tillage operations.

The positive and significant marginal effects of the adoption of improved wheat varieties on the adoption of one or more of the CA components is consistent with recent research showing the existence of complementarity between the adoption of CA and improved varieties (Kassie et al., 2015; Wainaina et al., 2016). This is because farmers who adopt and benefit from one technology are likely to have the exposure, experience, and confidence to adopt other technologies, especially those which are complementary to those that they have already adopted (Yigezu et al., 2018b).

The negative effect of livestock ownership on CA adoption in general and residue retention in particular is theoretically explicable because in drylands, where livestock are an important source of livelihoods, there is trade-off between the use of residue as mulch and as feed. This result is consistent with the findings of Marenya et al. (2017) and Van den Broeck et al. (2013) and is intuitive, because farmers with livestock which are very valuable may have lower economic incentive to retain crop residues on the field relative to removing and using it as feed or grazing it on site. This finding is also consistent with a previous study on CA adoption in Central Morocco (Bonzanigo et al., 2016). The culture and wide practices of open grazing are often cited as a major challenge to practicing CA in MENA. Livestock ownership is also often associated with soil compaction through trampling, which might in turn cause some farmers who have tried CA to abandon it.

Given the moisture retention benefits of ZT and residue retention, lower adoption in areas with lower precipitation seems counterintuitive. However, owing to higher climatic risks, farmers in drier areas may be reluctant to venture into adoption of new technologies such as CA. In such areas, the moisture retention benefits of ZT and residue retention may be insufficient to ensure the minimum moisture needed for crop establishment, possibly failing to provide sufficient reason for farmers to adopt. Particularly, farmers in unfavorable zones with <300 mm of rainfall would not expect yields that justify the investment in a ZT seeder and giving up residue which would have saved them a substantial amount of money in the purchase of feed for animals. In these areas, farmers plant wheat knowing well that grain harvest may not possible but they still plant wheat in anticipation of biomass production for on-site grazing by their livestock.

The positive relationship between farm size and CA adoption is also consistent with the findings of Mavunganidze et al. (2013). Given the generally small area cultivated to wheat in Morocco (average 3.86 ha/family), this result makes good sense because smaller farms (generally owned by poorer households) have limited access to ZT seeders and inputs with generally lower risk-bearing capacity. In Morocco, the manufacturers of direct seeders still offer only limited types of seeders and are not able to deliver sufficient numbers of seeders adapted to smallholders' conditions. Therefore, there are few privately owned ZT seeders in Morocco, and these are usually owned by large farms. However, the majority of ZT seeders are owned by the government or non-governmental organizations, which often target larger farms to achieve higher degrees of adoption (in terms of area). In contrast, other studies have found a negative association between farm size and CA adoption because small farms who use conservation practices may realize higher productivity gains through such practices compared to larger farms (Binswanga, 2013; Chisenga, 2015; Muyanga and Jayne, 2019; Ngwira et al., 2014; Ntshangase et al., 2018). This shows that a one-size-fits-all approach would not be effective for promotion of CA.

Table 5
Average expected treatment and heterogeneity effects on yield and gross margins from Endogenous Switching Regression.

Treatment	Subsamples effects	Yield				Net Income (MAD/ha)				Consumption kg/capita/year			
		To adopt (n=65)	Not adopt (n=628)	Treat. effect	% change	To adopt (n=65)	Not adopt (n=628)	Treat. effect	% change	To adopt (n=65)	Not adopt (n=628)	Treat. effect	% change
Adoption of CA (counterfactuals are those who did not use any of the three components of CA)	Adopter	1189.19 (28.73)	881.84 (22.41)	307.35*** (20.57)	+34.85	3165.29 (82.46)	2208.35 (81.62)	956.94*** (71.3)	+43.33	84.77 (2.35)	61.56 (1.21)	23.22*** (1.39)	+37.71
	Non-adopter	930.59 (8.85)	779.85 (6.24)	150.74*** (5.82)	+19.33	2208.35 (25.64)	1826.21 (21.64)	382.13*** (18.11)	+20.93	66.69 (0.57)	49.40 (0.29)	17.28*** (0.40)	+34.98
	Heterogeneity effects	258.59*** (29.01)	101.99*** (20.69)	156.61*** (19.26)		956.94*** (83.98)	382.13*** (72.19)	574.81*** (60.77)		18.09*** (1.9)	12.16*** (0.97)	5.93*** (1.32)	
Treatment	Subsamples effects	Yield				Net Income (MAD/ha)				Consumption kg/capita/year			
		To Adopt (n=65)	Not adopt (n=815)	Treat. effect	% change	To adopt (n=65)	Not adopt (n=815)	Treat. effect	% change	To adopt (n=65)	Not adopt (n=815)	Treat. effect	% change
Adoption of CA (counterfactuals are those who used only one of the three components of CA)	Adopters	1189.17 (28.69)	921.74 (24.69)	267.43*** (20.05)	+29.04	3191.67 (81.31)	2321.57 (76.08)	870.10*** (58.85)	+37.47	84.77 (2.36)	64.72 (2.15)	20.06*** (1.02)	+30.99
	Non-adopters	1037.97 (8.49)	869.51 (7.24)	168.46*** (5.11)	+19.37	2667.51 (25.63)	2126.43 (22.80)	541.08*** (15.08)	+25.44	54.60 (0.36)	45.60 (0.35)	8.99** (0.21)	+19.72
	Heterogeneity effects	151.21*** (31.13)	52.24** (26.57)	98.97*** (18.95)		524.16*** (93.62)	195.14* (21.88)	329.02*** (55.90)		30.18*** (1.94)	19.11*** (1.90)	11.07*** (1.11)	
Treatment	Subsamples effects	Yield				Net Income (MAD/ha)				Consumption kg/capita/year			
		To Adopt (n=65)	Not Adopt (n=393)	Treat. effect	% change	To Adopt (n=65)	Not adopt (n=393)	Treat. effect	% change	To Adopt (n=65)	Not adopt (n=393)	Treat. effect	% change
Adoption of CA (counterfactuals are those who used only two out of the three components of CA)	adopters	1189.25 (28.66)	1004.06 (22.22)	185.19*** (14.68)	+18.44	3191.67 (81.32)	2591.52 (67.73)	600.15*** (47.54)	+23.16	84.77 (2.37)	67.36 (1.60)	17.42*** (1.25)	+25.86
	Non- adopters	1273.38 (14.47)	1024.49 (10.48)	248.89*** (7.54)	+24.29	3190.87 (41.69)	2643.87 (31.75)	547.00*** (22.51)	+20.68	73.70 (0.82)	64.72 (0.77)	8.98** (0.45)	+13.88
	Heterogeneity effects	−84.13** (37.47)	−20.43 (27.31)	−63.70*** (19.49)		0.80 (1.91)	−52.35** (82.81)	53.15** (42.36)		11.08*** (2.22)	2.64 (1.20)	8.43*** (1.22)	
Adoption of any two components (counterfactuals are those who did not use any of the three components of CA)	Adopters	1024.46 (10.47)	831.52 (8.56)	192.94*** (4.11)	+23.20	2751.94 (32.04)	2137.93 (32.03)	614.00*** (15.88)	+28.72	71.44 (0.77)	50.67 (0.53)	20.77*** (1.25)	+40.99
	Non- adopters	882.06 (7.30)	779.89 (6.24)	102.17*** (2.68)	+13.10	2195.97 (18.57)	1891.15 (21.61)	304.82*** (8.89)	+16.12	53.92 (0.38)	40.92 (0.29)	13.01*** (0.14)	+37.76
	Heterogeneity effects	142.39*** (12.40)	51.63*** (10.41)	90.77*** (90.77)		555.97 (34.54)	246.79*** (37.27)	309.18** (16.86)		17.52*** (0.77)	9.76*** (0.56)	7.76*** (0.29)	
		To Adopt (n=65)	Not Adopt (n=393)	Treat. effect	% change	To Adopt (n=65)	Not adopt (n=393)	Treat. effect	% change	To Adopt (n=65)	Not adopt (n=393)	Treat. effect	% change
Adoption of any two components (counterfactuals are those who used only one of the three components of CA)	Adopters	1024.50 (10.49)	870.66 (9.96)	153.84*** (3.15)	+17.67	2751.06 (31.80)	2208.41 (30.75)	542.65 *** (13.48)	+24.57	71.44 (0.77)	55.62 (0.99)	15.82*** (0.38)	+28.44
	Non-adopters	1014.03 (7.54)	869.63 (7.26)	144.40*** (2.09)	+16.60	2568.29 (18.30)	2212.01 (22.80)	356.28*** (9.08)	+16.11	65.12 (0.38)	52.87 (0.57)	12.25*** (0.25)	+23.17
	Heterogeneity effects	10.47 (13.07)	1.03 (12.53)	9.44** (3.72)		182.77 (34.38)	−3.61 (39.16)	186.37*** (16.08)		6.32** (0.76)	2.75 (0.56)	3.59*** (0.44)	

***, **, * represent significant difference between adopters and non-adopters of ZT at 0.01, 0.05 and 0.1 levels, respectively.

Table 6
Results of the endogenous switching regression for measuring impacts of the adoption of the complete conservation agriculture (CA) package (low intensity tillage, crop rotation, and retaining residue) on Gross margins (MAD/ha).

Independent Variables	Adoption of all three components (CA) (No = 0, Yes = 1)		Gross margins for adopters of CA (counterfactual – those who used none of the three components)		Gross margins for those who did not use any of the components)		Gross margins for adopters of CA (counterfactual- those who used only one of the three components)		Gross margins for those who used only one of the three components)		Gross margins for non-adopters of CA (counterfactual -those who used any two of the three components)		Gross margins for those who used any two of the three components)	
	Coef.	Std.Er	Coef.	Std.Er	Coef.	Std.Er	Coef.	Std.Er	Coef.	Std.Er	Coef.	Std.Er	Coef.	Std.Er
Age (Years)	0.131	0.373	−0.087	0.101	0.059	0.079	−0.097	0.104	−0.098	0.061*	−0.109	0.162	0.043	0.072
Number of years of education	0.643	0.281**	0.118	0.087	0.057	0.052	0.126	0.086	0.041	0.045	0.114	0.127	−0.066	0.052
Sex (0=Male,1=Female)	0.601	0.469	−0.015	0.107	0.196	0.120*	−0.036	0.104	0.132	0.070**	−0.032	0.104	0.019	0.069
ImpvVar (No = 0, Yes = 1)	0.610	0.229***	0.249	0.092***	0.477	0.055***	0.201	0.090**	0.480	0.042***	0.204	0.085**	0.412	0.045***
Quantity of nitrogen fertilizer used (kg/ha)			0.061	0.043	−0.032	0.023	0.050	0.041	0.013	0.019	0.051	0.041	−0.013	0.026
Quantity of DAP fertilizer used (kg/ha)			0.068	0.044	0.067	0.017***	0.085	0.044**	0.042	0.014***	0.083	0.041**	0.070	0.018***
Quantity of seed used (kg/ha)			0.123	0.115	0.017	0.047	0.114	0.117	0.100	0.042**	0.120	0.119	0.033	0.052
Amount of labor used (person days/ha)			−0.051	0.069	0.084	0.052*	−0.052	0.070	−0.008	0.040	−0.052	0.070	0.029	0.046
Quantity of herbicide (kg/ha)			−0.160	0.071**	−0.200	0.050***	−0.157	0.071**	−0.103	0.038***	−0.158	0.072**	−0.172	0.045***
Quantity of pesticide (kg/ha)			0.046	0.075	−0.103	0.054**	0.027	0.074	−0.044	0.043	0.028	0.072	−0.024	0.050
Rainfall (mm)	1.036	0.346***	0.600	0.133***	0.080	0.059	0.537	0.111***	0.171	0.049***	0.514	0.246**	0.293	0.065***
ZT seeder availability	0.029	0.023					4.389	1.127***	6.330	0.444***				
Wheat area (ha)	0.938	0.134***												
Total cropped area (ha)	−0.188	0.094**												
Ownership of livestock	−0.255	0.082***												
Constant	−9.375	2.548***	3.819	1.147***	6.334	0.548***					4.612	2.651*	5.497	0.546***
Rho			0.283	0.372	−0.200	0.073**	−0.077	0.517	−0.184	0.168	−0.258	1.949	−0.133	0.320
sigma			0.205	0.022***	0.437	0.013***	0.202	0.019***	0.402	0.010***	0.207	0.090***	0.328	0.013***
Wald test x2	180.6***						341.95***				167.0***			
Log likelihood	−493.6						−598.9				−287.9			

***, **, * represent significant difference between adopters and non-adopters of ZT at 0.01, 0.05 and 0.1 levels, respectively.

Table 7
Results of the endogenous switching regression for measuring impacts of the adoption of the complete conservation agriculture package (reduced tillage, crop rotation, and retaining residue) on consumption (kg/capita/year).

Independent Variables	Adoption of all three components (CA) (No = 0, Yes = 1)		consumption for adopters of CA (counterfactual – those who used none of the three components)		consumption for those who did not use any of the components)		consumption for adopters of CA (counterfactual- those who used only one of the three components)		consumption for those who used only one of the three components)		consumption for non-adopters of CA (counterfactual -those who used any two of the three components)		consumption for those who used any two of the three components)	
	Coef.	Std.Er	Coef.	Std.Er	Coef.	Std.Er	Coef.	Std.Er	Coef.	Std.Er	Coef.	Std.Er	Coef.	Std.Er
Age (Years)	0.368	0.350	0.145	0.158	0.029	0.054	0.192	0.172	−0.150	0.061***	0.177	0.168	−0.051	0.096
Number of years of education	0.526	0.248**	−0.002	0.136	0.051	0.037	0.052	0.154	0.083	0.045*	0.008	0.139	0.061	0.070
Sex (0=Male,1=Female)	0.618	0.393	0.102	0.165	−0.101	0.083	0.099	0.163	−0.061	0.069	0.081	0.165	0.012	0.091
ImpvVar (No = 0, Yes = 1)	0.608	0.214***	0.320	0.176*	0.343	0.048***	0.357	0.141***	0.513	0.042***	0.319	0.129***	0.318	0.059***
Quantity of nitrogen fertilizer used (kg/ha)			0.070	0.066	−0.016	0.015	0.064	0.064	−0.009	0.019	0.070	0.064	−0.012	0.033
Quantity of DAP fertilizer used (kg/ha)			−0.115	0.065*	−0.043	0.011***	−0.106	0.065*	−0.038	0.014***	−0.113	0.064*	−0.055	0.023**
Quantity of seed used (kg/ha)			−0.010	0.183	−0.004	0.032	−0.019	0.183	0.037	0.041	−0.010	0.183	−0.063	0.068
Amount of labour used (person days/ha)			0.104	0.111	0.129	0.035***	0.107	0.109	0.170	0.040***	0.100	0.110	0.101	0.060*
Quantity of herbicide (kg/ha)			−0.067	0.111	−0.058	0.034*	−0.057	0.112	0.033	0.037	−0.062	0.112	0.028	0.059
Quantity of pesticide (kg/ha)			0.072	0.115	−0.027	0.036	0.064	0.112	0.007	0.043	0.075	0.113	−0.028	0.065
Rainfall (mm)	1.062	0.315***	0.131	0.241	−0.045	0.052	0.286	0.277	0.031	0.051	0.161	0.209	−0.080	0.086
ZT seeder availability	0.031	0.021									2.169	1.963	4.797	0.734***
Wheat area (ha)	0.726	0.012***												
Total cropped area (ha)	−0.207	0.102**												
Ownership of livestock	−0.219	0.069***												
Constant	−9.276	2.302***	2.608	2.016	3.488	0.422***	1.202	2.424	3.451	0.455***				
Rho			0.146	0.514	−0.022	0.516	0.521	0.425	0.076	0.225	0.384	0.516	−0.250	0.387
sigma			0.319	0.033***	0.295	0.008***	0.358	0.090***	0.399	0.010***	0.336	0.067***	0.431	0.021***
Wald test x2	117.4***						346.94***				86***			
Log likelihood	−308.1						−631				−419			

***, **, * represent significant difference between adopters and non-adopters of ZT at 0.01, 0.05 and 0.1 levels, respectively.

Instead, efforts for wider dissemination of CA should be tailored to the specificities of local conditions.

The positive effect of ZT seeder availability is also intuitive because, without access to seeders, ZT adoption would be nearly impossible. This is also consistent with other reports that better access to ZT seeders enhances CA adoption (e.g., Yigezu et al., 2018a).

6.2. Impacts of partial or full adoption of CA

Combining the results of the treatment and heterogeneity effects shows that both adopters and non-adopters are better off with CA. This result is consistent with many studies which found that the introduction of CA is associated with significant productivity gains (Bista et al., 2019; El-Shater et al., 2016; Mousques and Friedich, 2007; Sharma et al., 2015). The gains however seem to be higher in Morocco, possibly associated with the benefits under moisture-constrained conditions and the relatively longer history of CA in the country (Mrabet et al., 2012). Moreover, the results of the adjusted potential heterogeneity in the sample shows that even in the absence of CA practices, farm households who actually adopt any of the three CA components still obtain higher yields than those who do not. This suggests that the additional yield which the farmers who adopted CA are now enjoying may not have come only from the direct benefits of CA that is available to everybody who adopts it but from their natural excellence and superior ability, which may have been enhanced because they adopted CA.

Farmers in Morocco have adopted CA at varying levels – some adopting the full CA package, others only two components, and still others only one component, with each obtaining some benefits. At the current adoption levels of the different combinations of the three components, CA principles have contributed to improved national food security and household-level livelihoods. For example, introduction of CA in Morocco is associated with a 28 % increase in national wheat production which saves the country annual import costs of about US$172 million. Consumption of an average of 23.22 kg/capita/year (37.71 %) more wheat and 43.33 % higher gross margins from wheat production are also associated with adoption of CA principles – showing clear livelihood and food security improvements from the efforts on CA dissemination in Morocco.

Our results show that adoption of the full CA package has advantages in grain yield and gross margins over partial adoption of one or two components (Table 5), and is consistent with the theory and practice of CA. More interestingly, even partial adoption of one or two of the CA components has economic advantages over the conventional practice. Along with the findings of other studies (El-Shater et al., 2015; El-Shater and Yigezu, *under review*; Yigezu and El-Shater, forthcoming; Yigezu et al., 2019a,b), this result has important implications in the design of practical approaches for enhancing the adoption and hence achieving wider dissemination of CA. For example, these results provide the basic evidence to justify experimentation on an incremental approach for CA dissemination without risking economic loss to farmers.

7. Conclusions

This study was based on a nationally representative sample of 995 farm households cultivating 1901 wheat fields drawn using a multi-stage sampling procedure from the wheat-based production systems in Morocco. First, we used area weighting for upward aggregation of estimates of the partial and full adoption of the CA package from district to province and ultimately to national levels. The OP model was employed to analyze the determinants of partial and complete adoption CA. We also employed the ESR model to provide empirical comparisons of the livelihoods impacts of adoption of the full CA package of all three complementary practices of RT, rotation, and residue retention and adoption of only two, only one, or none of the practices (i.e., the conventional practice).

The most important contribution of this paper is that it provided credible evidence that farmers who partially adopted only one or two of the three CA principles obtained higher yield and income from their wheat fields than those who continued with conventional agriculture. It also provided clear evidence that the adoption of all three components of the CA system led to higher socioeconomic benefits than both partial adoption of CA and the conventional system. This indicates that wider diffusion of the complete package has potential to improve the productivity, profitability, and sustainability of agricultural production in Morocco and other similar countries with dryland agriculture. The results of this study therefore confirmed that dissemination of the full CA package should be the ultimate goal for experts in MENA. However, in the face of the low and slow adoption of CA in Morocco, we conclude that an incremental approach toward full CA adoption might prove effective in the dissemination of the CA system and hence is worth testing for contrasting climates, soils, and cropping systems in the drylands of Morocco and other similar areas in the MENA region.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgements

Funding for this research was obtained from the CGIAR Research Program on Wheat – CRP-WHEAT (Agreement No. 200077).

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.still.2021.105067.

References

Abawi, G., Widmer, T., 2000. Impact of soil health management practices on soil borne pathogens, nematodes and root diseases of vegetable crops. App. Soil Ecol. 15, 37–47. https://doi.org/10.1016/S0929-1393(00)00070-6.
Amanuel, G., kuhne, R.F., Tanner, D.G., Vlek, P.L.G., 2000. Biological nitrogen fixation in faba-beans (Vicia faba L.) in the Ethiopian highlands as affected by P fertilization and inoculation. Biol. Fertil. Soils 32, 353–359. https://doi.org/10.1007/s003740000258.
Andersson, J.A., D'Souza, S., 2014. From adoption claims to understanding farmers' and contexts: a literature review of Conservation Agriculture (CA) adoption among smallholder farmers in southern Africa. Agric. Ecosyst. Environ. 187, 116–132. http://www.fao.org/tempref/AG/agp/ca/CA_Cop_Apr14.
Aryal, J.P., Rahut, D.B., Maharjan, S., Erenstein, O., 2018. Factors affecting the adoption of multiple climate-smart agricultural practices in the Indo-Gangetic plains of India. Nat. Resour. Forum 42 (3), 141–158. https://doi.org/10.1111/1477-8947.12152.
Badraoui, M., Dahan, R., 2010. The Green Morocco Plan in relation to food security and climate change. In: Solh, M., Saxena, M.C. (Eds.), Proceedings of International Conference on Food Security and Climate Change in the Dry Areas. 1–4 February 2010. ICARDA Publication, Amman, Jordan, pp. 61–70.
Ben Zekri, Y., Barkaoui, K., Marrou, H., Mekki, I., Belhouchette, H., Wery, J., 2018. On farm analysis of the effect of the preceding crop on N uptake and grain yield of durum wheat (Triticum durum Desf.) in Mediterranean conditions. Arch. Agron. Soil Sci. 65 (5), 596–611. https://doi.org/10.1080/03650340.2018.1514111.
Bidzakin, J.K., Fialor, S.C., Awunyo-Vitor, D., Yahaya, I., 2019. Impact of contract farming on rice farm performance: endogenous switching regression. Cogent Econ. Financ. 7 (1), 1618229 https://doi.org/10.1080/23322039.2019.1618229.
Binswanga, E., 2013. The influence of conservation agriculture adoption on input demand and maize production in Butha Buthe, Lesotho. MSc Thesis. The University of Tennessee, Knoxville, USA.
Bista, A., Joshi, T.N., Biswokarma, K., Yadav, S., 2019. Agronomic and environmental aspects of conservation agriculture on wheat crop production. Int. J. Appl. Sci. Biotechnol. 7 (2), 161–166.
Bliss, C.I., 1934. The method of probits. Science 79 (2037), 38–39. https://doi.org/10.1126/science.79.2037.38.
Bogdan, R.C., Biklen, S.K., 2007. Qualitative Research for Education. An Introduction to Theories and Methods, 5th e.d. Pearson Education Inc., Boston. MA.
Bolliger, A., Magid, J., Amado, T.J.C., Skora Neto, F., Ribeiro, M.F.S., Calegari, A., Ralisch, R., De Neergard, A., 2006. Taking stock of the Brazilian "Zero-Till Revolution": a review of land-mark research and farmers' practice. Adv. Agro. 91, 47–110.
Bonzanigo, L., Giupponi, C., Moussadek, R., 2016. Conditions for the adoption of conservation agriculture in Central Morocco: an approach based on Bayesian network modelling. Ital. J. Agron. 11 (1), 24. https://doi.org/10.4081/ija.2016.665.

Chisenga, C.M., 2015. Socio-economic factors associated with the adoption of conservation agriculture among women farmers in Balaka District, Malawi. MSc Thesis. Purdue University, West Lafayette, IN., USA.

Clougherty, J.A., Duso, T., Muck, J., 2016. Correcting for self-selection based endogeneity in management research: review, recommendations and simulations. Organ. Res. Methods 19 (2), 286–347. https://doi.org/10.1177/1094428115619013.

Darnhofer, I., Schneeberger, W., Freyer, B., 2005. Converting or not converting to organic farming in Austria: farmer types and their rationale. Agric. Hum. Values 22, 39–52. https://doi.org/10.1007/s10460-004-7229-9.

Dessart, F.J., Barreiro-Hurle, J., van Bavel, R., 2019. Behavioural factors affecting the adoption of sustainable farming practices: a policy-oriented review. Eur. Rev. Agric. Econ. 46, 417–471. https://doi.org/10.1093/erae/jbz019.

Devkota, M., Yigezu, Y.A., 2020. Explaining yield and gross margin gaps for sustainable intensification of the wheat-based systems in a Mediterranean climate. Agric. Syst. 185 (102946), 1–16.

Di Falco, S., Veronesi, M., Yesuf, M., 2011. Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. Am. J. Agric. Econ. 93 (3), 825–842. https://doi.org/10.1093/ajae/aar006.

Dumanski, J., Peiretti, R., Benetis, J., McGarry, D., Pieri, C., 2006. The paradigm of conservation tillage. Proc. World Assoc. Soil Water Conserv. P1, 58–64.

El-Shater, T., Yigezu, Y. A., [Under Review]. Can retention of crop residues on the field be justified on socio-economic grounds in mixed crop-livestock production systems of the drylands.

El Gharras, O., El Mourid, M., Boulal, H., 2017. Conservation Agriculture in North Africa: experiences, achievements and challenges. In: Kassam, A., Mkomwa, S., Friedrich, T. (Eds.), Conservation Agriculture for Africa: Building Resilient Farming Systems in a Changing Climate. CAB International, Wallingford, UK, pp. 127–138.

El-Shater, T., Yigezu, Y.A., Mugera, A., Piggin, C., Haddad, A., Khalil, Y., Loss, S., Aw-Hassan, A., 2016. Does zero tillage improve the livelihoods of smallholder cropping farmers? J. Agric. Econ. 67 (1), 154–172. https://doi.org/10.1111/1477-9552.12133.

FAOSTAT, 2010. Statistics Division. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Giller, K.E., Witter, E., Corbeels, M., Tittonell, P., 2009. Conservation agriculture and smallholder farming in Africa: the heretics' view. Field Crop Res. 114, 23–34. https://doi.org/10.1016/j.fcr.2009.06.017.

Giller, K.E., Corbeels, M., Nyamangara, J., Triomphe, B., Affholder, F., Scopel, E., Tittonell, P., 2011. A research agenda to explore the role of conservation agriculture in African smallholder farming systems. Field Crops Res. 124, 468–472. https://doi.org/10.1016/j.fcr.2011.04.010.

Greene, W.H., 2008. Econometric Analysis. Macmillan Publishing Company.

Habtemichial, K.H., Singh, B.R., Aune, J.B., 2007. Wheat response to N2 fixed by faba-beans (Vicia faba L.) as affected by sulfur fertilization and rhizobial inoculation in semi-arid Northern Ethiopia. J. Plant Nutr. Soil Sci. 170, 412–418. https://doi.org/10.1002/jpln.200625006.

Hobbs, P.R., 2007. Conservation agriculture: what is it and why is it important for future sustainable food production? J. Agric. Sci. 145, 127–137.

Hobbs, P.R., Sayre, K., Gupta, R., 2008. The role of conservation agriculture in sustainable agriculture. Phil. Trans. Royal Soc. Ser. B 363, 543–555. https://doi.org/10.1098/rstb.2007.2169.

Jaleta, M., Kassie, M., Tesfaye, K., Teklewold, T., Jena, P.R., Marenya, P., Erenstein, O., 2016. Resource saving and productivity enhancing impacts of crop management innovation packages in Ethiopia. Agric. Econ. 47, 513–522. https://doi.org/10.1111/agec.12251.

Jemo, M., Abaido, R.C., Nolte, C., Tchienkoua, M., Sanginga, N., Horst, W.J., 2006. Phosphorus benefits from grain legume crops to subsequent maize grown on acid soils of southern Cameroon. Plant Soil 284, 385–397. https://doi.org/10.1007/s11104-006-0052-x.

Jensen, E.S., Peoples, M.B., Hauggaard-Nielsen, H., 2010. Faba-beans in cropping systems. Field Crops Res. 115, 203–216. https://doi.org/10.1016/j.fcr.2009.10.008.

Kassam, A., Kassam, L., 2020. Rethinking Food and Agriculture. New Ways Forward. A volume in Woodhead Publishing Series in Food Science, Technology and Nutrition. https://doi.org/10.1016/C2017-0-04570-6.

Kassam, A., Mkomwa, S., Friedrich, T. (Eds.), 2017. Conservation Agriculture for Africa: Building Resilient Farming Systems in a Changing Climate. CABI, Walingford, UK. https://doi.org/10.1080/00207233.2017.1319620.

Kassam, A., Derpsh, R., Friedrich, T., 2020. Development of conservation agriculture systems globally. In: Kassam, A. (Ed.), Advances in Conservation Agriculture Volume 1: Systems and Science. Burleigh Dodds Science Publishing, Cambridge, UK, pp. 1–56, 2020, ISBN: 978 1 78676 264 1. www.bdspublishing.com.

Kassie, M., Hailemariam, T., Moti, J., Marenya, P., Erenstein, O., 2015. Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. Land Use Policy 42, 400–411. https://doi.org/10.1016/j.landusepol.2014.08.016.

Kieninger, P.R., Gugerell, K., Biba, V., Auberger, I., Winter, S., Penker, M., 2018. Motivation crowding and participation in agri-environmental schemes – the case of the Austrian opul-programme in vineyards. Eur. Countrys. 10, 355–376. https://doi.org/10.2478/euco-2018-0021.

Kirkegaard, J., Christen, O., Krupinsky, J., Layzell, D., 2008. Break crop benefits in temperate wheat production. Field Crops Res. 107, 185–195. https://doi.org/10.1016/j.fcr.2008.02.010.

Knowler, D., Bradshaw, B., 2007. Farmers' adoption of conservation agriculture: a review and synthesis of recent research. Food Policy 32, 25–48. https://doi.org/10.1016/j.foodpol.2006.01.003.

Kutter, T., Louwagie, G., Schuler, J., Zander, P., Helming, K., Hecker, J.-M., 2011. Policy measures for agricultural soil conservation in the European Union and its member states: policy review and classification. Land Degrad. Dev. 22, 18–31. https://doi.org/10.1002/ldr.1015.

Lahmar, R., 2010. Adoption of conservation agriculture in Europe. Lessons of the Kassa project. Land Use Policy 27, 4–10. https://doi.org/10.1016/j.landusepol.2008.02.001.

Li, L., Huang, G., Zhang, R., Bill, B., Guangdi, L., Kwong, Y.C., 2011. Benefits of conservation agriculture on soil and water conservation and its progress in China. Agric. Sci. China 10 (6), 850–859. https://doi.org/10.1016/S1671-2927(11)60071-0.

Lopez-Bellido, L., Lopez-Bellido, R.J., Redondo, R., Benitez, J., 2006. Faba-beans nitrogen fixation in a wheat-based rotation under rain fed Mediterranean conditions: effect of tillage system. Field Crops Res. 98, 253–260. https://doi.org/10.1016/j.fcr.2006.03.001.

Loss, S., Haddad, A., Khalil, Y., Alrijabo, A., Feindel, D., Piggin, C., 2014. Evolution and adoption of conservation agriculture in the Middle East. In: Farooq, M., Siddique, K.H.M. (Eds.), Conservation Agriculture. Springer.

Maddala, G.S., Nelson, F.D., 1975. Switching regression models with exogenous and endogenous switching. In: Proceedings of the Business and Economic Statistics Section. American Statistical Association, pp. 423–426.

Magnan, N., Lybbert, T.J., Mrabet, R., Fadlaoui, A., 2011. The quasi-option value of delayed input use under catastrophic drought risk: the case of zero tillage in Morocco. Amer. J. Agric. Econ 93, 498–504. https://doi.org/10.1093/ajae/aaq136.

Malikov, E., Kumbhakar, S.C., 2014. A generalized panel data switching regression model. Econ. Lett. 124 (3), 353–357. https://doi.org/10.1016/j.econlet.2014.06.022.

Marenya, P.P., Kassie, M., Jaleta, M., Rahut, D.B., Erenstein, O., 2017. Predicting minimum tillage adoption among smallholder farmers using micro-level and policy variables. Agric. Food Econ. 5 (12), 1–22. https://doi.org/10.1186/s40100-017-0081-1.

Marschner, P., Joergensen, R.G., Piepho, H.P., Buerkert, A., 2004. Legume rotation effects on early growth and rhizosphere microbiology of sorghum in West African Soils. Plant Soil 264, 325–334. https://doi.org/10.1023/B:PLSO.0000047767.62179.25.

Mavunganidze, Z., Madakadze, I.C., Mutenje, M.J., Nyamangara, J., 2013. Factors affecting the choice of conservation agriculture practices adopted by smallholder cotton farmers in Zimbabwe. Afr. J. Agric. Res. 8 (17), 1641–1649. https://doi.org/10.5897/AJAR12.2099.

Mousques, C., Friedrich, T., 2007. Conservation agriculture in China and the Democratic People's Republic of Korea. FAO Crop and Grassland Service Working Paper. Food and Agriculture Organization of the United Nations, Rome.

Moussadek, R., Mrabet, R., Zante, P., Lamachère, J.M., Pépin, Y., Bissonnais, Y.L., Ye, L., Verdoodt, A., Van Ranst, E., 2011. Effets du travail du sol et de la gestion des résidus sur les propriétés du sol et sur l'érosion hydrique d'un Vertisol Méditerranéen. Can. J. Soil Sci. 91, 627–635. https://doi.org/10.4141/cjss10096.

Moussadek, R., Mrabet, R., Dahan, R., Zouahri, A., El Mourid, M., Van Ranst, E., 2014. Tillage System affects soil organic carbon storage and quality in Central Morocco. Appl. Environ. Soil Sci. https://doi.org/10.1155/2014/654796.

Mrabet, R., 2011a. No-tillage agriculture in West Asia & North Africa. In: Tow, P.G., Cooper, I.M., Partridge, I., Birch, C.J. (Eds.), Rainfed Farming Systems. Springer, Dordrecht Netherlands, pp. 1015–1042. ISBN: 978-1-4020-9131-5.

Mrabet, R., 2011b. Effects of residue management and cropping systems on wheat yield stability in a semiarid Mediterranean clay soil. Am. J. Plant Sci. 2, 202–216. https://doi.org/10.4236/ajps.2011.22022.

Mrabet, R., Moussadek, R., Fadlaoui, A., van Ranst, E., 2012. Conservation agriculture in dry areas of Morocco. Field Crops Res. 132, 84–94. https://doi.org/10.1016/j.fcr.2011.11.017.

Mupangwa, W., Twomlow, S., Walker, S., Hove, L., 2007. Effect of minimum tillage and mulching on maize (Zea mays L.) yield and water content of clayey and sandy soil. Phys. Chem. Earth 32, 1127–1134.

Muyanga, M., Jayne, T., 2019. Revisiting the farm size-productivity relationship based on a relatively wide range of farm sizes: evidence from Kenya. Am. J. Agric. Econ. 101 (4), 1140–1163.

Namuyiga, D.B., Bashaasha, B., 2019. Drivers of adoption of conservation agriculture practices in maize-based production systems in Eastern Uganda and Western Kenya. J. Appl. Agric. Econ. Policy Anal. 2 (1), 16–21. https://doi.org/10.12691/jaaepa-2-1-3.

Ngwira, A., Thierfelder, C., Lambert, D., 2013. Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. Renew. Agric. Food Syst. 28 (4), 350–363. https://doi.org/10.1017/S1742170512000257.

Ngwira, A., Johnsen, F.H., Aune, J.B., Mekuria, M., Thierfelder, C., 2014. Adoption and extent of conservation agriculture practices among smallholder farmers in Malawi. J. Soil Water Conserv. 69 (2), 107–119.

Ntshangase, N.L., Muroyiwa, B., Sibanda, M., 2018. Farmers' perceptions and factors influencing the adoption of no-till conservation agriculture by small-scale farmers in Zashuke, KwaZulu-Natal province. Sustainability (Switzerland) 10 (2).

Nuruzzaman, M., Lambers, H., Bolland, M.D.A., Veneklaas, E.J., 2005. Phosphorus benefits of different legume crops to subsequent wheat grown in different soils of Western Australia. Plant Soil 271, 175–187. https://doi.org/10.1007/s11104-004-2386-6.

Oumer, A.M., Burton, M., 2018. Drivers and synergies in the adoption of sustainable agricultural intensification practices: a dynamic perspective. In: 2018 Annual Meeting. August 5–7, Washington, D.C., 273871, Agricultural and Applied Economics Association.

Paltasingh, K., Goyari, P., 2018. Impact of farmer education on farm productivity under varying technologies: case of paddy growers in India. Agric. Food Econ. 6 https://doi.org/10.1186/s40100-018-0101-9.
Pannell, D.J., Claassen, R., 2020. The roles of adoption and behavior change in agricultural policy. Appl. Econ. Perspect. Policy 42, 31–41.
Peoples, M.B., Brockwell, J., Herridge, D.F., Rochester, I.J., Alves, B.J.R., Urquiaga, S., Boddey, R.M., Dakora, F.D., Bhattarai, S., Maskey, S.L., Sampet, C., Rerkasem, B., Khan, D.F., Nielsen, H., Jensen, E.S., 2009. The contributions of nitrogen-fixing legumes to the productivity of agricultural systems. Symbiosis 48, 1–17.
Pittelkow, C.M., Liang, X., Linquist, B.A., Van Groenigen, K.J., Lee, J., Lundy, M.E., van Gestel, N., Six, J., Venterea, R.T., van Kessel, C., 2015. Productivity limits and potentials of the principles of conservation agriculture. Nature 517, 365–368.
Pypers, P., Huybrighs, M., Diels, J., Abaidoo, R., Smolders, E., Merckx, R., 2007. Does the enhanced P acquisition by maize following legumes in a rotation result from improved soil P availability? Soil Biol. Biochem. 39, 2555–2566.
Rogers, E.M., 2003. Diffusion of Innovations, 5th ed. The Free Press, New York, NY, USA.
Ruisi, P., Amato, G., Badagliacca, G., Frenda, A.S., Giambalvo, D., Di Miceli, G., 2017. Agro-ecological benefits of faba-beans for rainfed Mediterranean Cropping Systems. Ital. J. Agron. 12 (3), 223–245. https://doi.org/10.4081/ija.2017.865.
Sharma, P.C., Jat, H.S., Kumar, V., Gathala, M.K., Datta, A., et al., 2015. Sustainable intensification opportunities under current and future cereal systems of North-West India. Technical Bulletin: CSSRI/Karnal/2015/4. Central Soil Salinity Research Institute, Karnal, India. https://doi.org/10.13140/RG.2.2.16550.83521, p 46.
StataCorp, 2017. Stata Statistical Software: Release 15. StataCorp LP, College Station, TX.
Thierfelder, C., Wall, P.C., 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil Tillage Res. 105, 217–227.
Thierfelder, C., Matemba-Mutasa, R., Rusinamhodzi, L., 2014. Yield response of maize (Zea mays L.) to conservation agriculture cropping system in Southern Africa. Soil Tillage Res. 146, 230–242. https://doi.org/10.1016/j.still.2014.10.015.
Thierfelder, C., Rusinamhodzi, L., Ngwira, A.R., Mupangwa, W., Nyagumbo, I., Kassie, G. T., Cairns, J.E., 2015. Conservation agriculture in Southern Africa: advances in knowledge. Renew. Agric. Food Syst. 30, 328–348.
Thierfelder, C., Baudron, F., Setimela, P., Nyagumbo, I., Mupangwa, W., Mhlanga, B., Lee, N., Gérard, B., 2018. Complementary practices supporting conservation agriculture in southern Africa. A review. Agron. Sustain. Dev. 38, 16.
Valbuena, D., Erenstein, O., Homann-Kee Tui, S., Abdoulaye, T., Claessens, L., Duncan, A.J., Gérard, B., Rufino, M.C., Teufel, N., van Rooyen, A., van Wijk, M.T., 2012. Conservation Agriculture in mixed crop-livestock systems: scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. Field Crops Res. 132, 175–184.
Van den Broeck, G., Grovas, R.R.P., Maertens, M., Deckers, J., Verhulst, N., Govaerts, B., 2013. Adoption of conservation agriculture in the Mexican Bajío. Outlook Agric. https://doi.org/10.5367/oa.2013.0136.
Wainaina, P., Tongruksawattana, S., Quaim, M., 2016. Tradeoffs and complementary in the adoption of improved seeds, fertilizer and natural management technologies in Kenya. Agric. Econ. 47 (2), 351–362. https://doi.org/10.1111/agec.12235.
Wall, P.C., 2007. Tailoring Conservation Agriculture to the needs of small farmers in developing countries: an analysis of issues. J. Crop. Improv. 19, 137–155. https://doi.org/10.1300/J411v19n01_07.
Wollni, M., Lee, D., Thies, J., 2010. Conservation agriculture, organic marketing, and collective action in the Honduran hillsides. Agric. Econ. 41, 373–384. https://doi.org/10.1111/j.1574-0862.2010.00445.x.
Yigezu, Y.A., El-Shater, T., Mugera, A., Aw-Hassan, A., Piggin, C., Haddad, A., Khalil, Y., Loss, S., 2018a. Enhancing adoption of agricultural technologies requiring high initial investment among smallholders. Technol. Forecast. Soc. Change 134, 199–206. https://doi.org/10.1016/j.techfore.2018.06.006.
Yigezu, Y.A., Yirga, C., Kassie, G.T., Aw-Hassan, A., 2018b. Modelling land use decisions in production systems involving multiple crops and varieties. Afr. J. Agric. Resour. Econ. 13 (3), 240–250.
Yigezu, Y.A., Boughlala, M., El-Shater, T., 2019a. Adoption, impacts, and seed demand analysis of improved whet varieties. In: Bishaw, Z., Yigezu, Y.A., Niane, A., Telleria, R.J., Najjar, D. (Eds.), The Moroccan Wheat Sector: Seed System, Varietal Adoption, and Impacts. Cairo, Egypt. https://dx.doi.org/20.500.11766/9682.
Yigezu, Y.A., El-Shater, T., Boughlala, M., Bishaw, Z., Niane, A., Maalouf, F., Degu, W.T., Wery, J., Boutfiras, M., Aw-Hassan, A., 2019b. Legume-based rotations have clear economic advantages over cereal monocropping in dry areas. Agron. Sustain. Dev. 39, 58. https://doi.org/10.1007/s13593-019-0602-2.
Yigezu, Y. A. and El-Shater, T. [Forthcoming]. Socio-economic impacts of zero and reduced tillage in wheat fields of the Moroccan drylands. Agric. Econ.
Yusuf, A.A., Iwuafor, E.N.O., Abaidoo, R.C., Olufajo, O.O., Sanginga, N., 2009. Grain legume rotation benefits to maize in the northern Guinea savanna of Nigeria: fixed nitrogen versus other rotation effects. Nutr. Cycl. Agroecosyst. 84, 129–239. https://doi.org/10.1007/s10705-008-9232-9.
Zheng, C., Jiang, Y., Chen, C., Sun, Y., Feng, J., Deng, A., Song, Z., Zhang, W., 2014. The impacts of conservation agriculture on crop yield in China depend on specific practices, crops and cropping regions. Crop J. 2 (5), 289–296.