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Adoption of climate-smart agriculture among smallholder farmers: Does farmer entrepreneurship matter?

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ABSTRACT

Climate change poses significant challenges to agriculture, with serious impacts on smallholder farmers' food security and livelihoods. Climate-smart agriculture (CSA) is being promoted to facilitate climate change adaptation and mitigation. While there is evidence that CSA supports smallholders' adaption to climate change, the rate of CSA adoption remains low, particularly in sub-Saharan Africa. Previous studies have explained the low adoption based on generic factors such as farm, farmer, institutional and location characteristics, yet little is known about the role of farmers' cognitive traits. This study investigates the influence of farmer entrepreneurial orientation, a cognitive trait reflecting a farmer's innovativeness, proactiveness and propensity to take risks. We use data from smallholder potato farmers in Kenya and estimate a set of multivariate probit models to analyse the adoption decisions. Results show that risk-taking positively influences the adoption of irrigation, changing cultivation calendar, use of certified seed, crop rotation and soil testing. Proactiveness is positively related to the use of irrigation, changing the cultivation calendar and use of certified seed, while it is negatively related to intercropping. Contrary to our hypothesis that innovative farmers are more likely to adopt CSA practices, we find a negative relation between innovativeness and the use of certified seed. After categorizing CSA practices based on the main resources required, we find that risk-taking is positively associated with the adoption of practices that require high intensity of skilled labour and financial resources. Innovativeness is negatively associated with practices that require high intensity of financial resources. Lastly, we find proactiveness to be positively associated with the adoption of finance-intensive practices but negatively associated with unskilled-labour-intensive practices. These findings imply, first, that development practitioners should consider the interrelations among CSA practices and farmer entrepreneurial orientation in designing development interventions. Second, policymakers need to create an environment conducive to farmer entrepreneurship as an indirect way to support the adoption of appropriate CSA practices.

1. Introduction

Global food production is under serious threat from climate change. Particularly in sub-Saharan Africa (SSA) where agriculture is an important sector for economic development, climate change adds another layer of challenges to agricultural production and rural development (Maggio and Sitko, 2019). In Kenya, the main climatic challenges facing smallholder farmers include frequent droughts, periodic floods and unpredictable rainfall patterns, which continue to pose a threat to food and livelihood security (Ochieng et al., 2016). In response to these challenges, various mitigation and adaptation strategies such as climate-smart agriculture (CSA) have been developed and promoted to improve farm productivity and enhance food security (FAO, 2013). However, smallholder farmers in SSA continue to suffer from the effects of climate change, because of their limited adaptive capacity (Asfaw et al., 2016).

CSA encompasses practices and technologies that have the potential to achieve the "triple-win" of increasing food security and incomes, climate change adaptation and mitigation (Campbell et al., 2014). While CSA has been presented as having the ability to deliver synergistic mitigation-adaptation-development outcomes and therefore appeals to policy and development practitioners, no single CSA practice has been shown to deliver the triple-win benefits. Instead, the potential to achieve triple-win is through careful combinations of different CSA practices

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(Ellis and Tschakert, 2019). Despite the potential benefits, CSA practices in developing countries are not achieving their full potential given the low levels of adoption (Westermann et al., 2018). Factors that explain the low adoption of CSA practices include farm and farmer characteristics, and institutional constraints (Bernier et al., 2015) as well as the characteristics of the practices themselves (Senyolo et al., 2018).

While various farm and farmer characteristics have been studied relating to the adoption of CSA (Amadu et al., 2020; Yegbemey et al., 2013), the role of farmers' cognitive traits in adoption decisions remains underexplored (Dessart et al., 2019). Cognitive traits are behavioural or psychological in nature and relate to learning and reasoning: they include, for example, farmers' perception of costs and risks preferences associated with a particular practice (Dessart et al., 2019). Notably, cognitive traits can be shaped as people develop them over time, for instance, through targeted training programmes (Palich and Ray Bagby, 1995), or learning individually or collectively from past experiences. So far, and for decades since the work of Feder et al. (1985), studies on farmers' cognitive traits have largely focused on how risk preferences (the tendency to choose an action or activity with high risks) influence technology adoption decisions (Isik and Khanna, 2003; Jianjun et al., 2015; Liu, 2013). Yet, in addition to this literature stream, we suggest that farmers' risk preferences are not the only cognitive traits driving innovation adoption. Other cognitive traits include perceptions about the benefits of innovations, as well as aspirations, intentions and attitudes (Dessart et al., 2019; Serebrennikov et al., 2020). In terms of literature on farmers' cognitive traits, the theory of planned behaviour (TPB) and theory of reasoned action (TRA) (Arunrat et al., 2017; Borges et al., 2016; Martínez-García et al., 2016) have been widely used to explain farmers' innovation adoptions. These theories pay more attention to understanding the process of innovation adoption with little emphasis on the link to the outcome of adoption, which is the ultimate purpose of the innovation.

To contribute to these literature strands in understanding how farmers' cognitive traits influence innovation adoption, in this paper, we hypothesise that farmer entrepreneurship plays a relevant role in decisions to adopt CSA practices. This happens when potential innovation adopters face uncertain environments such as climate change (York and Venkataraman, 2010). We specifically hypothesise that farmers' entrepreneurial orientation (EO), which reflects not only their risk preferences but also their innovativeness and proactiveness, might represent an important driver of their innovation adoption (Gellynck et al., 2015). Risk-taking signifies the willingness to commit significant resources to activities for which the outcomes are uncertain. Innovativeness is the tendency to deviate from established practices and technologies and the willingness to follow new ideas and practices, through learning and experimenting. Lastly, proactiveness reflects the ability to anticipate and act on emerging opportunities and threats by developing and introducing new ideas and practices before others (Lumpkin and Dess, 1996). This hypothesis aligns with the recent land use policy literature which suggests that entrepreneurship supports farmers in adapting to environmental challenges (De Rosa et al., 2019; Pindado et al., 2018).

Therefore, our focus on farmers' EO adds a valuable explanation, relative to the extant literature, on explaining and predicting farmers' innovation adoption. Recent studies have shown that, when facing both economic and environmental challenges, some farmers are more capable to adapt than others. This heterogeneity in the ability to adapt has been attributed to farmer EO (Barzola Iza and Dentoni, 2020; York and Venkataraman, 2010). For example, the findings of Barzola Iza and Dentoni (2020) indicate that farmers' innovativeness supports the adoption of new farm practices by taking up new ways of farm organisation emerging from access to new information, they refer this to process innovation. Furthermore, Etriya et al. (2019) showed that more entrepreneurial farmers have better farm performance both in terms of technology adoption and income.

Rooted in the strategic management literature, EO might be of specific importance for farmers facing climate-change challenges as they can no longer continue farming as usual: they have to adapt their farming practices to the unpredictably changing environment. One way of adapting is through investment in CSA practices. While this points to the importance of farmer risk-taking behaviour in decisions to invest in CSA practices, exclusive focus on risk-taking behaviour is not sufficient, farmers need to be innovative and proactive (entrepreneurial) in their production decisions when facing climate-change challenges (York and Venkataraman, 2010). For instance, farmer innovativeness has been shown to exert a positive influence on the adoption of water-saving technologies in Italy (Pino et al., 2017). At the farm level, this reflects process innovation, the act of adopting new farm practices and executing new information (Barzola Iza and Dentoni, 2020).

With respect to climate change adaptation, Kangogo et al. (2020) proposed based on theory that higher farmer EO increases farmers' adaptive capacity and, in turn, their propensity to adopt climate change adaptation strategies at farm level. As defined in Adger et al. (2004), adaptive capacity is the ability of a system to modify its characteristics or behaviour in order to cope better with existing or anticipated shocks. Relating to the adaptive capacity as a behavioural characteristic, Grothmann and Patt (2005) describes it as the capacity to learn and to respond flexibly to environmental and socioeconomic changes. EO is the manifestation of proactive and innovative behaviour coupled with readiness to pursue opportunities under uncertainty (Wiklund and Shepherd, 2005). Following these definitions, Eshima and Anderson (2016) have shown that EO contributes to increased adaptive capacity through pursuing entrepreneurial activities. Accordingly, the joint exhibition of innovative, proactive and risk-taking behaviours creates opportunities to respond to needs and challenges (adaptive capacity). In this paper, we test the hypothesis that farmer EO increases farmers' capacity to adapt to climate challenges as manifested by the adoption of CSA practices.

Given this societal and scientific background, this paper addresses the questions of whether and how farmer EO influences the adoption of CSA practices. We use a novel dataset from smallholder potato farmers in Kenya, where we assess both farmer entrepreneurship and a set of control variables.

In testing the hypotheses about farmer EO as a driver of CSA adoption, we contextualise entrepreneurship using a case of smallholder potato farming in Kenya to understand when, why and how entrepreneurship is important (Welter, 2011). The potato-farming context is particularly relevant since potatoes represent a so-far understudied crop in relation to CSA practices. The current literature on the adoption of CSA practices has mainly addressed cereal crops such as maize (Amadu et al., 2020; Kassie et al., 2015) and rice (Ojo and Baiyegunhi, 2019; Trinh et al., 2018). Evidence on the adoption of CSA practices in potato farming remains underdeveloped, yet potato is highly susceptible to climate change (Parker et al., 2019). In Kenya, potato farming contributes significantly to household income and food security (Parker et al., 2019). Hence, understanding potato farmers' decisions to adopt CSA practices is of key importance to policy-makers and development practitioners, as it lays a foundation for the design and implementation of impactful policies and interventions.

The benefits of CSA practices hinge on farmers adopting multiple practices simultaneously to maximise the synergies among CSA practices. Methodologically, some studies have analysed adoption of farm practices as a combination of multiple practices, thus unravelling the salient relationships between different practices as either complements or substitutes (Gebremariam and Tesfaye, 2018; Teklewold et al., 2019; Wainaina et al., 2016). Other studies use a count of practices that farmers have adopted as a proxy of the intensity of adoption (Kpadonou et al., 2017; Muriithi et al., 2018). The weakness of the latter approach is the assumption that adopting more practices is better than adopting fewer practices. In an attempt to overcome this limitation, we adapted a typology proposed in Amadu et al. (2020) that focuses on the intensity of resources required to effectively adopt a CSA practice.

The contribution of this paper is threefold. First, the paper extends the literature on determinants of adoption beyond the generic characteristics such as farmer, farm and institutional to include cognitive traits which have received less attention to date. Second, the paper identifies farmer EO as a specific set of cognitive traits that encompass farmer innovativeness, proactiveness and risk-taking behaviour and explores how these traits influence CSA adoption. Third, building upon the typology developed in Amadu et al. (2020), the analysis relates the three dimensions of farmer EO to the CSA categories based on the main resources necessary for adoption.

The remainder of the paper is structured as follows. Section two presents the theoretical framework underlying this study. Section three presents the data and the empirical model. Section four provides the results and discussion of the main findings, and in the final section, we present the conclusion and implications of this study.

2. Theoretical framework

2.1. CSA practices

Climate-smart agriculture refers to practices that increase productivity and income, build farm resilience and mitigate climate change by reducing greenhouse gas emissions (FAO, 2013). At the farm level, the adoption of CSA practices is context-specific influenced by institutional factors, resource availability and prevailing climate conditions (Lipper et al., 2014). Regardless of the context under consideration, the level of farmer adoption of CSA practices signifies the farmer's adaptive capacity (Asfaw et al., 2016), which in turn depends on the resources that a farmer can access and his/her ability to combine resources (Cinner et al., 2018). Following this, adoption of CSA practices may be explained by the level of farmer entrepreneurship defined as the process of recombining agricultural resources innovatively to create opportunities for value creation and to respond to emerging needs (Shane and Venkataraman, 2000).

Faced with climate change challenges, farmers are increasingly adopting multiple adaptation practices with complementary effects (Amadu et al., 2020; Teklewold et al., 2019). Adopting a combination of practices enables farmers to maximise synergies among CSA practices. This also enables farmers to diversify and improve production in the face of overlapping challenges such as low soil fertility and climate change (Khanna, 2001). Within the farm technology adoption literature, it has been shown that different socioeconomic, institutional and environmental factors influence the adoption of CSA practices (Teklewold et al., 2019). Yet, the effect of farmer cognitive traits such as farmer entrepreneurship remains understudied resulting in an incomplete overview and limited theoretical understanding of how and why these factors affect adoption decisions (Dessart et al., 2019).

2.2. Adoption of agricultural innovations and farmer entrepreneurship

Theories on adoption and diffusion of agricultural innovations have generally centred around three perspectives. First, theories that focus on the characteristics of the innovation explaining when and how diffusion and adoption occur (Rogers, 2003). Relevant determinants are the level of learning investment, initial investment cost and additional labour required when adopting a farm innovation (Senyolo et al., 2018). Second, theories that relate to the farmer's adoption intention and behaviour, such as the TPB (Ajzen, 1991). As to the farmer's adoption intention, Barnes et al. (2019) studied the adoption of precision agricultural technologies and found that attitudinal difference, such as optimism towards the economic benefits of technology leads to an increase in the probability of adoption. Third, theories that focus on the expected utility, using a random utility framework (Dorfman, 1996). While the premise of expected utility theory is to maximize utility taking into account the various adoption constraints including labour and capital among other production constraints, such theories do not explicitly take into account the cognitive and behavioural characteristics that may hinder adoption (Hess et al., 2018).

Relative to the foregoing theories, in this paper we challenge the notion that smallholder farmers are typical price takers and passive decision makers. On the contrary, we argue that smallholder farmers continuously adapt to changing circumstances that affect their farming businesses (Morris et al., 2017). These changing circumstances may be social, economic or environmental including climate change. The process of adapting to these changes requires that farmers act entrepreneurially (McElwee and Smith, 2012) and thus the cognitive traits of risk-taking, innovativeness and proactiveness play important roles (Etriya et al., 2019). The combination of these traits has been referred to as EO (Lumpkin and Dess, 1996).

Broadly speaking, farmer entrepreneurship refers to the process of recombining resources innovatively to pursue opportunities towards the achievement of economic and social goals (Fitz-Koch et al., 2018; Shane and Venkataraman, 2000). Viewed this way, entrepreneurship is a cognitive trait related to the farmers' decision-making styles (Dessart et al., 2019). In Finland for instance, Mikko Vesala et al. (2007) show that when faced with pressure to restructure farming, entrepreneurial identity is part of the solution. Based on farmer self-categorisation as an entrepreneur or not and how this affects farm diversification, Mikko Vesala et al. (2007) focus on eight dimensions of entrepreneurial identity, namely economic values, innovativeness, growth-orientation, risk-taking, self-efficacy, optimism and personal control. They find that compared to traditional farmers, the entrepreneurial farmers perceive themselves as growth-oriented, risk-takers, innovative, optimistic and having more personal control over their farms. These cognitive traits shape how farmers combine resources such as labour, knowledge, skills, finances and physical capital. Hence, entrepreneurial farmers are usually among the first to engage in novel farming and business practices by taking calculated risks and acting innovatively (Barzola Iza et al., 2019).

As the first dimension of EO, innovativeness is the ability to deviate from established practices and technologies towards supporting new ideas, often through learning and experimentation (Lumpkin and Dess, 1996). For farmers facing climate change challenges, innovativeness may induce them to try out CSA practices. As a second EO dimension, proactiveness implicates the ability to anticipate and act on future threats and opportunities. Different from reactive traits (Brzozowski and Cucculelli, 2016), proactive traits are associated with an orientation towards searching or creating new opportunities. Hence, proactive farmers usually are those that first engage in new processes and practices or developing new products. When facing climate change, proactive farmers might foresee and act upon opportunities and threats.

The third EO dimension is the propensity of taking calculated risks (or risk-taking). Taking calculated risks involves committing resources to ventures or activities for which returns are not assured (Rauch et al., 2009). Risk-taking farmers might invest more resources in the adoption of CSA practices, while risk aversion results in under-investment and thus low adoption (Hansen et al., 2019).

This operationalisation of farmer entrepreneurship allows for exploration of the role of the specific dimensions of farmer EO in the adoption of a set of specific CSA practices. The following hypotheses are tested:

H1. . More risk-taking farmers are more likely to adopt CSA practices.

H2. . More innovative farmers are more likely to adopt CSA practices.

H3. . More proactive farmers are more likely to adopt CSA practices.

In addition to the role of farmer EO in farm technology adoption decisions, context-related issues are also important for farmer adoption decisions (Welter et al., 2016). In the adoption of precision farming tools in Italy, Vecchio et al. (2020) define three categories of context-related issues. The first issue (the *who*) relates to the social and demographic characteristics of the farmer, including age, gender, education level, years of farming, involvement in off-farm activities. Considering age, gender and the level of education, evidence shows that relatively younger farmers, men and those with higher levels of education have a higher probability of adopting new farming practices (Kassie et al., 2015; Wainaina et al., 2016). The second issue (the *where*) relates to the structural characteristics of the farm such as farm size. Previous studies show mixed findings on farm size and technology adoption. While some have found that larger farms are more likely to adopt (Teklewold et al., 2013; Trinh et al., 2018), others have found no such effect (Zeweld et al., 2019) or found positive effects for some technologies and negative for others (Kassie et al., 2015). These findings indicate that farm size has a differential effect on the adoption of farm technologies. The last issue (the *why*) relates to the farmer's intrinsic motivation to adopt new farming technologies (Greiner and Gregg, 2011). In this paper, we focus on the *who* question, and instead of focusing only on the social and demographic characteristics of the farmer, we include cognitive traits. We also explore the role of the *where* issue by including variables relating to the farm itself and the institutional environment in which the farm operates.

3. Methodology

3.1. Data and sampling procedure

The data used in this study come from a farm household survey that was conducted from June to August 2019 among smallholder potato farmers in Kenya. While potatoes are grown in almost all arable parts of Kenya, the main potato-producing counties are Meru, Elgeiyo Marakwet, Bungoma, Nakuru, Narok, Bomet, Nyandarua, Nyeri, Taita Taveta and Kiambu. The top five counties in terms of the land under potato cultivation are Meru, Nyandarua, Nakuru, Elgeiyo Marakwet and Kiambu, with Meru and Nakuru accounting for over 30% of the land used for potato (Kaguongo et al., 2014).

A multistage sampling procedure was used to select farmers. In the first stage, Meru and Nakuru counties were purposively selected being two of the leading potato-producing counties in Kenya. Within these two counties, locations (*since 2010 referred to as wards*) with high potato production were selected in consultation with the county extension officers. In particular, Kisima, Timau and Kibirichia locations were selected in Meru county, while Keringet and Molo locations were selected in Nakuru county. Second, we asked the ward extension officers to provide us with the list of potato farmer groups in their locations. From the lists we randomly selected target farmer groups; 39 groups were randomly selected from the locations in Meru county and 18 groups were randomly selected from the locations in Nakuru county. Therefore, a total of 57 potato farmer groups were selected. Third, we acquired the lists of the farmers in all the selected groups and applied a proportional random sampling procedure to select individual farmers to be interviewed.

Given that we did not have the lists of non-group member farmers, we randomly interviewed non-group member farmers in the villages of group member farmers. To do this systematically, enumerators were asked that, after interviewing every second selected group member, to skip two households and interview the third household, only if the farmer was a non-group member. Although this may not yield a perfect random sample, this approach has previously been applied in an attempt to attain a more representative sample in the absence of a population list and with resource constraints (McCord et al., 2015). In total, 792 potato farmers were interviewed comprising 500 group members and 292 non-members. A structured questionnaire was used to collect data on a range of topics including farmer and farm characteristics, farmer EO, potato production and marketing activities.

3.2. Empirical estimation strategy

Based on the collected, data potato farmers are faced with a range of CSA practices to choose from in their attempts to adapt to climate change. Farmers may adopt a single practice or a combination of practices depending on the climate change effects on their farms and the available resources. The adoption decision can thus be modelled using either univariate or multivariate models. However, where adoption of more than one practice is possible, it is necessary to model the decisions using a multivariate technique to account for the interdependence among practices. We, therefore, use a multivariate probit (MVP) econometric technique which models the influence of a set of explanatory variables on the adoption of different CSA practices while allowing the error terms to freely correlate. Part of the correlation in the error terms accounts for the relation among CSA practices as being either complementary or substitutive (Belderbos et al., 2004). Failure to account for the interdependence among the practices may lead to inefficient and biased estimates (Greene, 2008).

The MVP model was formulated using six dummy variables representing the CSA practices applied by farmers (see below for more information on these practices). The MVP model is characterised by a set of binary dependent variables k that is equal to 1 if the i^{th} farmer adopts the CSA practice K[1] and 0 otherwise, such that:

$$Y_{ik}^* = X_i\beta_k + \varepsilon_i, \quad k = 1, \quad \ldots\ldots, \quad 6 \tag{1}$$

and

$$Y_k = \left\{ \begin{array}{ll} 1 & if \quad Y_{ik}^* > 0 \\ 0 & otherwise \end{array} \right\} \quad k = 1, \quad \ldots.., \quad 6. \tag{2}$$

where k denotes the available CSA practices.

In Eq. (1), the assumption is that the i^{th} farmer has a latent variable Y_{ik}^* which captures the unobserved preference associated with the k^{th} choice of CSA practice. The latent variable Y_{ik}^* is assumed to be a linear combination of observed characteristics (X_i) – the farmer and farm characteristics, farmer EO, and institutional characteristics that affect the adoption of k^{th} CSA practice as well as the unobserved characteristics ε_i. The vector of parameters to be estimated is denoted by β_k.

If the adoption of a specific CSA practice is independent of a farmer adopting another CSA practice, then Eqs. (1) and (2) specify a univariate probit model. However, if adopting multiple CSA practices is possible, then it is realistic to assume that the error terms in Eq. (1) jointly follow a multivariate normal distribution with zero conditional mean, a unit variance and symmetric covariance matrix Ω given by:

$$\Omega = \begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} & \rho_{15} & \rho_{16} \\ \rho_{21} & 1 & \rho_{23} & \rho_{24} & \rho_{25} & \rho_{26} \\ \rho_{31} & \rho_{32} & 1 & \rho_{34} & \rho_{35} & \rho_{36} \\ \rho_{41} & \rho_{42} & \rho_{43} & 1 & \rho_{45} & \rho_{46} \\ \rho_{51} & \rho_{52} & \rho_{53} & \rho_{54} & 1 & \rho_{56} \\ \rho_{61} & \rho_{62} & \rho_{63} & \rho_{64} & \rho_{65} & 1 \end{bmatrix} \tag{3}$$

ρ is the pairwise correlation coefficient between the error terms of any two adoption equations in the model. The sign and significance of ρ provide evidence of the nature of the relationship between adoption equations. A positive sign denotes a complementary relationship while a negative sign indicates that the practices are substitutes. This model specification with non-zero off-diagonal elements allows for correlation across the error terms in the latent equations and represents the unobserved characteristics that influence the choice of CSA practices.

The MVP technique models the probability of adopting individual CSA practices with no distinction being made about the nature of practice combinations where it is possible. There is evidence that farmers adopt a combination of CSA practices depending on the intensity of resources required for adoption (Amadu et al., 2020). It is,

[1] Irrigation; Change in Cultivation Calendar; Certified Seed; Crop Rotation; Soil Testing; Intercropping.

Table 1
Description of the variables.

Variable	Description	Mean	Std. dev
Dependent variables			
Irrigation	Applied the practice: *1 = Yes; 0 = No*	0.31	0.46
Change in cultivation calendar	Applied the practice: *1 = Yes; 0 = No*	0.42	0.49
Certified seed	Applied the practice: *1 = Yes; 0 = No*	0.30	0.46
Crop rotation	Applied the practice: *1 = Yes; 0 = No*	0.44	0.50
Soil testing	Applied the practice: *1 = Yes; 0 = No*	0.22	0.41
Intercropping	Applied the practice: *1 = Yes; 0 = No*	0.36	0.48
Independent variables			
Farmer characteristics			
Sex	Sex of the farmer: *1 = Male; 0 = Female*	0.53	0.50
Age	Age of the farmer in years *(Years)*	49.55	12.67
Household size	Number of household members *(Number)*	4.63	1.93
Education	Years of formal education of the farmer *(Years)*	9.14	3.36
Years growing potato	Number of years growing potato *(Years)*	17.91	12.23
Farmer entrepreneurial orientation statements (on a scale of 1 = Completely disagree to 7 =Completely agree)			
Risk-taking			
I prefer to stick to my current farming practices rather than trying new ones[R]		3.76	1.77
With the current challenging farming environment, I prefer to avoid further investment on my farm[R]		3.86	2.50
I am always ready to try new farming practices		4.83	1.64
Innovativeness			
I like to use new farming practices		5.70	1.12
I often improve my farming practices		5.33	1.07
I like to have the latest information on farming practices		5.79	1.22
Proactiveness			
I respond more quickly to changes in the environment of my farm compared to other farmers		4.00	1.47
I am among the first farmers to adopt new farming practices in my village		4.18	1.47
I am constantly looking out for new ways to improve my farm.		5.19	1.37
Farm characteristics			
Land ownership	Land ownership status:*1 = Owned: 0 = Otherwise*	0.78	0.41
Land size owned	Total land owned by the farmer *(Ha)*	1.21	1.61
Information and knowledge			
Access climate info.	Farmer accessed climate information: *1 = Yes; 0 = No*	0.31	0.46
Credit	Received credit for farm operations: *1 = Yes; 0 = No*	0.22	0.42
Group membership	Is the farmer a member of potato farmer org: *1 = Yes; 0 = No*	0.63	0.48
Location			
County	County of the farmer: *1 =Meru; 0 = Nakuru*	0.59	0.49

Note: Std. dev refers to standard deviation.

therefore, necessary to understand the factors that lead to the adoption of a combination of CSA practices.

Consequently, the second part of our econometrics approach involves the application of an additional MVP technique to model the effect of farmer EO on farmers' adoption of different combinations of CSA practices. First, building on the typology of Amadu et al. (2020) we develop a categorisation of CSA practices based on the intensity of resources required for adoption. Following this, if the adoption of a specific CSA category is independent of a farmer adopting another CSA category, then this can be estimated through a univariate probit model. However, if adopting multiple CSA categories is possible, then it can be estimated through a multivariate probit approach. We estimate a MVP model given the possibility of farmers adopting different categories of CSA practices. The estimation follows the procedure described in Eqs. 1 and 2 above. Finally, the unit variance and symmetric covariance matrix Ω for this estimation is given by:

$$\Omega = \begin{bmatrix} 1 & \rho_{12} & \rho_{13} \\ \rho_{21} & 1 & \rho_{23} \\ \rho_{31} & \rho_{32} & 1 \end{bmatrix} \quad (4)$$

3.3. Descriptive statistics: Dependent and independent variables

The descriptive statistics for the CSA practices as dependent variables and all the explanatory variables including the farmer EO are presented in Table 1.

3.3.1. Dependent variables

For the analysis, we consider six CSA practices that relate to potato production and increasingly practised in the study areas in response to climate change. The CSA practices were identified from existing CSA literature and validated by the agriculture extension officers in the selected counties to ensure that practices are applied in potato farming. The first practice is irrigation, which is increasingly being used by farmers in Kenya to curb the effects of drought and heat. In our study sites, the traditional labour-intensive furrow irrigation is commonly applied. While irrigated crops in Kenya are mostly high-value vegetables, the irrigation of potato fields is an emerging practice. Irrigation presents a risk to farmers because there is no guaranteed market for potatoes. The second practice is changing the cultivation calendar. This implies altering cultivation activities such as planting time in an attempt to respond to climate variability (Gebrehiwot and van der Veen, 2013). Farmers were asked whether they had significantly changed their potato cultivation calendar in the last cropping year because of uncertain rainfall patterns; this measure was adapted from Gebrehiwot and van der Veen (2013) and Yegbemey et al. (2014). Changing the cultivation calendar is risky because decisions such as when to plant and what crop variety to grow depend on the knowledge of the farmer and his/her access to information. For potato farming, the cultivation calendar is important given the sensitivity to moisture stress (Lynch et al., 1995).

The third practice is the use of certified potato seed. Certified seeds are high-quality seeds with potential for high yields, tolerant to heat stress and tolerant to pests and diseases (Parker et al., 2019). In Kenya, the use of certified potato seed is low due to high seed and transport costs and limited supply (Okello et al., 2016). In this study, we only considered the use of certified seed since it is not easy for farmers to tell whether the seed they buy from other farmers or local markets meets the standard requirements to be termed as "clean seed". The certification process of clean seed in Kenya remains weak. The fourth practice is crop rotation, thus alternating between crops in successive seasons. Crop

Table 2
Typology of CSA practices based on the main resource requirement.

CSA practice		CSA category		
		Unskilled labour	Skilled labour	Finance
1	Irrigation	√		
2	Change cultivation calendar		√	
3	Certified seed			√
4	Crop rotation		√	
5	Soil testing			√
6	Intercropping	√		

Table 3
Principal component analysis for the farmer EO.

Principal component	% of variance explained	Cronbach alpha	Principal component statistics
Component 1: Innovativeness	34.93	0.865	KMO = 0.703
Component 2: Proactiveness	23.93	0.819	Bartlett Test for Sphericity:
Component 3: Risk-taking	17.67	0.833	$p < 0.000$

See the appendix Table A1 for the PCA component loadings for each item.

rotation helps minimise the build-up of crop-specific pests and pathogens such as potato cyst nematode (Barzman et al., 2015). Crop rotation for potato is a knowledge-intensive practice requiring access to agronomic information. In Kenya, a typical cropping year has two potato growing seasons (Gildemacher et al., 2009b). For crop rotation, it is a requirement that farmers should not plant potatoes in the same field in consecutive seasons. We asked farmers whether they planted potatoes in the same field in the last two seasons. The main crops grown in the study areas which farmers may use as rotation crops include maize, wheat, beans and cabbages. This measure was adapted from (Tey et al., 2014). The fifth practice is soil testing for fertilizer recommendation. This practice is necessary to enable farmers to apply the right fertilizer type on their fields. It aims to reduce the carbon emissions caused by excess fertilizer application (Chen et al., 2013). Additionally, soil testing has been described as a gateway technology to the adoption of other agricultural technologies (Schimmelpfennig and Ebel, 2011). Soil testing is a finance-intensive practice as smallholder farmers do not have the necessary equipment to perform soil testing, hence they have to engage soil-testing companies. We asked farmers whether they had their soil tested in the last cropping year. This measure has been used previously (Liu et al., 2019).

Intercropping is the last CSA practice considered in our analysis. It refers to the cultivation of one or more crops together with potato on the same plot. A typical example of intercropping is maize-legume intercrop for the benefit of nitrogen-fixing (Kassie et al., 2013). Faced with climate change and limited land availability, smallholder potato farmers combine potato with other crops as a diversification strategy to meet their food and nutrition security and increase their income (Kidane et al., 2017). Intercropping is a labour-intensive practice.

3.3.2. Independent variables

We explored literature on technology adoption to select a set of variables that affect farmers' technology adoption decisions. These include the generic variables such as farmer, farm and institutional characteristics as they have been used in previous adoption studies (Amadu et al., 2020; Kpadonou et al., 2017; Trinh et al., 2018; Yegbemey et al., 2013). Besides, we included data on farmer entrepreneurship to elicit the farmer's risk preferences, innovativeness and proactiveness (Etriya et al., 2019; Verhees et al., 2012).

To test the effect of the farmer EO dimensions (risk-taking, innovativeness and proactiveness) on CSA adoption, we adapted the EO measures that have been used previously in (Buli, 2017; Lumpkin and Dess, 2001) to our context. For each dimension, three questions were posed (See Table 1). The responses were recorded on a seven-point rating scale: 1 = completely disagree to 7 = completely agree. Detailed descriptions of the variables are shown in Table 1.

3.4. Categorisation of CSA practices

Adapting the CSA typology of Amadu et al. (2020), we develop a categorisation of CSA practices that conceptually links CSA practices with the main resource required (Table 2). The first category comprises of practices that require additional unskilled labour. This category generally requires farmers to perform basic tasks, such as opening and closing furrows during irrigation. The second category contains practices that require knowledge and skills of the farmer. Knowledge-smart practices (Khatri-Chhetri et al., 2017) require knowledge on what crops to rotate with potato and how to change the cultivation calendar. The last category includes practices that mainly require financial capital. These are practices that farmers must pay for, such as certified seed and soil-testing services.

While developing a typology is a step towards understanding the drivers and barriers of CSA adoption, we acknowledge its limitations, such as the difficulty to assign items to distinct categories (Collier et al., 2012). We solve this by highlighting the most essential resource, that is, the resource that is required in high intensity and without which the practice cannot be adopted. This way of categorisation has recently been used to categorise CSA practices in Malawi (Amadu et al., 2020). This has led to a categorisation based on three types of indispensable resources: 1) unskilled labour, 2) skilled labour, and 3) finance.

3.5. Principal component analysis

To reduce the farmer EO statements to a small number of variables, principal component analysis (PCA) was conducted. PCA is a linear transformation that reduces a set of variables into a smaller number of variables referred to as principal components. In PCA each successive principal component accounts as much as possible to the remaining variability in the data (Field, 2013). Dimension reduction using PCA has been used in previous studies on understanding farmer entrepreneurial orientation (Etriya et al., 2019), farmer social capital (Zhou et al., 2018), consumer food attitudes (Bechtold and Abdulai, 2014) and level of household capabilities (Kihiu, 2016).

In this study, PCA was used to extract the underlying factors of farmer EO which consist of nine items. The identified factors were then used as explanatory variables in the empirical models. The PCA results of the nine farmer EO statements indicated that three components should be retained. We retained components with eigenvalues greater than 1 and applied varimax rotation to determine the category of items (Kaiser, 1958). Component 1 accounts for statements that relate to farmer innovativeness, component 2 includes statements that relate to farmer proactiveness, and component 3 are statements that relate to farmer risk-taking behaviour.

To assess the adequacy of the components extracted, we rely on statistical tests summarised in Table 3. The Cronbach alphas are 0.865, 0.819 and 0.719 for innovativeness, proactiveness and risk-taking components, respectively. All the values of Cronbach alphas are greater than 0.6, indicating a high degree of internal consistency. The Kaiser-Meyer-Olkin (KMO) shows the extent of correlation between the statements measuring each component. The KMO of 0.706 is considered satisfactory. The Bartlett test for Sphericity assesses whether the correlation matrix of the statements differs significantly from the identity matrix. For the PCA to be appropriate the aim is to reject the null hypothesis that the correlation matrix is the identity matrix. As shown in Table 3, the Bartlett Test is significant ($p < 0.000$) indicating a correlation between statements measuring farmer EO.

Table A1
Principal component loadings for farmer EO.

Item	Component 1 (Innovativeness)	Component 2 (Proactiveness)	Component 3 (Risk-taking)
I prefer to stick with my current farming practices rather than trying new ones[R]			0.622
With the current challenging farming environment, I prefer to avoid further investment on my farm[R]			0.616
I am always ready to try new farming practices			0.481
Cronbach's alpha			*0.833*
I like to use new farming practices	0.588		
I often improve my farming practices	0.577		
I like to have the latest information on farming practices	0.549		
Cronbach's alpha	*0.865*		
I respond more quickly to changes in the environment of my farm compared to other farmers		0.638	
I am among the first farmers to adopt new farming practices in my village		0.615	
I am constantly looking out for new ways to improve my farm.		0.461	
Cronbach's alpha		*0.819*	

[R]the item was reversed before analysis.

Using the extracted components, three dependent variables (innovativeness, proactiveness and risk-taking) were constructed for each household (the procedure is detailed in (Córdova, 2009)).

4. Results and discussion

Table 1 shows the descriptive statistics of both the dependent and independent variables. The CSA adoption levels fall below 45% for all the practices (Table 1). This is consistent with previous studies, which have found that CSA adoption remains low in developing countries (Lipper et al., 2014) Table A1.

4.1. Adoption of multiple CSA practices: MVP model results

The MVP model estimates for the adoption of CSA practices are reported in Table 4. The Wald test statistic tests the null hypothesis that the regression coefficients in each equation are jointly equal to zero. The results, $\chi^2(90) = 735.33$; $p > \chi^2$ 0.000 indicate that the error terms across the adoption equations are correlated, and thus the null hypothesis is rejected. This is further supported by the significant likelihood ratio test which reports the significant pairwise correlation coefficient between error terms (Appendix Table A2). The consistency between the Wald test and the likelihood ratio test signifies the robustness of the results. The MVP model is therefore an appropriate estimator to predict adoption decisions. Further results unravel the interdependence between CSA practices. The results (see Appendix Table A2) show that on the one hand, certified seed and irrigation, soil testing and irrigation, changing cultivation calendar and crop rotation, changing cultivation calendar and soil testing, and soil testing and certified seed are used as complementary practices. On the other hand, intercropping and irrigation, and intercropping and certified seed are substitutes.

The key variables of interest in this paper are the dimensions of farmer EO: risk-taking, innovativeness and proactiveness. Table 4 shows the distinct effects of farmer EO dimensions on the adoption of CSA practices. Consistent with previous studies (Isik and Khanna, 2003; Liu, 2013; Zeweld et al., 2019), our results demonstrate that risk-taking plays an important role in CSA adoption. Specifically, we find that risk-taking positively drives the decision to adopt all practices except intercropping.

In our study areas, irrigation is largely applied to grow high-value vegetables such as cabbage, French beans, kale, carrot and garden peas. Irrigating field crops like potato is a new practice, involving two

Table 4
Coefficient estimates of the multivariate probit model for the adoption of individual CSA practices.

Variable	(1) Irrigation		(2) Change in cultivation calendar		(3) Certified seed		(4) Crop rotation		(5) Soil testing		(6) Intercropping	
	Coef	Robust Std. Err	Coef	Robust Std. Err	Coef	Robust Std. Err	Coef	Robust Std. Err	Coef	Robust Std. Err	Coef	Robust Std. Err
Sex	0.468***	0.104	0.141	0.098	0.371***	0.104	0.198**	0.096	0.237**	0.112	-0.421***	0.105
Age	0.027	0.028	0.010	0.026	0.003	0.028	0.038	0.026	-0.021	0.028	-0.008	0.029
Age squared	-0.000	0.000	-0.000	0.000	-0.000	0.000	-0.000*	0.000	0.000	0.000	0.000	0.000
Household size	-0.043	0.030	-0.024	0.026	-0.002	0.027	0.005	0.025	-0.009	0.032	0.014	0.028
Education	0.014	0.017	0.026*	0.015	0.036**	0.017	0.008	0.015	0.041**	0.018	-0.015	0.016
Years growing potato	0.009	0.006	0.006	0.006	0.008	0.006	0.004	0.005	0.012**	0.006	-0.016***	0.006
Risk-taking	0.092**	0.039	0.215***	0.042	0.103***	0.039	0.111***	0.035	0.112**	0.047	0.007	0.035
Innovativeness	-0.055	0.039	0.025	0.036	-0.070**	0.039	0.029	0.035	-0.066	0.042	-0.018	0.038
Proactiveness	0.086**	0.039	0.068*	0.036	0.083**	0.039	0.014	0.035	-0.059	0.040	-0.366***	0.040
Land ownership	0.454***	0.130	0.051	0.117	0.229*	0.129	0.230**	0.116	0.241*	0.138	0.263**	0.130
Total land size	-0.016	0.033	0.007	0.030	0.055	0.038	0.075	0.048	0.116**	0.054	-0.174***	0.059
Access climate info	-0.038	0.110	0.487***	0.105	0.373***	0.109	0.194*	0.102	0.435***	0.112	-0.053	0.117
Credit	0.117	0.121	0.195*	0.116	0.303**	0.120	-0.008	0.116	0.357***	0.122	-0.099	0.132
Group membership	0.110	0.121	0.235**	0.115	0.353***	0.125	0.331***	0.112	0.337**	0.138	-0.545***	0.117
County	0.944***	0.120	-0.057	0.104	0.460***	0.114	0.068	0.103	0.104	0.125	0.223*	0.118
Wald chi^2 (90)	735.33***											
Observations	792											

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A2
Correlation coefficients of error terms after the MVP model estimation for individual practices.

CSA practices	Irrigation	Change cultivation calendar	Certified seed	Crop rotation	Soil testing	Intercropping
Irrigation	1.000					
Change cultivation calendar	-0.051 (0.060)	1.000				
Certified seed	0.122** (0.061)	-0.047 (0.064)	1.000			
Crop rotation	-0.033 (0.058)	0.246*** (0.054)	-0.068 (0.058)	1.000		
Soil testing	0.118* (0.069)	0.163** (0.065)	0.198*** (0.066)	0.041 (0.064)	1.000	
Intercropping	-0.175*** (0.062)	0.061 (0.061)	-0.126* (0.070)	0.012 (0.061)	0.037 (0.074)	1.000

Likelihood ratio test $\chi^2(15) = 49.72$; $p > \chi^2$ 0.000.

Table 5
Multivariate probit model estimates for the categories of CSA practices.

Variable	Unskilled labour-intensive CSA practices		Skilled labour-intensive CSA practices		Finance-intensive CSA practices	
	Coef	Robust Std. Err	Coef	Robust Std. Err	Coef	Robust Std. Err
Sex	-0.019	0.100	0.171*	0.100	0.335***	0.100
Age	0.019	0.026	0.026	0.026	-0.012	0.026
Age squared	-0.000	0.000	-0.000	0.000	0.000	0.000
Household size	-0.019	0.026	-0.007	0.026	-0.007	0.027
Education	0.003	0.016	0.030*	0.015	0.039**	0.016
Years growing potato	-0.003	0.006	0.006	0.005	0.011**	0.006
Risk-taking	0.048	0.034	0.219***	0.037	0.114***	0.036
Innovativeness	-0.048	0.036	0.047	0.036	-0.071*	0.038
Proactiveness	-0.203***	0.039	0.024	0.036	0.064*	0.037
Land ownership	0.470***	0.116	0.269**	0.119	0.299**	0.124
Total land size	-0.069*	0.036	0.003	0.038	0.092	0.057
Access climate info	-0.012	0.109	0.425***	0.111	0.443***	0.106
Credit	0.143	0.119	0.093	0.124	0.441***	0.117
Group membership	-0.304***	0.116	0.458***	0.114	0.353***	0.116
County	0.974***	0.109	-0.060	0.105	0.352***	0.109
Wald chi^2 (45)	496.84***					
Observations	792					

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

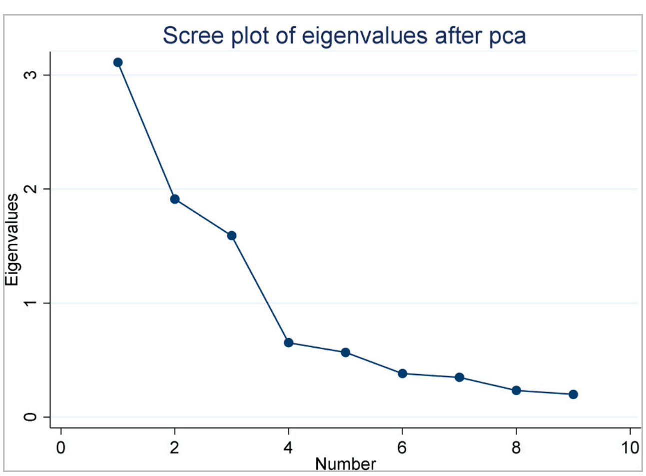

Fig. A1. Scree plot showing the number of components retained after PCA.

types of risks. First, potato requires more labour as it is often grown in large plots of land compared to high-value vegetables. Second, higher production due to irrigation brings forth a high market risk because the market is not guaranteed. This implies that risk-taking farmers are more likely to take the risk of applying irrigation in potato fields.

Like any other new practice, changing the cultivation calendar is a risky strategy particularly when weather information is unavailable or unreliable. For instance, if a potato farmer changes the cultivation calendar and the onset of rains does not match with the planting dates, that farmer is likely to incur both yield and tuber quality loss. On the other hand, where a farmer can plant just before the rains start, holding other factors constant, the benefits of yield and tuber quality are assured. This may explain the positive relation between risk-taking and the changing cultivation calendar. Farmers that are willing to take risks are more likely to change the cultivation calendar. This is consistent with the findings of Yegbemey et al. (2014) who found that farmers in Benin adjusted their cultivation calendars even with limited access to advisory services and with no insurance.

The use of certified seed and testing the soil represent two practices that require additional finance. Specifically, certified seed forms the largest proportion of potato production costs (Okello et al., 2016). The risk associated with the investment in certified potato seed and testing the soil is higher in the face of adverse climatic change. The farmer may not be able to recover the investment costs, and the risk is even higher when seeds are purchased on credit. This explains our results that risk-taking farmers are more likely to adopt certified seed and soil testing practices. This is consistent with the findings of Kassie et al. (2013), who reported that risk-taking farmers are more likely to invest in improved seed varieties in Tanzania.

Crop rotation requires knowledge about which crop to rotate with potato, and in which rotation cycles. Crop rotation is associated with higher yields, improved soil fertility and reduced pest and disease incidence. Apart from the knowledge requirements, crop rotation is constrained by small land sizes, a characteristic of the majority of smallholder farmers. Crop rotation prescribes that potatoes can only be grown on a piece of land once every three seasons, therefore, a farmer can only grow potatoes on one-third of her land. This perhaps explains the positive relationship between risk-taking and the decision to apply crop rotation. Risk-taking farmers are willing to forego the short-term benefits of continuing potato farming without rotation for long-term benefits of high yields which result from appropriate crop rotation. In a recent study, Boyabatlı et al. (2019), demonstrate that while crop rotation planning is beneficial in the long run, the risk of short term revenue losses is inevitable. They argue that the losses may be minimised by efficient rotation planning which takes into account market dynamics and crops used in the rotation. This argument is consistent with Muriithi et al. (2018) who found that farmers with small farm sizes are less likely to apply crop rotation. We found that with small farm sizes, farmers practice limited crop rotation and mainly produce staple food crops. The limited crop rotation result from the inability of land constrained farmers (given the small farm sizes) to reduce the area under staple food crops in order to practice crop rotation. Attempts to reduce the area under staple food crops for rotation purposes puts the household food security at risk.

Contrary to our hypothesis that more innovative farmers are more likely to adopt CSA practices, we find a negative relation between farmer innovativeness and the use of certified seed. One possible explanation is that because of the high cost and limited availability certified potato seed, innovative farmers invest in learning and experimenting with on-farm potato seed technologies such as positive selection. Positive selection is a farm-level potato seed multiplication technique carried out by farmers in two steps (a) identifying and marking the best potato plants in the field, and (b) harvesting the marked plants and storing the tubers separately as seed for the next season. This is a knowledge-intensive practice that requires farmers to be trained. If correctly applied, the yield increase in potato can be more than 100% compared to the common practice of recycling potato seed (Gildemacher et al., 2012).

Finally, we find that farmer proactiveness is positively related to the use of irrigation, changing the cultivation calendar and use of certified seed, however, it is negatively related to the adoption of intercropping in potato growing. As proactiveness is the tendency to be a first-mover in attempts to respond to needs and take advantage of opportunities, proactive farmers are more likely to be the first to irrigate potato fields, change cultivation calendar of their farms and use certified seeds (especially for crops such as potato where the majority of the farmers still use recycled seed). Our results corroborate with the findings of Hansen (2015) who found that proactive behaviour is necessary for farmers to adapt technologies to their specific farm needs. In the Netherlands and Slovenia, Verhees et al. (2011) found that farmer proactiveness is the most influential EO dimension for farm performance.

Conversely, we find a negative effect of farmer proactiveness on the decision to intercrop potato with other crops. Existing literature identifies two main reasons for intercropping (Snapp et al., 2010), these are; a) to ensure that they have a variety of crops for household food security needs, and b) to spread risk (such that when one crop fails because of insufficient rainfall, another crop may survive). While intercropping may be viewed as a beneficial practice, it may not be applicable to all crops. Some crops are recommended to be grown in monocropping systems to increase yields and for efficient application of other cultivation practices. We found that more proactive potato farmers do not practice intercropping, this is because they are market-oriented in their production decisions. This market orientation of more proactive farmers is further shown by the positive relation between proactiveness and practices such as the use of certified seed and application of irrigation. On the other hand, less proactive farmers are more concerned with household food security than producing for the market, therefore, they intercrop their potato with other crops to increase household food diversity.

In addition to the effect of farmer EO dimensions on the adoption of CSA practices, we also discuss the effect of other control variables. First, beyond farmer EO, the gender of the farmer plays an important role in adoption decisions. Often in sub-Saharan Africa, women farmers are constrained in accessing productive resources and this explains why the adoption of farm innovations is lower for women farmers compared to that of their counterpart men (Kpadonou et al., 2017). Our findings corroborate this argument. We find male farmers to be more likely to adopt irrigation, certified seed, crop rotation and soil testing. On the contrary, women are more likely to practice intercropping. Women in Sub-Saharan Africa mainly rely on own farm food production for their household food and nutrition security (Teklewold et al., 2019).

Second, education is positively associated with the adoption of certified seed and soil testing, practices that require financial investment on the part of the farmer. Plausibly, more educated farmers are more informed about farm innovations, have more sources of income and thus less financial constraints to invest in financial-intensive innovations. This aligns with the findings of Wainaina et al. (2016) who found that more educated Kenyan smallholders are more likely to adopt improved maize seeds and fertilizer given their knowledge and additional income sources. Third, as expected, we find that access to credit is positively associated with the adoption of financial-intensive practices these are certified seed and soil testing. This is in line with previous studies (Ojo and Baiyegunhi, 2019). It implies that financially constrained farmers may overcome this constraint by accessing credit services.

Fourth, land size is positively associated with the adoption of soil testing but negatively associated with intercropping. For instance, farmers with larger land size would be willing to invest in soil testing given their scale advantage. The finding of a positive relationship between land size and adoption decisions is consistent with previous findings (Kpadonou et al., 2017). The inverse relationship between land size and intercropping suggests that small land size induces diversification (intercropping) particularly to meet household food needs. This is consistent with recent findings by Teklewold et al. (2019).

Fifth, in terms of membership in farmer organisations, we find a positive and significant relationship with changing the cultivation calendar, certified seed, crop rotation and soil testing. Membership in farmer organisations indicates how farmers are socially connected and their ability to access information and other services such as credit and market. Access to such services through membership in farmer organisations increase the farmers' adaptive capacity and thus, the probability of adoption of CSA practices. This is consistent with the findings of Ojo and Baiyegunhi (2019) and Kassie et al. (2013), who found a positive and significant relationship between adoption of agrochemical and varying planting and harvesting date in Nigeria, and chemical fertilizer in Tanzania, respectively.

4.2. Adoption of the categories of CSA practices: multivariate probit model results

We have categorised CSA practices into three groups reflecting the intensity of resource requirement (Table 2): unskilled labour, skilled labour and financial resources. Table 5 gives the multivariate probit model estimates predicting the effect of farmer EO dimensions on the decision to adopt the various categories of CSA practices.

The MVP results in Table 5 show that, first, risk-taking is positively associated with the adoption of practices that require high intensity of skilled labour and financial resources. In other words, the probability of adopting practices that require skilled labour and financial resources is higher for farmers that are more risk-taking compared to risk-averse farmers. These resources require farmers to invest in assets that may not be within the farm, for instance, in searching for production knowledge or finance that is often sought from financial institutions. This finding is in line with Kassie et al. (2013), who found that risk-taking farmers in rural Tanzania were more likely to adopt practices that require financial resources.

Second, our results show that innovativeness is negatively associated with the adoption of practices that require high intensity of financial resources. As farmers become more innovative, they pursue innovative ways to minimize financial investment, hence more innovative farmers are less likely to adopt finance-intensive CSA practices. This is in line with past evidence of Bowman and Zilberman (2013) that innovativeness allows farmers to pursue activities that reduce financial and physical risks and labour requirements while increasing income. Therefore, innovative potato farmers in Kenya are expected to reduce the adoption of finance-intensive CSA practices as they replace them with less finance-intensive practices. Furthermore, results show that, though not significant, innovativeness and adoption of skilled labour-intensive CSA practices are positively correlated (Table 5).

Third, we find that farmer proactiveness is negatively associated with the adoption of unskilled labour-intensive CSA practices but positively associated with the adoption of finance-intensive CSA practices. In other words, more proactive farmers are less likely to adopt practices that predominantly require unskilled labour and more likely to adopt practices that predominantly require financial investment. This might mean that proactive farmers constantly look for ways to improve their farms by continuously seeking agricultural information and training, thus providing them with knowledge and skills sufficient to invest in finance-intensive practices and avoid unskilled labour-intensive practices.

5. Conclusion and implications

As climate change is a challenge to food security and livelihoods worldwide, recent academic discussions on how farmers can adapt to climate change have focused on the adoption of CSA practices. In this paper, we aimed to contribute to explaining when and why the adoption of CSA practices occurs, by analysing farmer entrepreneurship, and more specifically by three dimensions of farmer EO (innovativeness, proactiveness and risk-taking) as the hypothesised drivers.

Our empirical results first revealed that farmers adopt multiple CSA practices simultaneously and in combinations as either complements or substitutes. Specifically, certified seed and irrigation, soil testing and irrigation changing cultivation calendar and crop rotation, changing cultivation calendar and soil testing, and soil testing and certified seed are complementary practices. Vice versa, intercropping and irrigation, and intercropping and certified seed are substitutes. Furthermore, the results provide empirical evidence for the role of farmer EO dimensions in the adoption of CSA practices. We show that the EO dimensions have a variety of effects. First, risk-taking increases the likelihood of adopting all the practices except intercropping, which show a non-significant effect. Second, innovativeness reduces the likelihood of adopting certified seed. Third, proactiveness positively influences the adoption of irrigation, changing cultivation calendar and certified seed, but has a negative effect on the adoption of intercropping. When the categories of CSA practices are considered, risk-taking has a positive effect on the adoption of skilled labour-intensive and finance-intensive CSA practices; innovativeness has a negative effect on the adoption of finance-intensive CSA practices; lastly, proactiveness has a positive effect on the adoption of finance-intensive CSA practices and a negative effect on the adoption of unskilled labour-intensive CSA practices. In relation to previous studies that have focused only on the farmer risk preferences, we show that while risk-taking behaviour is important, risk-taking alone is not sufficient in explaining farmers adoption decisions. Taking an EO perspective which accounts for risk-taking, innovativeness and proactiveness provide a deeper understanding of the adoption decisions.

This paper contributes to the literature on innovation adoption at the farm level. First, it unravels the effect of farmer EO on the adoption of CSA practices, the diverse effects of farmer EO on CSA adoption contribute to the ongoing debate around theorising and measuring EO either as a unidimensional or a multidimensional concept (Covin and Wales, 2012). We show that measuring EO as a multidimensional rather than a unidimensional concept reveals important cognitive traits of smallholder farmers that matter for their decision-making on CSA practices. At the same time, this is a step away from studies that focus only on generic factors such as farm characteristics, farmer characteristics and institutional constraints (Kpadonou et al., 2017; Teklewold et al., 2019). Second, it develops a categorisation of CSA practices based on the intensity of resource needs, thus overcoming the limitation of assuming that adopting more practices is better than fewer practices (Muriithi et al., 2018; Teklewold et al., 2013). Understanding how farmer entrepreneurship and resource needs affect the adoption of CSA practices lays a solid foundation for the design and implementation of more tailored policies and intervention programmes.

These findings lead to the following two recommendations for agricultural development practitioners and policy-makers. First, given the low rate of CSA adoption in potato farming, we suggest that entrepreneurship programmes in potato farming deserve policy attention as part of national and county government strategies for adaptation and resilience to climate change. In Kenya, potato is the second most important crop after maize contributing to household food and livelihood security (Muthoni and Nyamongo, 2009), and as such, potato production needs to increase even in the face of climate change. Additionally, focusing on CSA practices in potato farming is important as potato crop is more vulnerable to climate change as compared to other field crops (Lynch et al., 1995). Thus, investing in the diffusion and adoption of CSA practices in potato farming is crucial. To accomplish so, our findings suggest that agricultural extension departments, development agencies and policy-makers need to integrate agronomic and entrepreneurship (i.e., social and business-oriented) knowledge in their training services for farmers. These services involving entrepreneurship knowledge provision might require important public (and perhaps private) investments, as – generally in Sub-Saharan Africa – farmers currently receive agronomic training with limited entrepreneurship training. Finally, along with training, policy-makers would need to develop and implement agricultural policies that support farmer entrepreneurship, for example, by facilitating market transactions and by creating a business climate conducive for farmers to innovate and take calculated risks. Such policy support can, for example, facilitate access to other support services such as credit, and encourage the formation and participation in farmer organisations which may provide diverse services such as credit, marketing and advisory services to smallholder farmers (Poulton et al., 2010).

Second, our findings suggest that entrepreneurship training and education programmes dedicated to farmers must be tailored to influence the three dimensions of EO that we analysed: risk-taking, innovativeness and proactiveness. This means that to translate each of these three farmer EO dimensions into the adoption of appropriate CSA practices, access to specific support services is necessary. For instance, to stimulate the adoption of finance-intensive CSA practices, tailored training on risk management in relation to CSA adoption will be crucial, along with providing accessible and affordable credit facilities. While training on risk management in the CSA adoption enhances farmers' risk-taking behaviour, it is important to note that in general, the degree of risk-taking, innovative and proactive behaviours are not the same for all farmers. Thus, farmer training on entrepreneurship for climate adaptation should not be designed as a one-size-fits-all activity. Instead, tailored and incremental training that fits farmers' EO dimensions and their resources at hand would be more effective for the adoption of appropriate CSA practices. For example, training to farmers with low risk-taking behaviour may focus on CSA practices that bear low risks and require lower financial investments, while training to those with higher risk-taking behaviour may focus on how to take calculated risks while investing in financial-intensive practices. One approach to deliver such tailored and incremental training to different sets of farmers might be through a farmer field schools approach that encourages experiential learning activities and group experiments designed for different groups of farmers (Chandra et al., 2017). This enables farmers to acquire the specific dimensions of EO that they need for adopting CSA practices together with the resources that they might need.

Our study is limited by two issues. First, the geographical coverage, as the study was conducted in two potato producing counties in Kenya, Meru and Nakuru. Future research to understand the effect farmer entrepreneurship on the adoption of farm innovations would benefit from studying farmers in different agroecological zones with different climate, soil conditions and producing different crops to strengthen the generalizability of results. Second, the study used cross-sectional data, thus collected at one point in time. Future research needs to consider collecting panel data that will allow studying the farmers' evolution of the EO dimensions over time to better understand the entrepreneurial process and the effectiveness of interventions meant to improve farmer entrepreneurship. Furthermore, it may be relevant for future research to study the impact of the adoption of CSA practices on potato yield, income and household food and nutrition security. This is important because promoting the adoption of CSA practices with established benefits may trigger an increase in adoption. It also offers more information to practitioners on resource needs they should focus on in the design of development interventions.

CRediT authorship contribution statement

Daniel Kangogo: Conceptualization, Methodology, Data analysis and curation, Writing – original draft, and final draft preparation. **Domenico Dentoni**: Conceptualization, Writing – review & Editing**. Jos Bijman:** Conceptualization, Writing – review & Editing.

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Appendix

Fig. A1.

References

Adger, W.N., Brooks, N., Bentham, G., Agnew, M., Eriksen, S., 2004. New indicators of vulnerability and adaptive capacity. Technical Report 7. Tyndall Centre for Climate Change Research. University of East Anglia, Norwich.

Ajzen, I., 1991. The theory of planned behavior. Organ. Behav. Hum. Decis. Process. 50 (2), 179–211.

Amadu, F.O., McNamara, P.E., Miller, D.C., 2020. Understanding the adoption of climate-smart agriculture: a farm-level typology with empirical evidence from southern Malawi. World Dev. 126, 104692 https://doi.org/10.1016/j.worlddev.2019.104692.

Arunrat, N., Wang, C., Pumijumnong, N., Sereenonchai, S., Cai, W.J., 2017. Farmers' intention and decision to adapt to climate change: a case study in the Yom and Nan basins, Phichit province of Thailand. J. Clean. Prod. 143, 672–685. https://doi.org/10.1016/j.jclepro.2016.12.058.

Asfaw, S., McCarthy, N., Lipper, L., Arslan, A., Cattaneo, A., 2016. What determines farmers' adaptive capacity? Empirical evidence from Malawi. Food Secur. 8 (3), 643–664. https://doi.org/10.1007/s12571-016-0571-0.

Barnes, A.P., Soto, I., Eory, V., Beck, B., Balafoutis, A., Sánchez, B., Gómez-Barbero, M., 2019. Exploring the adoption of precision agricultural technologies: a cross regional study of EU farmers. Land Use Policy 80, 163–174. https://doi.org/10.1016/j.landusepol.2018.10.004.

Barzman, M., Bàrberi, P., Birch, A.N.E., Boonekamp, P., Dachbrodt-Saaydeh, S., Graf, B., Sattin, M., 2015. Eight principles of integrated pest management. Agron. Sustain. Dev. 35 (4), 1199–1215. https://doi.org/10.1007/s13593-015-0327-9.

Barzola Iza, C.L., Dentoni, D., 2020. How entrepreneurial orientation drives farmers' innovation differential in Ugandan coffee multi-stakeholder platforms. J. Agribus. Dev. Emerg. Econ. 10, 629–650. https://doi.org/10.1108/jadee-01-2020-0007.

Barzola Iza, C.L., Dentoni, D., Mordini, M., Isubikalu, P., Oduol, J.B.A., Omta, O., 2019. The Role of Farmers' Entrepreneurial Orientation on Agricultural Innovations in Ugandan Multi-Stakeholder Platform. In The Climate-Smart Agriculture Papers. Springer, Cham, Switzerland, pp. 201–213.

Bechtold, K.-B., Abdulai, A., 2014. Combining attitudinal statements with choice experiments to analyze preference heterogeneity for functional dairy products. Food Policy 47, 97–106. https://doi.org/10.1016/j.foodpol.2014.05.007.

Belderbos, R., Carree, M., Diederen, B., Lokshin, B., Veugelers, R., 2004. Heterogeneity in R&D cooperation strategies. Int. J. Ind. Organ. 22 (8–9), 1237–1263. https://doi.org/10.1016/j.ijindorg.2004.08.001.

Bernier, Q., Meinzen-Dick, R.S., Kristjanson, P.M., Haglund, E., Kovarik, C., Bryan, E., Silvestri, S., 2015. Gender and institutional aspects of climate-smart agricultural practices: evidence from Kenya. CGIAR Research Program on Climate Change. Agriculture and Food Security (CCAFS), Copenhagen, Denmark.

Borges, J.A.R., Tauer, L.W., Lansink, A.G.J.M.O., 2016. Using the theory of planned behavior to identify key beliefs underlying Brazilian cattle farmers' intention to use improved natural grassland: a MIMIC modelling approach. Land Use Policy 55, 193–203. https://doi.org/10.1016/j.landusepol.2016.04.004.

Bowman, M.S., Zilberman, D., 2013. Economic factors affecting diversified farming systems. Ecol. Soc. 18 (1), art33. https://doi.org/10.5751/es-05574-180133.

Boyabatlı, O., Nasiry, J., Zhou, Y., 2019. Crop planning in sustainable agriculture: dynamic farmland allocation in the presence of crop rotation benefits. Manag. Sci. 65 (5), 2060–2076. https://doi.org/10.1287/mnsc.2018.3044 mnsc.2018.3044.

Brzozowski, J., Cucculelli, M., 2016. Proactive and reactive attitude to crisis: evidence from european firms. Entrep. Bus. Econ. Rev. 4 (1), 181–191. https://doi.org/10.15678/eber.2016.040111.

Buli, B.M., 2017. Entrepreneurial orientation, market orientation and performance of SMEs in the manufacturing industry. Manag. Res. Rev. 40 (3), 292–309. https://doi.org/10.1108/mrr-07-2016-0173.

Campbell, Thornton, P., Zougmoré, R., van Asten, P., Lipper, L., 2014. Sustainable intensification: what is its role in climate smart agriculture. Curr. Opin. Environ. Sustain. 8, 39–43. https://doi.org/10.1016/j.cosust.2014.07.002.

Chandra, A., Dargusch, P., McNamara, K.E., Caspe, A.M., Dalabajan, D., 2017. A study of climate-smart farming practices and climate-resiliency field schools in Mindanao, the Philippines. World Dev. 98, 214–230. https://doi.org/10.1016/j.worlddev.2017.04.028.

Chen, C., Pan, J., Lam, S.K., 2013. A review of precision fertilization research. Environ. Earth Sci. 71 (9), 4073–4080. https://doi.org/10.1007/s12665-013-2792-2.

Cinner, J., Adger, W.N., Allison, E.H., Barnes, M.L., Brown, K., Cohen, P.J., Morrison, T. H., 2018. Building adaptive capacity to climate change in tropical coastal communities. Nat. Clim. Change 8 (2), 117–123. https://doi.org/10.1038/s41558-017-0065-x.

Collier, D., LaPorte, J., Seawright, J., 2012. Putting typologies to work: concept formation, measurement, and analytic rigor. Political Res. Q. 65 (1), 217–232. https://doi.org/10.1177/1065912912437162.

Córdova, A., 2009. Methodological note: measuring relative wealth using household asset indicators. Am. Insights 6, 1–9.

Covin, J.G., Wales, W.J., 2012. The measurement of entrepreneurial orientation. Entrep. Theory Pract. 36 (4), 677–702. https://doi.org/10.1111/j.1540-6520.2010.00432.x.

De Rosa, M., McElwee, G., Smith, R., 2019. Farm diversification strategies in response to rural policy: a case from rural Italy. Land Use Policy 81, 291–301. https://doi.org/10.1016/j.landusepol.2018.11.006.

Dessart, F.J., Barreiro-Hurlé, J., van Bavel, R., 2019. Behavioural factors affecting the adoption of sustainable farming practices: a policy-oriented review. Eur. Rev. Agric. Econ. 46 (3), 417–471.

Dorfman, J.H., 1996. Modeling multiple adoption decisions in a joint framework. Am. J. Agric. Econ. 78 (3), 547–557. https://doi.org/10.2307/1243273.

Ellis, N.R., Tschakert, P., 2019. Triple-wins as pathways to transformation? A critical review. Geoforum 103, 167–170. https://doi.org/10.1016/j.geoforum.2018.12.006.

Eshima, Y., Anderson, B.S., 2016. Firm growth, adaptive capability, and entrepreneurial orientation. Strateg. Manag. J. 38 (3), 770–779. https://doi.org/10.1002/smj.2532.

Etriya, E., Scholten, V.E., Wubben, E.F.M., Omta, S.W.F., 2019. The impact of networks on the innovative and financial performance of more entrepreneurial versus less entrepreneurial farmers in West Java, Indonesia. NJAS Wagening. J. Life Sci. 89, 1–14. https://doi.org/10.1016/j.njas.2019.100308.

FAO, 2013. Climate-smart Agriculture: Sourcebook. FAO, Rome, Italy.

Feder, G., Just, R.E., Zilberman, D., 1985. Adoption of agricultural innovations in developing countries: a survey. Econ. Dev. Cult. Change 33 (2), 255–298. https://doi.org/10.1086/451461.

Field, A., 2013. Discovering Statistics using IBM SPSS Statistics. Sage Publications, London.

Fitz-Koch, S., Nordqvist, M., Carter, S., Hunter, E., 2018. Entrepreneurship in the agricultural sector: a literature review and future research opportunities. Entrep. Theory Pract. 42 (1), 129–166. https://doi.org/10.1177/1042258717732958.

Gebrehiwot, T., van der Veen, A., 2013. Farm level adaptation to climate change: the case of farmer's in the Ethiopian highlands. Environ. Manag. 52 (1), 29–44. https://doi.org/10.1007/s00267-013-0039-3.

Gebremariam, G., Tesfaye, W., 2018. The heterogeneous effect of shocks on agricultural innovations adoption: microeconometric evidence from rural Ethiopia. Food Policy 74, 154–161. https://doi.org/10.1016/j.foodpol.2017.12.010.

Gellynck, X., Cardenas, J., Pieniak, Z., Verbeke, W., 2015. Association between innovative entrepreneurial orientation, absorptive capacity, and farm business performance. Agribusiness 31 (1), 91–106. https://doi.org/10.1002/agr.21394.

Gildemacher, P.R., Kaguongo, W., Ortiz, O., Tesfaye, A., Woldegiorgis, G., Wagoire, W. W., Leeuwis, C., 2009b. Improving potato production in Kenya, Uganda and Ethiopia: a system diagnosis. Potato Res. 52 (2), 173–205. https://doi.org/10.1007/s11540-009-9127-4.

Gildemacher, P.R., Leeuwis, C., Demo, P., Borus, D., Schulte-Geldermann, E., Mundia, P., Struik, P.C., 2012. Positive selection in seed potato production in Kenya as a case of successful research-led innovation. Int. J. Technol. Manag. Sustain. Dev. 11 (1), 67–92. https://doi.org/10.1386/tmsd.11.1.67_1.

Greene, W.H., 2008. Econometric Analysis. Prentice Hall, New Jersey.

Greiner, R., Gregg, D., 2011. Farmers' intrinsic motivations, barriers to the adoption of conservation practices and effectiveness of policy instruments: empirical evidence from northern Australia. Land Use Policy 28 (1), 257–265. https://doi.org/10.1016/j.landusepol.2010.06.006.
Grothmann, T., Patt, A., 2005. Adaptive capacity and human cognition: the process of individual adaptation to climate change. Glob. Environ. Change 15 (3), 199–213. https://doi.org/10.1016/j.gloenvcha.2005.01.002.
Hansen, B.G., 2015. Robotic milking-farmer experiences and adoption rate in Jæren, Norway. J. Rural Stud. 41, 109–117. https://doi.org/10.1016/j.jrurstud.2015.08.004.
Hansen, J., Hellin, J., Rosenstock, T., Fisher, E., Cairns, J., Stirling, C., Campbell, B., 2019. Climate risk management and rural poverty reduction. Agric. Syst. 172, 28–46. https://doi.org/10.1016/j.agsy.2018.01.019.
Hess, S., Daly, A., Batley, R., 2018. Revisiting consistency with random utility maximisation: theory and implications for practical work. Theory Decis. 84 (2), 181–204. https://doi.org/10.1007/s11238-017-9651-7.
Isik, M., Khanna, M., 2003. Stochastic technology, risk preferences, and adoption of site-specific technologies. Am. J. Agric. Econ. 85 (2), 305–317. https://doi.org/10.1111/1467-8276.00121.
Jianjun, J., Yiwei, G., Xiaomin, W., Nam, P.K., 2015. Farmers' risk preferences and their climate change adaptation strategies in the Yongqiao District, China. Land Use Policy 47, 365–372. https://doi.org/10.1016/j.landusepol.2015.04.028.
Kaguongo, W., Maingi, G., Giencke, S., 2014. Post-harvest losses in potato value chains in Kenya: analysis and recommendations for reduction strategies. Top Kopie GmbH. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Frankfurt.
Kaiser, H.F., 1958. The varimax criterion for analytic rotation in factor-analysis. Psychometrika 23 (3), 187–200. https://doi.org/10.1007/Bf02289233.
Kangogo, D., Dentoni, D., Bijman, J., 2020. Determinants of farm resilience to climate change: the role of farmer entrepreneurship and value Chain collaborations. Sustainability 12 (3), 868. https://doi.org/10.3390/su12030868.
Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., Mekuria, M., 2013. Adoption of interrelated sustainable agricultural practices in smallholder systems: evidence from rural Tanzania. Technol. Forecast. Soc. Change 80 (3), 525–540. https://doi.org/10.1016/j.techfore.2012.08.007.
Kassie, M., Teklewold, H., Jaleta, M., 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.
Khanna, M., 2001. Sequential adoption of site-specific technologies and its implications for nitrogen productivity: a double selectivity model. Am. J. Agric. Econ. 83 (1), 35–51.
Khatri-Chhetri, A., Aggarwal, P.K., Joshi, P.K., Vyas, S., 2017. Farmers' prioritization of climate-smart agriculture (CSA) technologies. Agric. Syst. 151, 184–191. https://doi.org/10.1016/j.agsy.2016.10.005.
Kidane, B.Z., Hailu, M.H., Haile, H.T., 2017. Maize and potato intercropping: a technology to increase productivity and profitability in tigray. Open Agric. 2 (1) https://doi.org/10.1515/opag-2017-0044.
Kihiu, E.N., 2016. Basic capability effect: collective management of pastoral resources in southwestern Kenya. Ecol. Econ. 123, 23–34. https://doi.org/10.1016/j.ecolecon.2016.01.003.
Kpadonou, R.A.B., Owiyo, T., Barbier, B., Denton, F., Rutabingwa, F., Kiema, A., 2017. Advancing climate-smart-agriculture in developing drylands: Joint analysis of the adoption of multiple on-farm soil and water conservation technologies in West African Sahel. Land Use Policy 61, 196–207. https://doi.org/10.1016/j.landusepol.2016.10.050.
Lipper, L., Thornton, P., Campbell, B., Baedeker, T., Braimoh, A., Bwalya, M., Torquebiau, E.F., 2014. Climate-smart agriculture for food security. Nat. Clim. Change 4 (12), 1068–1072. https://doi.org/10.1038/Nclimate2437.
Liu, E.M., 2013. Time to change what to sow: risk preferences and technology adoption decisions of cotton farmers in China. Rev. Econ. Stat. 95 (4), 1386–1403. https://doi.org/10.1162/REST_a_00295.
Liu, Y., Ruiz-Menjivar, J., Zhang, L., Zhang, J., Swisher, M.E., 2019. Technical training and rice farmers' adoption of low-carbon management practices: The case of soil testing and formulated fertilization technologies in Hubei, China. J. Clean. Prod. 226, 454–462. https://doi.org/10.1016/j.jclepro.2019.04.026.
Lumpkin, G.T., Dess, G.G., 1996. Clarifying the entrepreneurial orientation construct and linking it to performance. Acad. Manag. Rev. 21 (1), 135–172. https://doi.org/10.2307/258632.
Lumpkin, G.T., Dess, G.G., 2001. Linking two dimensions of entrepreneurial orientation to firm performance. J. Bus. Ventur. 16 (5), 429–451. https://doi.org/10.1016/s0883-9026(00)00048-3.
Lynch, D.R., Foroud, N., Kozub, G.C., Fames, B.C., 1995. The effect of moisture stress at three growth stages on the yield, components of yield and processing quality of eight potato varieties. Am. Potato J. 72 (6), 375–385. https://doi.org/10.1007/bf02849334.
Maggio, G., Sitko, N., 2019. Knowing is half the battle: seasonal forecasts, adaptive cropping systems, and the mediating role of private markets in Zambia. Food Policy 89, 101781. https://doi.org/10.1016/j.foodpol.2019.101781.
Martínez-García, C.G., Arriaga-Jordán, C.M., Dorward, P., Rehman, T., Rayas-Amor, A. A., 2016. Using a socio-psychological model to identify and understand factors influencing the use and adoption of a successful innovation by small-scale dairy farmers of Central Mexico. Exp. Agric. 54 (1), 142–159. https://doi.org/10.1017/s0014479716000703.
McCord, P.F., Cox, M., Schmitt-Harsh, M., Evans, T., 2015. Crop diversification as a smallholder livelihood strategy within semi-arid agricultural systems near Mount Kenya. Land Use Policy 42, 738–750. https://doi.org/10.1016/j.landusepol.2014.10.012.
McElwee, G., Smith, R., 2012. Classifying the strategic capability of farmers: a segmentation framework. Int. J. Entrep. Ventur. 4 (2), 111–131. https://doi.org/10.1504/ijev.2012.046517.
Mikko Vesala, K., Peura, J., McElwee, G., 2007. The split entrepreneurial identity of the farmer. J. Small Bus. Enterp. Dev. 14 (1), 48–63. https://doi.org/10.1108/14626000710727881.
Morris, W., Henley, A., Dowell, D., 2017. Farm diversification, entrepreneurship and technology adoption: analysis of upland farmers in Wales. J. Rural Stud. 53, 132–143. https://doi.org/10.1016/j.jrurstud.2017.05.014.
Muriithi, B.W., Menale, K., Diiro, G., Muricho, G., 2018. Does gender matter in the adoption of push-pull pest management and other sustainable agricultural practices? Evidence from Western Kenya. Food Secur. 10 (2), 253–272. https://doi.org/10.1007/s12571-018-0783-6.
Muthoni, J., Nyamongo, D., 2009. A review of constraints to ware Irish potatoes production in Kenya. J. Hortic. For. 1 (7), 98–102.
Ochieng, J., Kirimi, L., Mathenge, M., 2016. Effects of climate variability and change on agricultural production: the case of small scale farmers in Kenya. NJAS Wagening. J. Life Sci. 77, 71–78. https://doi.org/10.1016/j.njas.2016.03.005.
Ojo, T.O., Baiyegunhi, L.J.S., 2020. Determinants of climate change adaptation strategies and its impact on the net farm income of rice farmers in south-west Nigeria. Land Use Policy 95, 103946. https://doi.org/10.1016/j.landusepol.2019.04.007.
Okello, J., Zhou, Y., Kwikiriza, N., Ogutu, S., Barker, I., Schulte-Geldermann, E., Ahmed, J., 2016. Determinants of the use of certified seed potato among smallholder farmers: the case of potato growers in central and Eastern Kenya. Agriculture 6 (4), 55. https://doi.org/10.3390/agriculture6040055.
Palich, L.E., Ray Bagby, D., 1995. Using cognitive theory to explain entrepreneurial risk-taking: challenging conventional wisdom. J. Bus. Ventur. 10 (6), 425–438. https://doi.org/10.1016/0883-9026(95)00082-j.
Parker, M.L., Low, J.W., Andrade, M., Schulte-Geldermann, E., Andrade-Piedra, J., 2019. Climate change and seed systems of roots, tubers and bananas: the cases of potato in Kenya and Sweetpotato in Mozambique. The Climate-Smart Agriculture Papers (pp. 99-111). Springer,, Cham.
Pindado, E., Sánchez, M., Verstegen, J.A.A.M., Lans, T., 2018. Searching for the entrepreneurs among new entrants in European agriculture: the role of human and social capital. Land Use Policy 77, 19–30. https://doi.org/10.1016/j.landusepol.2018.05.014.
Pino, G., Toma, P., Rizzo, C., Miglietta, P., Peluso, A., Guido, G., 2017. Determinants of farmers' intention to adopt water saving measures: evidence from Italy. Sustainability 9 (1), 77. https://doi.org/10.3390/su9010077.
Poulton, C., Dorward, A., Kydd, J., 2010. The future of small farms: new directions for services, institutions, and intermediation. World Dev. 38 (10), 1413–1428. https://doi.org/10.1016/j.worlddev.2009.06.009.
Rauch, A., Wiklund, J., Lumpkin, G., Frese, M., 2009. Entrepreneurial orientation and business performance: an assessment of past research and suggestions for the future. Entrep. Theory Pract. 33 (3), 761–787. https://doi.org/10.1111/j.1540-6520.2009.00308.x.
Rogers, E.M., 2003. Diffusion of innovations. Free Press,, New York, p. 551.
Schimmelpfennig, D., Ebel, R., 2011. On the doorstep of the information age: recent adoption of precision agriculture. Economic Research Service, Paper No. EIB-80.
Senyolo, M.P., Long, T.B., Blok, V., Omta, O., 2018. How the characteristics of innovations impact their adoption: an exploration of climate-smart agricultural innovations in South Africa. J. Clean. Prod. 172, 3825–3840. https://doi.org/10.1016/j.jclepro.2017.06.019.
Serebrennikov, D., Thorne, F., Kallas, Z., McCarthy, S.N., 2020. Factors influencing adoption of sustainable farming practices in europe: a systemic review of empirical literature. Sustainability 12 (22), 9719. https://doi.org/10.3390/su12229719.
Shane, S., Venkataraman, S., 2000. The promise of entrepreneurship as a field of research. Acad. Manag. Rev. 25 (1), 217–226. https://doi.org/10.5465/amr.2000.2791611.
Snapp, S.S., Blackie, M.J., Gilbert, R.A., Bezner-Kerr, R., Kanyama-Phiri, G.Y., 2010. Biodiversity can support a greener revolution in Africa. Proc. Natl. Acad. Sci. USA 107 (48), 20840–20845. https://doi.org/10.1073/pnas.1007199107.
Teklewold, H., Gebrehiwot, T., Bezabih, M., 2019. Climate smart agricultural practices and gender differentiated nutrition outcome: an empirical evidence from Ethiopia. World Dev. 122, 38–53. https://doi.org/10.1016/j.worlddev.2019.05.010.
Teklewold, H., Kassie, M., Shiferaw, B., 2013. Adoption of multiple sustainable agricultural practices in rural Ethiopia. J. Agric. Econ. 64 (3), 597–623. https://doi.org/10.1111/1477-9552.12011.
Tey, Y.S., Li, E., Bruwer, J., Abdullah, A.M., Brindal, M., Radam, A., Darham, S., 2014. The relative importance of factors influencing the adoption of sustainable agricultural practices: a factor approach for Malaysian vegetable farmers. Sustain. Sci. 9 (1), 17–29. https://doi.org/10.1007/s11625-013-0219-3.
Trinh, T.Q., Rañola, R.F., Camacho, L.D., Simelton, E., 2018. Determinants of farmers' adaptation to climate change in agricultural production in the central region of Vietnam. Land Use Policy 70, 224–231. https://doi.org/10.1016/j.landusepol.2017.10.023.
Vecchio, Y., De Rosa, M., Adinolfi, F., Bartoli, L., Masi, M., 2020. Adoption of precision farming tools: a context-related analysis. Land Use Policy 94, 104481. https://doi.org/10.1016/j.landusepol.2020.104481.
Verhees, F.J.H.M., Kuipers, A., Klopcic, M., 2011. Entrepreneurial proclivity and farm performance. Int. J. Entrep. Innov. 12 (3), 169–177. https://doi.org/10.5367/ijei.2011.0039.
Verhees, F.J.H.M., Lans, T., Verstegen, J.A.A.M., 2012. The influence of market and entrepreneurial orientation on strategic marketing choices: the cases of Dutch

farmers and horticultural growers. J. Chain Netw. Sci. 12 (2), 167–179. https://doi.org/10.3920/JCNS2012.x011.
Wainaina, P., Tongruksawattana, S., Qaim, M., 2016. Tradeoffs and complementarities in the adoption of improved seeds, fertilizer, and natural resource management technologies in Kenya. Agric. Econ. 47 (3), 351–362. https://doi.org/10.1111/agec.12235.
Welter, F., 2011. Contextualizing entrepreneurship-conceptual challenges and ways forward. Entrep. Theory Pract. 35 (1), 165–184. https://doi.org/10.1111/j.1540-6520.2010.00427.x.
Welter, F., Gartner, W.B., Wright, M., 2016. The context of contextualizing contexts. In A Research Agenda for Entrepreneurship and Context. Edward Elgar Publishing.
Westermann, O., Forch, W., Thornton, P., Korner, J., Cramer, L., Campbell, B., 2018. Scaling up agricultural interventions: case studies of climate-smart agriculture. Agric. Syst. 165, 283–293. https://doi.org/10.1016/j.agsy.2018.07.007.
Wiklund, J., Shepherd, D., 2005. Entrepreneurial orientation and small business performance: a configurational approach. J. Bus. Ventur. 20 (1), 71–91. https://doi.org/10.1016/j.jbusvent.2004.01.001.
Yegbemey, R.N., Kabir, H., Awoye, O.H.R., Yabi, J.A., Paraïso, A.A., 2014. Managing the agricultural calendar as coping mechanism to climate variability: a case study of maize farming in northern Benin, West Africa. Clim. Risk Manag. 3, 13–23. https://doi.org/10.1016/j.crm.2014.04.001.
Yegbemey, R.N., Yabi, J.A., Tovignan, S.D., Gantoli, G., Haroll Kokoye, S.E., 2013. Farmers' decisions to adapt to climate change under various property rights: a case study of maize farming in northern Benin (West Africa). Land Use Policy 34, 168–175. https://doi.org/10.1016/j.landusepol.2013.03.001.
York, J.G., Venkataraman, S., 2010. The entrepreneur–environment nexus: uncertainty, innovation, and allocation. J. Bus. Ventur. 25 (5), 449–463. https://doi.org/10.1016/j.jbusvent.2009.07.007.
Zeweld, W., Van Huylenbroeck, G., Tesfay, G., Azadi, H., Speelman, S., 2020. Sustainable agricultural practices, environmental risk mitigation and livelihood improvements: empirical evidence from Northern Ethiopia. Land Use Policy 95, 103799. https://doi.org/10.1016/j.landusepol.2019.01.002.
Zhou, J., Liu, Q., Liang, Q., 2018. Cooperative membership, social capital, and chemical input use: evidence from China. Land Use Policy 70, 394–401. https://doi.org/10.1016/j.landusepol.2017.11.001.