Vol. 13(2), pp. 156-173, April-June 2021
DOI: 10.5897/JDAE2021.1191
Article Number: 0134F0266857
ISSN 2006-9774

http://www.academicjournals.org/JDAE

Journal of Development and Agricultural Economics

Full Length Research Paper

Smallholder adoption of technology: Evidence from the context of climate smart agriculture in South Africa

Mmapatla Precious Senyolo[1]*, Thomas B. Long[2], Vincent Blok[3], Onno Omta[4] and Gerben van der Velde[4]

[1]Department of Agricultural Economics and Animal Production, University of Limpopo, Private Bag X1106, Sovenga, 0727, South Africa.
[2]Centre for Environmental Strategy, University of Groningen/Campus Fryslân, Sophialaan 1 8911 AE Leeuwarden, The Netherlands.
[3]Philosophy Group, School of Social Sciences, Wageningen University, Hollandseweg 1, 6706 KN, Wageningen (Building 201) De Leeuwenborch, The Netherlands.
[4]Business Management and Organisation Group, School of Social Sciences, Wageningen University, Hollandseweg 1, 6706 KN, Wageningen (Building 201) De Leeuwenborch, The Netherlands.

Received 25 June, 2020; Accepted 25 February, 2021

Climate change represents a serious threat to African agriculture, consequently leading to water scarcity and climate variability. These challenges negatively impact agricultural production. Climate-smart Agriculture (CSA) technologies, such as drought-tolerant seed varieties (DTSVs), can provide a solution. However, effective adoption and use of these technologies within smallholder communities is not straight forward. This study investigated the factors determining adoption of CSA technologies by exploring the farmers' characteristics, contextual factors, and considered additional factors extracted from farmers' perceptions of CSA technology-specific attributes. The study was carried out in Limpopo Province, South Africa. Quantitative and qualitative data from farmers' cross-sectional survey (n=196) and focused group discussions (n=5), was subjected to descriptive and inferential statistical analysis. Factor analysis reduced 19 identified CSA technologies specific attributes to 5 factors that were used in the multinomial logistic regression model. Results show a range of drivers and barriers influencing DTSVs adoption. The adoption of DTSVs by sampled smallholder farmers were influenced by training and demonstration; knowledge and benefits related to DTSVs; necessary requirements like receiving tractor services on time, knowledge on better dates of DTSVs and weather information; enabling factors like additional training on DTSVs and information including knowledge about other CSA technologies other than DTSVs, gender, marital status and credit access. These results have policy implications for various stakeholders which reinforce multi-actor approach to climate change adaptation and building of functional institutions, enhancing training of smallholder farmers, improving on access to sufficient demonstrations, climate change information and credit support amongst other support.

Key words: Climate smart agriculture, smallholder farmers, drought-tolerant seeds technology adoption, multinomial logit regression.

INTRODUCTION

Climate change represents a serious threat to the agricultural sector, requiring resilience to climate impacts and reductions in greenhouse gas (GHG) emissions. Rural communities in Africa largely depend on rain-fed small-scale agriculture for their livelihood, and this makes them vulnerable to changes in climate and climate variability (Nyasimi et al., 2017; Rankoana, 2016; Zizinga et al., 2017). While concerns regarding mitigation and adaption to climate change are renewing the momentum for investments in agricultural research and are emerging as added innovation priorities, it is expected that development and effective diffusion of new agricultural technologies and practices will influence how well farmers mitigate and adapt to climate change (Lybbert and Sumner, 2010).

The main challenge facing agriculture concerning adaptation and mitigation is that more food which is produced efficiently under highly unpredictable conditions with net reductions in GHG emissions from production and marketing is needed. Hence, input use efficiency is necessary to keep up with these productivity demands and to compensate for the effects of climate change. Innovative approaches, which can be institutional or technological, will be an important response (Asayehegn et al., 2017; Msangi et al., 2012). A prominent approach is climate-smart agriculture (CSA), which attempts to sustainably increase agricultural productivity, food security and incomes through adaptation and enhancing resilience to climate change as well as by reducing GHG emissions (Arslan et al., 2015; FAO, 2010, 2013). CSA can help to achieve the development goals of vulnerable populations who depend on agriculture (Partey et al., 2018), but this will involve effective management of synergies and trade-offs between mitigation, adaptation and productivity goals.

South Africa, like many African countries, has been identified as being highly vulnerable to the impacts of climate change (Elum et al., 2017). Although the country has a huge territory with a diverse range of climate, it is dominated by a semi-arid climate (Chami and Moujabber, 2016). The South African agricultural sector's specific climate change impacts include moisture stress, climate variability, drought, scarce rain, erratic rainfall, depletion of water resources, excessive heat, soil erosion, and barrenness, which negatively impact agricultural production (Chami and Moujabber, 2016; Mpandeli et al., 2015; Rankoana, 2016). These impacts are changing the functioning of the agricultural landscapes in devastating and often destructive ways. South African farmers are expected to adapt their agricultural practices to build their adaptive capacity and boost their resilience. CSA targets both crop and livestock production and can include conservation agriculture, soil and land management practices, use of new crop varieties and animal breeds, rainwater harvesting, agroforestry, mixed cropping, crop type diversification, adaptation to changing soils structure (Below et al., 2010; Mpandeli et al., 2015; Rankoana, 2016; Ubisi et al., 2017). Given the evidence that climate-related challenges demand modification to agricultural practices, the transition to CSA necessitates farmers' access to productivity-enhancing and climate-smart technologies (Mutamba and Mugoya, 2014). This is especially true for smallholder farmers who are predominantly exposed to climate change (Grainger-Jones, 2011; Zizinga et al., 2017).

Technological innovations and improved farming practices that increase productivity while boosting climate resilience present in South Africa include drought-tolerant seed varieties, drip irrigation, and the precision of application of fertilizers and agrochemicals, as well as practices such as integrated pest management, conservation farming, and improved watershed and soil management, among others (Senyolo et al., 2018; Weisenfeld and Wetterberg, 2015). The challenge however is, to get these technologies into the hands of the farmers who need them (Nyasimi et al., 2017; Weisenfeld and Wetterberg, 2015). Thus, while CSA technologies have been promoted for their potential to help farmers mitigate climate change impacts, effective adoption and use within the smallholder farmers is not straightforward.

Despite evidence that effective uptake of CSA practices and initiatives enable the agricultural sector to become more adaptive and resilient to climate variability and farmers got protection against changing weather patterns, pests and diseases (Suleman, 2017; Wekesa et al., 2018), smallholder farmers adoption is insufficient (Barnard et al., 2015).Technology adoption and specifically the transition to CSA is affected by several factors (Baiyegunhi, 2015; Fischer et al., 2015; Long et al., 2016; Meijer et al., 2015; Mushunje et al., 2011; Nyasimi et al., 2017; Senyolo et al., 2018). These include barriers related to capital and high costs of labour, availability of inputs, uncertainty, cost and benefits of the technology, gender, socio-cultural practices, access to market, access to credits and lack of knowledge among others, and the fact that some CSA measures often reduce short-term profits (Drechsel et al., 2005; Fischer et al., 2015; Mulaudzi and Oyekale, 2015; Nyasimi et al., 2017). Failures to take specific contexts and the

*Corresponding author. E-mail: mmapatla.senyolo@gmail.com, mmapatla.senyolo@ul.ac.za. Tel: +27 15 268 4628.

perception of farmers into account during technology development and application is also a contributing factor (Long et al., 2016; Senyolo et al., 2018). Interventions are often required to encourage technology adoption. Slower adoption rates result in loss of potential benefits of sustainable practices to farmers and the public (Ghane et al., 2011). The perceptions and attitudes of farmers are highlighted as important in previous research (Drechsel et al., 2005; Fischer et al., 2015; Mekoya et al., 2008; Nyasimi et al., 2017; Zubair and Garforth, 2006), however, they are not adequately addressed and understood (Meijer et al., 2015).

Previous research has explored farmers' perceptions of climate change, evaluated CSA technologies and practices, explored demographic use patterns, and agronomic, economic and environmental benefits of the technologies (Baiyegunhi, 2015; Fischer et al., 2015; Gandure et al., 2013; Mulaudzi and Oyekale, 2015; Mutamba and Mugoya, 2014; Rankoana, 2016). Considering that farmers' socio-economic conditions and perceptions of technology affect adoption decisions (Bryan et al., 2009; Deressa et al., 2009; Drechsel et al., 2005; Tessema et al., 2013; Ubisi et al., 2017), we seek to analyse the role of these factors within the context of CSA technologies in smallholder settings. For instance, factors such as poverty, income, education, or investment costs, may limit the widespread implementation of CSA (Harvey et al., 2014).

This study focuses on drought-tolerant seed varieties (DTSVs) for maize as a CSA technology relevant for smallholder farmers in rain-fed crop production (Asayehegn et al., 2017; Senyolo et al., 2018). In sub-Saharan Africa in general and in South Africa in particular, maize is the critical crop due to its importance to food security and economic wellbeing. However, the production of this crop by smallholder farmers largely relies on rainfall, which is increasingly erratic (Fischer et al., 2015). Unreliable rainfall accompanied by frequent droughts, make it difficult for smallholder farmers to obtain high crop yields and, therefore, susceptible to food insecurity (Mdungela et al., 2017; Mpandeli et al., 2015).

This paper aims to better understand smallholder decision making about DTSVs as an example of CSA technology, in order to pinpoint how opportunities might be created to assist farmers in implementing CSA. The results highlight the value of considering the context-specific biophysical factors, socio-economic realities and perceived characteristics of innovations, knowledge, attitudes, and perceptions of farmers when exploring CSA implementation in South Africa.

This paper contributes to an improved understanding of smallholder farmers' CSA technology adoption in developing countries by explaining the specific socio-economic and socio-technical variables that are important for promoting CSA in South Africa. These variables are important and may improve our understanding of the disparity between perspectives of users (e.g. farmers) and developers as well as promoters of CSA technologies and practices (Harvey et al., 2014; Meijer et al., 2015). Understanding what drives or hinders adoption of promoted CSA technologies among smallholder farmers in South Africa may assist in targeting existing CSA technologies or redesigning them to suit the preferences and specific situations of farmers to safeguard adoption and sustainability.

Context for CSA technologies perception and adoption

Despite the benefits of CSA technologies (Elum et al., 2017; Khatri-Chhetri et al., 2017, 2016), adoption by farmers can be fairly low as numerous factors influence the extent to which farmers adopt them (Khatri-Chhetri et al., 2017; Palanisami et al., 2015). While technological adaptations may benefit from the literature on agricultural technology adoption (Tessema, 2018), understanding the adoption process of specific CSA technology (DTSVs in this case) is necessary to ascertain if the determinants of adoption are similar or unique in the face of changing climate. In agriculture, adoption processes take place amid specific policy, social and cultural, climate, geographical, technological, and economic contexts (Botha and Atkins, 2005; Falaki et al., 2013; Mackrell et al., 2009).

Considering that technology uptake is a multifaceted process, shaped by many factors, the exploration to understand diffusion and utilisation of agricultural technologies cannot be limited to just understanding the characteristics of adopters, their biophysical contextual factors or information sources. The adopter's perceptions of climate change and/or technologies or practices to address them is also needed to provide a comprehensive picture for analysing decision making (Jiri et al., 2015; Meijer et al., 2015; Mushunje et al., 2011; Pannell et al., 2006; Rankoana, 2016; Ubisi et al., 2017). For instance, a comprehensive framework comprising the extrinsic (e.g. characteristics of adopter and innovations) and intrinsic (knowledge, perceptions, and attitudes) variables may increase our understanding of the complex process of adoption (Meijer et al., 2015). Accordingly, exploring the contribution of socio-psychological factors such as perceptions of farmers regarding the specific attributes of CSA technologies in addition to the highlighted socio-economic factors could contribute to our understanding and on-going discussion about CSA adoption. In the following subsections, we continue to explain specific sets of factors in greater detail. Figure 1 shows the conceptual model. We assume that adoption decisions are conditioned by the socio-economic realities of the farmer, the characteristics of the external environment (or contextual factors), as well as the perceived

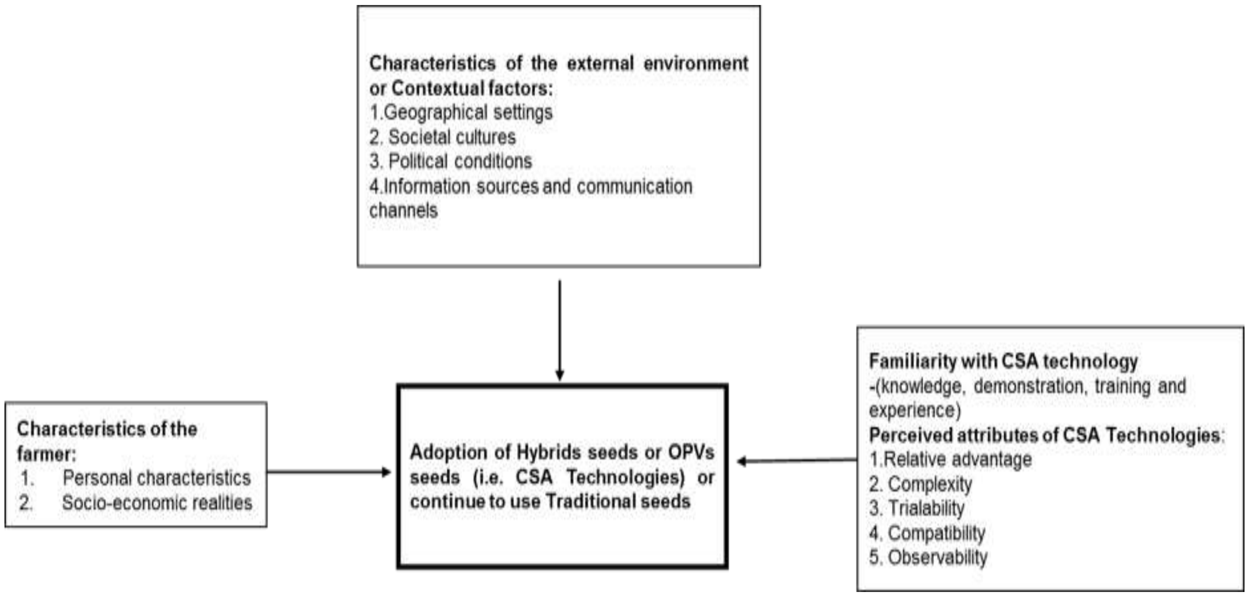

Figure 1. Conceptual framework reflecting factors affecting adoption of CSA technologies (ithat is, DTSVs).
Source: Adapted from Meijer et al. (2015).

characteristics of CSA technologies.

Influences of agricultural technology adoption decisions

Various technology adoption studies conducted in developing countries (Adesina and Chianu, 2002; Akinola et al., 2010; Doss, 2006; Feder and Umali, 1993), indicate that the importance of factors affecting technology adoption vary across countries and regions owing to differences in natural resources, political and cultural ideologies, and socio-economic realities. Moreover, determinants of adoption of agricultural technologies can be grouped in several ways (Mwangi and Kariuki, 2015). Categories include technology and location, among others (Bonabana-Wabbi, 2002). In this study, we investigated the factors determining adoption of CSA technologies by exploring not only the farmers' socio-economic realities and characteristics of external environment (that is, contextual factors). We have also considered additional factors extracted from farmers' perceptions of CSA technology-specific attributes as well as the role of communication and extension.

Effects of familiarity with technologies and perceived technology attributes on adoption decisions

The role of familiarity, which can come from education, awareness creation, training, and demonstration during adoption process, is widely recognized (Deressa et al., 2009; Meijer et al., 2015; Mushunje et al., 2011; Ubisi et al., 2017). Generally, people's familiarity and understanding of technologies underlie their knowledge, perceptions, and attitudes towards them. Furthermore, innovation characteristics that influence adoption include relative advantage, observability, trialability, compatibility and complexity (Adesina and Zinnah, 1993; Ghane et al., 2011; Mwangi and Kariuki, 2015; Rogers, 2003). Innovations, which are perceived as having a superior relative advantage, observability, compatibility, trialability, and less complexity, will have a better rate of adoption than other innovations (Rogers, 2003). These attributes can be elaborated as follows:

(1) Relative advantage refers to the perceived net benefits when individuals adopt.
(2) Trialability refers to how easy it is to move from non-adoption to adoption through learning (Pannell et al., 2006).
(3) Compatibility refers to the extent to which an innovation is attuned to current norms and practices and (4), complexity, measures the effort required to understand and use the new innovation (Mannan and Nordin, 2014). For instance, farmers find a technology to be a positive investment if they perceive it to be consistent with their needs and compatible to their environment (Mignouna et al., 2011). Lastly,
(5) observability of the technology, describes the extent to which results of an innovation are visible to others. Thus, the more advantage witnessed, the easier the

diffusion. The following subsections will indicate the role of farmers' socio-economic realities and the external environment on the likelihood of CSA technology adoption decisions.

Effects of farmers' socio-economic realities on adoption decisions

Specific characteristics (gender, age, marital status), economic variables (income, assets, education) and networks (farmer organisations) affect adoption directly and indirectly by influencing the knowledge, familiarity with technologies, and perceptions of farmers. This in turn influences their decision to adopt certain technologies in relation to others or not to adopt (Kariyasa and Dewi, 2013; Meijer et al., 2015; Mushunje et al., 2011; Mwangi and Kariuki, 2015; Pannell et al., 2006; Wanigasundera and Alahakoon, 2014).

Effects of external environment on adoption decisions

In smallholder farming, external forces such as information on new and alternative technologies, political conditions, geographical settings and ecological conditions, also have influence on technology adoption decisions and processes (Asayehegn et al., 2017; Meijer et al., 2015). For example, climate variability and change may increase the frequency and intensity of drought, and consequently influence the innovation to adapt to changes (Asayehegn et al., 2017; Chami and Moujabber, 2016; Mpandeli et al., 2015). Accordingly, farmers tend to embark on several agricultural and technical activities, such as adjustment of fertilizer input, adoption of DTSVs and plant crops that require less water, during drought periods (Mpandeli et al., 2015). Governmental support and the political will to introduce technologies and biotechnology for smallholder farmers is understood to be crucial for the success of interventions aimed at enhancing smallholder farmers' adoption of biotechnology and climate change adaptation practices, for instance (Edge et al., 2018; Zizinga et al., 2017). Generally, smallholder farmers in Africa rely on extension services, usually provided by government. Poorly performing extension services are often blamed for the limited uptake of technologies. According to Drechsel et al. (2005), knowledge about the technology can be shared by means of communication infrastructure, media access and networks of continuously updated extension agents. As previous studies alluded to the role of communication and extension in influencing adoption (Meijer et al., 2015; Pannell et al., 2006), it was worth exploring to see if these factors also hold when considering the transition to CSA technologies.

MATERIALS AND METHODS

Description of the study area

This study seeks to explore factors influencing farmers' decision-making and adoption of CSA technology (that is, DTSVs). The study was carried out in Vhembe, Capricorn, and Greater Sekhukhune Districts in Limpopo Province, South Africa (Figure 2). The multistage sampling approach was adopted. First, the three districts within Limpopo Province were purposefully selected, (targeting areas where CSA technologies such as DTSVs were introduced). Second, from the list of smallholder farmers obtained from the provincial department agriculture and extension officers working in these areas, the smallholder farmers were randomly selected proportional to sample size per district (Table 1), giving them equal chance of being selected. Capricorn District is situated as a stopover between Gauteng (Johannesburg) and the northern areas of Limpopo, and between the northwestern areas and the Kruger National Park. It forms a gateway to Botswana, Zimbabwe and Mozambique and covers 21705 km^2. Greater Sekhukhune District covers 13528 km^2 and Vhembe District covers 25597 km^2. For most of Limpopo province, the bulk of precipitation occurs in summer, with annual rainfall ranging between 400-600 mm (Tshiala et al., 2011). Limpopo Province was selected as the study area because of its high climatic variability and largely arid to semi-arid nature; meaning CSA technologies and practices that reduce the impacts of droughts, water scarcity and moisture stress are needed. Many of the agricultural activities are undertaken by smallholder farmers. Furthermore, the existence of political organizations, research institutes, and NGOs' willpower to promote the use of DTSVs to address moisture stress, mitigate against water scarcity and to improve food security and livelihood of smallholder farmers, justified the selection. We used both qualitative and quantitative methods in data collection in order to explore the topic in breadth and depth and to reduce the chances of missing important variables (Creswell, 1994; Maponya and Mpandeli, 2012; Ubisi et al., 2017).

The socio-economic characteristics data were analysed using descriptive statistics. Factor analysis (FA) described the covariance relationships among many variables in terms of a few underlying, but unobservable, random quantities called factors and interpreted through weights of the variable called factor loadings, organized in a matrix (Hair et al., 1995). FA seeks to reduce a large set of measured variables in terms of relatively few new dimensions known as factors with the aim of condensing all the information from the original interdependent variables to a smaller set of independent variables (Mugi-Ngenga et al., 2016). The FA model is organized in such a way that all variables within each factor are highly correlated among themselves but have relatively small correlations with variables in other factors (Chaminuka et al., 2008). Usually, factors used for further analysis should contain unique variables. In this study, five factors were retained for subsequent analyses.

The significance of the factors that influence adoption of CSA technologies (in this case DTSVs) by farmers was analysed using Multinomial Logistic Regression (MNLR) Model. The dependent variable was clustered as Type of seeds farmers used (1= Hybrids and Hybrids with OPVs or Traditional seeds, 2= OPVs and OPVs with Traditional seeds, and 3 = Traditional seeds). For the estimation of the MNLR model, one category (that is, base/reference category) was normalized as being the last category (traditional seeds) and therefore all results were explained in reference to this category. This was with respect to the use of seeds. These analyses were conducted using SPSS version 24. Let Z_j (j=1,2,3) be the probability of a smallholder farmer falling in each seed use category, with j =3 representing the reference category. The MNLR model gives the relative probabilities of being in the

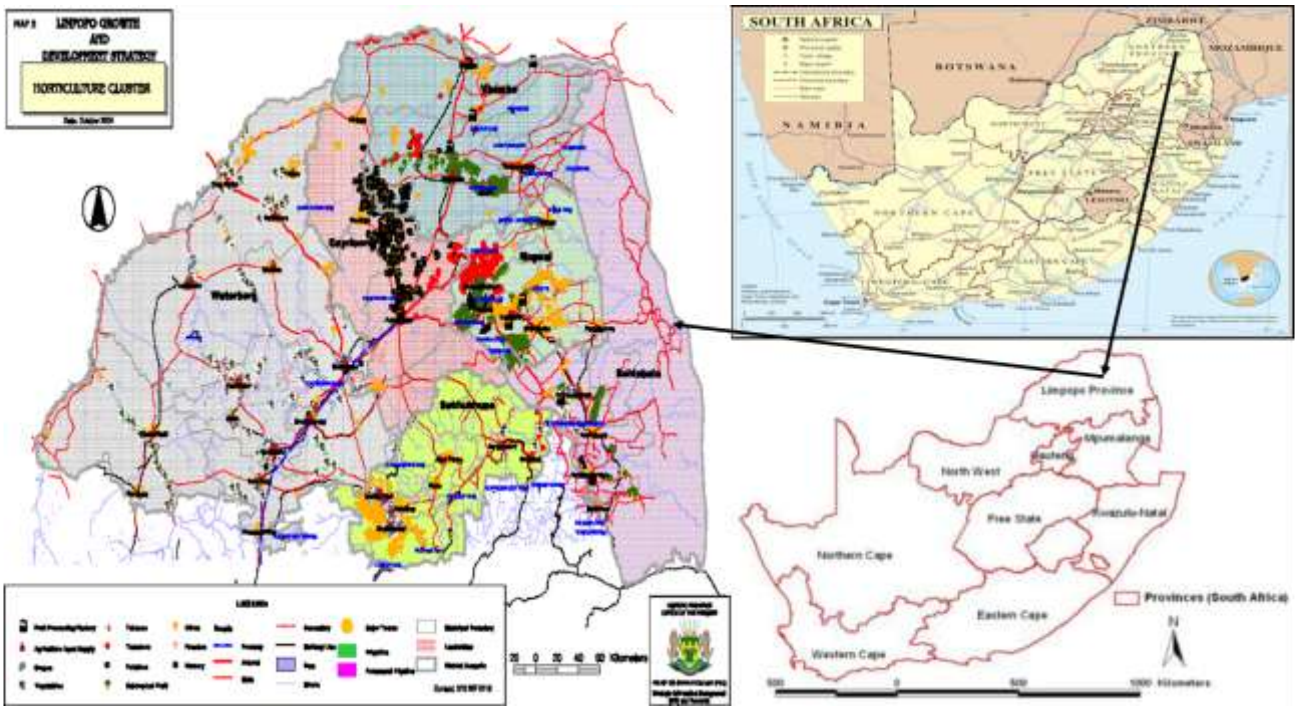

Figure 2. A map showing the 9 provinces of South Africa, the 5 Districts within Limpopo Province and the Horticulture Cluster. Sources : Drawn from Limpopo Development and Growth Strategy (available at : www.waterberg.gov.za/docs/agriculture/other) and Mpandeli et al. (2015).

three seed use categories as a linear function of X_k for the i^{th} farmer, according

$$\ln (Zj/Z3) = \beta_{0j} + \beta_{1j} x_{1i} + \ldots + \beta_{kj} x_{ki} + U_{ij} \quad (1)$$

For j = 1, 2 and i = 1, 2…n farmers where: ln= natural logarithm Z_3 = the probability of smallholder farmer being in the reference category (using Traditional seeds); Z_1 = the probability of smallholder farmer is using Hybrids and Hybrids with OPVs or Traditional seeds; and Z_2 = the probability of smallholder farmer using OPVs and OPVs with Traditional seeds. β_1 …... β_{kj} are MNLR coefficients to be estimated; X_1…. X_{ki} are the K^{th} explanatory variables describing the i^{th} farmer; and Uij = error term

Following Carter-Hill et al. (2008), the conditional probability of the ith household being in the three alternative categories (j=1,2 or 3) are estimated by Equations 2 to 4 as a function of the estimated βkj and Xki as:

$$Z\ (j=1) = \frac{1}{1+\exp\ (\beta_{02}+\beta_{12}X_{1i}+\cdots+\beta_{k2}X_{ki}) + \exp\ (\beta_{03}+\beta_{13}X_{1i}+\cdots+\beta_{k3}X_{ki})} \quad (2)$$

$$Z\ (j=2) = \frac{\exp(\beta_{02}+\beta_{12}X_{1i}+\cdots+\beta_{k2}X_{ki})}{1+\exp\ (\beta_{02}+\beta_{12}X_{1i}+\cdots+\beta_{k2}X_{ki}) + \exp\ (\beta_{03}+\beta_{13}X_{1i}+\cdots+\beta_{k3}X_{ki})} \quad (3)$$

$$Z\ (j=3) = \frac{\exp(\beta_{03}+\beta_{13}X1i+\cdots+\beta_{k3}X_{ki})}{1+\exp\ (\beta_{02}+\beta_{12}X_{1i}+\cdots+\beta_{k2}X_{ki}) + \exp\ (\beta_{03}+\beta_{13}X_{1i}+\cdots+\beta_{k3}X_{ki})} \quad (4)$$

Description of variables in the multinomial logistic regression model

Farmers were asked questions on their socio-economic realities and the description and measurement of those variables is presented in Table 2. Data were also collected on the perception of farmers on specific attributes of CSA technologies (that is, DTSVs in this case). The perception statements were measured on a 5 point Likert scale. The Likert scale ranged from one 'strongly disagreed' to five 'strongly disagreed'.

RESULTS AND DISCUSSION

Socioeconomic characteristics of surveyed farmers in Limpopo Province, South Africa

The socio-economic variables of the respondents, potentially impacting the adoption of CSA technologies are presented in Table 3. Data shows that 68% of the respondents were female while only 32% were male. The average age of the interviewed farmers is 55.15 years old, and the youth accounted for only 11% of the respondents. Regarding education, 41.3, 41.8 and 6.6% of the respondents obtained primary, secondary and post-secondary education respectively, and only 10% have not been to school. More than 80% of the farmers are married. Sixty-five percent of the farmers noted consumption and marketing as their main reason for

Table 1. Elaboration of how sampled farmers were selected.

Districts (total number of accessed smallholder farmers)	Probability proportional to sample size per district (%)	Total smallholder farmers interviewed
Vhembe (198 smallholder farmers, 42% of 475)	42	87
Capricorn (182 smallholder farmers, 38% of 475	38	71
Sekhukhune (95 smallholder farmers, 20% of 475)	20	38
Total sampled smallholder farmers (41% of the sampling frame of 475)		**196**

Table 2. Description of variables in the multinomial logistic regression model.

Variable	Description
Gender	1= male, 0 otherwise
Age	Age of the respondents in years
Marital status	1= married 0 otherwise
Household size	Number of farming household members
Farming experience	Years of farming experience
Education	Number of years smallholder farmer attended school
Reason for farming	1= farming for consumption and marketing, 0 otherwise
Income level	1= middle income (115.4-269.2), 0 otherwise
Land size	Land size in hectares (ha)
Government support	1= received government support, 0 otherwise
Credit access	1= credit access, 0 otherwise
Cooperative membership	1= member of cooperative, 0 otherwise

engaging in agriculture. Socio- economic factors are usually more influential to the dissemination of a technology than biophysical factors (Drechsel et al., 2005; Senyolo et al., 2018). This is largely because the biophysical conditions are often well described in common manuals, making them relatively easier to verify, yet with the social, cultural and economic perspectives, the situation is complex (Drechsel et al., 2005).

While access to government support (i.e. formal extension services) usually influence adoption of technologies positively (Diale, 2011; Ikheloa et al., 2013), this was not the case in our study. Our data shows negative but insignificant relationship between government support and the use of DTSVs. Notably, during discussions with farmers, concerns regarding extension services such as un-coordinated services, and lack of adequate monitoring and evaluation were raised, which might possibly explain these unexpected results. Only 34% of the farmers belonged to cooperatives. Farmers' concerns regarding extension support may have been attributed to the often-observed biases in service provision towards farmers belonging to agricultural cooperatives. Since the issue of climate change has assumed an important position in public discourse and media, we asked respondents if they think they experienced climate change. Almost all of them 99.5% (195) noted they have experienced it. Previous studies indicated the relationship between technology adoption (also in response to climate change) and access to land (Diale, 2011; Ikheloa et al., 2013). For instance, in previous research a positive relationship between farm size and technology adoption was expected but negative statistical significance was observed (Mulaudzi and Oyekale, 2015). The average land size that interviewed farmers had access to was 1.89 ha with the majority of the respondents having access to between 0.25 and 2.7 ha of land. Although from our results access to land was not significant, land access and land ownership in particular, may still have a role to play considering that collateral is needed when farmers apply for credit from financial institutions. Our data revealed that the majority 94.4% (185) of the sampled farmers hold only the permission to occupy (that is, no title deeds). The majority 65.3% (128) of the smallholder farmers produced mainly for family consumption, and marketed the surplus produce. Sixty-nine percent of the respondents came from a family of about 6 to 8 members, with an average household size of 6 (5.58) members. The mean farming experience for the farmers was 17 (that is, 16.68) years (Table 3).

Types of CSA technologies (that is, DTSVs) used by the respondents

Previous studies indicated that the availability and

Table 3. Socio-economic characteristics of the respondents.

Characteristics	Frequency	Mean	Percentage	Min	Max
Female	134		68.4		
Age (years)		55.15		25	84
Married	159		81.1		
Attended school	176		89.8		
Primary education	81		41.3		
Secondary education	82		41.8		
Post-secondary education	13		6.6		
Produce for family consumption and marketing	128		65.3		
Household size		5.58		2	9
Farming experience		16.68		3	35
Land size		1.89		0.25	17
Title deed	10		5.1		
Permission to occupy (PTO)	185		94.4		
Neither Title deed nor PTO	1		0.5		
Experienced climate change: Yes	195		99.5		
Government support	150		76.5		
Not cooperative membership	129		65.8		
No Access to credit	108		55.1		

Sources of credit: Formal institutions (3%); Stockvel or Saving group (18%); Loan Shack ('Matshonisa') (7%); Other sources (66%) and More than one sources (6%)

affordability of technologies potentially affect their adoption (Diale, 2011; Senyolo et al., 2018). Where crop farming is the main land-use option and especially given the climate change uncertainties, seed materials are often crucial. Farmers were asked about the seed varieties they used and their procurement processes. Table 4 indicates that 69.4% of the farmers used Hybrids and Hybrids with OPVs or traditional seeds. Twelve percent of the respondents reported using OPVs and OPVs with traditional seeds, while 18% were using traditional seeds only. Specific reasons were provided by farmers who reported using more than one seed variety in one season, within one field. Farmers noted that unavailability of the OPVs, unaffordability of the Hybrid seeds, and provision of the seeds by the government and/or research institutions influenced their choice of seeds. Moreover, some respondents indicated that Hybrid seeds gave relatively higher yields, justifying their expense, while others argued that recycling traditional seeds were preferred in ensuring household food security.

In response to unaffordability and unavailability, some farmers resorted to using traditional seeds and/or combination of seeds at their disposal. Twenty-six percent of the farmers purchased their own seeds and 50% acquired their seeds through a combination of channels. Although the South African government has attempted to assist farmers through different inputs provision programmes, this still seems inadequate as only 14% usually attained seeds from government seed provision schemes. However, it should be noted that among the 97 farmers who obtained seed materials from a combination of sources, there were those that received seeds from the government. In these cases, challenges, other than access, existed (that is, lack of monitoring of service providers, lack of planning resulting in late delivery of inputs, small quantities of seeds and fertilizers).

The previous subsection has provided an overview of farmers' socio-economic conditions that were expected to affect farmers' adoption of CSA technologies to safeguard food security in the face of climate change. The following section tests the significance of the socio-economic characteristics that are theorised to impact the perceptions of the CSA technologies specific attributes; and to test the significance of the theorised variables in driving or hindering farmers' adoption of CSA technologies. Factor analysis (FA) and a Multinomial logistic regression (MNLR) model were used for empirical analysis.

Farmers' perceptions of the CSA technology specific characteristics

Farmer's individual perception of a given challenge may influence their decision towards possible solutions (Drechsel et al., 2005). Limpopo farmers have

Table 4. Types and sources of seeds.

Variable	Frequency	Percentage
Types of seeds		
Hybrids and hybrids with open pollinated varieties (OPVs) or traditional seeds	136	69.4
OPVs and OPVs with Traditional seeds	24	12.2
Traditional seeds	36	18.4
Sources of seeds		
Self-purchased	50	25.5
Government seed provision scheme (i.e. LDA)	28	14.3
Saved from farm	21	10.7
Other sources and/or combination	97	49.5

OPVs in this study refers to improved OPVs which are certified and registered and Traditional seeds refers to specific type of open-pollinated varieties that have been passed on within families or communities for several years.

preferences for certain CSA technologies, based on real experience or perceived characteristics. Therefore, several questions were asked to understand this aspect. Farmers' perceptions of the CSA technology attributes were measured by respondents' opinions about the characteristics and important effects of CSA technologies in their area. This was based on Kaizer-Meyer-Olkin (KMO) Measure of Sampling Adequacy (KMO=0.80), similar to (Bidogeza et al., 2009; Mugi-Ngenga et al., 2016).

Table 5 shows the rotated factor farmers' perceptions of the CSA technology specific attributes. The Kaizer criterion (1960) was used for selecting the number of essential factors or principal components explaining the data. All components with Eigen values of less than one were left out, following the rule of thumb when conducting Principal Component Analysis (PCA) using correlation matrix (Mugi-Ngenga et al., 2016). Subsequently, the factor loadings for the reduced components as suggested by the criterion of Eigen values were retained for further analysis. The 5 factors extracted explained 63% of the variance in the 19 CSA technology specific characteristic components. These factors are:

Factor 1: Training and demonstration related to DTSVs, accounts for 23.7% of the variance. Adequate opportunities for training, training, access to agricultural advisory services and well demonstration related to DTSVs, loaded heavily in this factor. The loadings for all the items had positive signs, implying that these four CSA technology specific characteristics are positively correlated. That is, they are likely to influence adoption of DTSVs. The result implies that farmers with adequate opportunities for training and demonstration are also likely to be trained often and have regular access to agricultural services.

Factor 2: Knowledge possession and benefits related DTSVs, explained 14.8% of the total variance in the 19 CSA technology specific characteristic variables. Farmers' knowledge about DTSVs and its better planting dates as well as its ability to enhance yield, safeguard households' food security and to offer immediate benefits loaded heavily in this factor. The common positive signs of the loaded variables suggested positive correlation with CSA technology adoption. Thus, farmers who have knowledge about DTSVs and their better planting date, also attested that the DTSVs are likely to offer them immediate benefits while enabling them to enhance their yield as well as safeguarding their household food security. These corroborated the findings of Senyolo et al. (2018).

Factor 3: Knowledge and experience on non-agricultural activities, accounts for 12.2% of the variance. Knowledge of non-agricultural activities, relevant experience to get employment outside agriculture, consideration of knowledge about other activities other than agriculture and signal to consider non-agricultural opportunities loaded heavily in this factor and reflected positive correlation. These variables give an indication of farmers' decisions when faced with alternative opportunities outside agriculture. Farmers' with knowledge of better non-agricultural activities and relevant experience to get employment elsewhere may not adopt DTSVs and instead focus on alternatives. However, Langat et al. (2013) indicate that off-farm income often complements, rather than replaces farm income, potentially increasing the affordability of new (CSA) technologies.

Factor 4: Necessary requirements, explained 7.2% of the total variance in the CSA technology specific characteristics variables. The importance of receiving tractor services on time, knowledge on better planting dates of DTSVs and weather information loaded heavily in this factor, and also reflected positive correlation.

Table 5. Rotated component matrix[a] for farmers' perception of CSA technology specific characteristics.

Farmers' perceptions of the CSA technology attributes	Component/factor				
	1	2	3	4	5
I have adequate training on planting drought tolerant and fast maturing cultivars DTSVs	0.**820**	0.308	-0.176	-0.098	0.214
I currently have adequate opportunities for training related to (DTSVs)	**0.855**	0.164	-0.226	0.005	0.223
DTSVs have been well demonstrated in my area	**0.713**	0.271	0.109	-0.250	-0.002
I have adequate access to agricultural advisory services regarding DTSVs	**0.813**	0.074	-0.040	-0.014	0.157
I have knowledge about DTSVs	0.295	**0.755**	-0.141	-0.082	0.214
I have knowledge on better planting date for DTSVs	0.270	**0.746**	-0.078	-0.130	0.236
Planting DTSVs enable extra yield to be realized	0.181	**0.720**	-0.092	0.090	0.177
Planting DTSVs safeguard household food security	-0.167	**0.739**	0.046	0.186	-0.177
Planting DTSVs offers immediate benefits	0.052	**0.513**	0.225	0.074	-0.232
It is important to be informed about weather information in my area	-0.174	-0.039	0.000	**0.758**	0.015
It is important to know about better planting date for DTSVs	-0.104	-0.019	-0.039	**0.842**	0.058
It is important to receive tractor services in time to plant DTSVs	0.022	0.052	-0.075	**0.791**	-0.077
I have knowledge of non-agricultural activities that could sustain my life better	-0.036	0.054	**0.882**	-0.129	-0.091
I consider knowledge about other activities other than agriculture important	-0.027	0.093	**0.819**	0.127	-0.241
I can switch from agricultural production to exercise other activities if am informed about them	-0.078	-0.118	**0.564**	-0.158	-0.001
I have a relevant expertise and/or experience to get the job elsewhere	-0.100	0.054	**0.862**	0.065	-0.201
Additional training would increase my ability to adopt DTSVs	0.242	0.066	-0.163	0.018	**0.722**
Information about other CSA technologies would increase my ability to adopt them	0.173	0.078	-0.188	0.054	**0.811**
I consider knowledge about other CSA technologies and practices important	0.078	0.122	-0.070	0.445	**0.526**
% of total variance	**230.7**	**140.8**	**120.2**	**70.2**	**50.1**
Eigen values	**40.98**	**30.11**	**20.56**	**10.51**	**10.06**
Cronbach's alpha	**0.876**	**0.760**	**0.826**	**0.754**	**0.663**

Extraction Method: Principal Component Analysis: Varimax with Kaizer Normalization; Kaizer-Meyer-Olkin Measure of Sampling Adequacy (0.80, Chi-square =1894.97); Cut point for loadings and communalities = 0.5.

Based on farmers' opinions, it is important for them to receive tractor services on time, to be informed about better planting dates and to receive weather forecasts.

Factor 5: Enabling factors to adopt DTSVs and other CSA technologies, explained 5.15 of the total variance. Variables additional training on DTSVs and information as well as knowledge about other CSA technologies would increase the ability to adopt DTSVs and other CSA technologies, respectively, loaded heavily in this factor. The positive signs of the loaded variables implied positive correlation.

We concur with the interviewed farmers that despite the preference and reasons of those promoting a particular technology at a point in time, it is necessary and relevant to still be informed about alternatives as well as this will enhance their chances to adopt CSA technologies and practices that suit them best.

In the following subsection, the explained factors together with other socio-economic variables are used in the MNLR model as variables.

Multinomial logistic regression

The Multinomial Logistic Regression (MNLR) model was used to analyse the factors influencing smallholder farmers' choice of seed varieties. This was done to understand the drivers and barriers to adoption of CSA technologies such as DTSVs. MNLR model for the choice of seed varieties specifies the relationship between the probability of choosing a particular seed variety and the set of explanatory variables. MNLR can use standard regression techniques to select variables (Mugi-Ngenga et al., 2016; Petrucci, 2009; Ubisi et al., 2017). The dependent variables in the final model for this paper is the type of seed varieties that respondents in this study were using (Table 4). It was established that the sampled smallholder farmers were using three seed varieties namely: CSA technologies (Hybrids and OPVs) and traditional seeds. Therefore, the dependent variable was specified as the seed variety that farmers adopted/used, as follows: 1= "Hybrids and Hybrids with OPVs or traditional seeds"; 2= "OPVs and OPVs with traditional seeds"; and 3= "traditional seeds". The independent variables were derived from the 5 factors produced by the factor analysis, together with other socio-economic variables based on the literature (Ikheloa et al., 2013; Mugi-Ngenga et al., 2016; Mulaudzi and Oyekale, 2015; Senyolo et al., 2018; Ubisi et al., 2017).

There are numerous ways to assess the model fit in MNLR. According to Petrucci (2009), the most commonly used is the likelihood ratio test. The presence of a relationship between the dependent variable and combination of independent variables is based on the statistical significance of the final model chi-square. According to our results presented in Table 6, -2Log Likelihood (218. 432) and chi-square (103.787) with 38 degrees of freedom, the probability of the probability of the model chi-square was 0.000, less than the level of significance of 0.01. These indicate that the independent variables as a group contribute significantly to the prediction of the outcome. Furthermore, SPSS generates three different pseudo R2 summary statistics, used by some to assess model fit by determining the effect size of the model (Petrucci, 2009). For our analysis, pseudo R2 statistics were as follows: Cox and Snell, 0.411; Nagelkerke, 0.510 and McFadden, 0.322. The McFadden's is a transformation of the likelihood ratio statistic, and values from 0.2 to 0.4 for McFadden are considered highly satisfactory (Petrucci, 2009).

Discussion of the significant variables

Training and demonstration related to DTSVs

The variable "Training and demonstration related to DTSVs" in both contrasts is positive and statistically significant at the 5 and 10% level of significance, respectively. This implies a unit increase in the training and demonstration related to DTSVs to sampled smallholder farmers increases the probability both of using "Hybrids seeds and Hybrids with OPVs or traditional seeds" and "OPVs seeds and OPVs with traditional seeds" by 3.7 and 6.9% as compared to traditional seeds, respectively. number of years of sampled small-scale farmers increases the probability both of no climate change adaptation strategy and adaptation strategy out of the farming sector by 0.2 and 1.1% as opposed to adaptation strategy within the farming sector, respectively. These results corroborate previous research suggesting that receiving information on improved farming and contact with extension significantly explained the adoption of improved fallows among smallholder farmers (Matata et al., 2010). Farmers who have information about weather forecasts, are likely to adjust their planting decisions.
Furthermore, these results agree with similar results by Kielbasa (2016), who indicated that although education is important, it must be supported by experience, and verified in practical situations.

Knowledge possession and benefits related to DTSVs

The variable "Knowledge possession and benefits related to DTSVs" is positive and statistically significant significant at the1 and 5% level of significance, respectively in both contrasts. A positive relationship and marginal effect show that an increase in farmers who acquired knowledge about DTSVs and their better planting dates as well as familiarity with the perceived benefits of DTSVs increases the probability of using "Hybrids and Hybrids with OPVs or traditional seeds" and "OPVs and OPVs with traditional seeds" relative to the base category by 14 and 4.6%, respectively. Accordingly, farmers who were aware of the Hybrids and improved OPVs and thought they gave benefits such as immediate benefits, increased yield and improving households' food security were likely to use them relative to the traditional seeds. These results concur with research that found that if farmers believe that DTSVs were responsible for high yield and enhanced food security, they are most likely to adopt them to improve their livelihood (Diale, 2011; Ikheloa et al., 2013; Senyolo et al., 2018).

Necessary requirements

The variable "Necessary requirements" which in this study meant the combination of essentials that the sampled farmers noted were obligatory to complement the seeds technologies use (Factor 4 explanation), is

Table 6. Multinomial logit coefficient and marginal effect estimates, of sampled smallholder farmers within 3 districts of Limpopo Province, South Africa.

Dependent variable	**$Ln(Z_2/Z_3)$ Hybrids and hybrids with OPVs or traditional seeds vs. traditional seeds**			**$Ln(Z_2/Z_3)$ OPVs and OPVs with traditional seeds vs. traditional seeds**		
	Contrast 1			**Contrast 2**		
Independent variable	**Coefficient (Std. error)**	**Marginal effects dy/dx**	**Marginal effects P-value**	**Coefficient (Std. error)**	**Marginal effects dy/dx**	**Marginal effects P-value**2
Intercept	-14.848(1444)		(0.992)	0.681(1.748)		(0.125)
Training and demonstration related to DTSVs	0.786**(0.336)	0.037	**0.019**	0.735*(0.386)	0.069	**0.057**
Knowledge possession and benefits related to DTSVs	1.091***(0.279)	-0.141	**0.000**	0.761**(0.343)	-0.046	**0.027**
Knowledge on non-agricultural activities	0.156(0.337)	0.2030	0.677	0.018(.427)	0.025	0.965
Necessary requirements	0.803*(0.475)	0.014	**0.091**	-0.029(0.623)	-0.019	0.963
Enabling factors	0.961***(0.302)	-0.009	**0.001**	0.770**(0.378)	0.511	**0.041**
Gender	-1.020*(0.602)	0.066	**0.090**	-0.626(0.758)	-0.433	0.409
Age	1.171(0.784)	-0.048	0.135	-0.495(944)	0.032	0.600
Marital status	-1.791**(0.775)	0.103	**0.021**	-1.312(0.980)	0.102	0.181
Household size	-0.112(0.640)	0.047	0.862	-0.018(0.932)	-0.014	0.984
Farming experience	-0.685(0.739)	-0.006	0.354	0.058(0.921)	0.291	0.950
Education	-0.407(0.997)	-0.312	0.683	-1.274(1.468)	-0.403	0.385
Income: middle (115.4-269.2)a	0.292 (0.650)	-0.505	0.653	0.224(0.817)	-0.115	0.784
Income: high (higher than 269.2$)	0.871(1.074)	0.103	0.417	1.404(1.400)	0.031	0.316
Reason for farming	-0.195(0.598)	-0.037	0.745	-10.003(0.775)	0.069	0.196
Land size	16.872(1442)	0.027	0.822	-1.163(0.973)	0.036	0.306
Credit access	1.129**(0.558)	0.014	**0.043**	-0.466(0.711)	-0.019	0.512
Government support	-0.613(0.642)	-0.109	0.340	-0.190(0.867)	0.511	0.826
Cooperative membership	-0.185(0.671)	0.066	0.782	-1.171(8.28)	-0.433	0.157

Number of observations= 196; Reference category = Traditional seeds (Z3); Log likelihood= -218.432; Chi-square = 103.787 (significant level = .000); Pseudo-R2= 0.510; Classification accuracy (correctly predicted); Hybrids and Hybrids with OPVs or Traditional seeds = 91.9%; OPVs and OPVs with Traditional seeds = 29.2%; Traditional seeds = 63.9%; overall model = 79.1%; dy/dx is for discrete change of dummy variable from 0 to 1; Standard errors are in parentheses; Based on exchange rate of 1$ =13ZAR; ***, ** and * are significant levels at 1, 5 and 10% respectively.
Source: Survey data (2016). The dependent variable was specified as the seed variety that farmers adopted/used.

positive and negative in the first and second contrasts, respectively. This variable is positively related to the use of Hybrids seeds technologies and statistically significant at the first contrast at 10% level of significance. This implies a unit increase in the necessary requirements (that is, if farmers receive tractor services on time, possess knowledge on better planting dates of DTSVs and weather information) increases the likelihood of farmers using “Hybrids and Hybrids with OPVs or traditional seeds” by 0.014 (1.4%), relative to reference category. However, during FGDs farmers indicated their frustration of receiving tractor services and other inputs late in the season which in turn impacts planting dates recommended for DTSVs. Unquestionably, timing regarding inputs and services delivery is important in agriculture, particularly within smallholder agriculture where several barriers are farmers' reality.

Enabling factors

The variable "Enabling factors" which in this study meant the combination of empowering elements that sampled farmers noted were necessary in complementing the use of seeds technologies (Factor 5 explanation), in both contrasts is positive and statistically significant at the 1 and 5% level of significance, respectively. A positive relationship and marginal effect show that an increase in the enabling factors (that is, additional training on DTSVs and information as well as knowledge about other CSA technologies, other than DTSVs) increases the probability of using "Hybrids and Hybrids with OPVs or traditional seeds" and "OPVs and OPVs with traditional seeds" relative to the base category by 0.9 and 51.1%, respectively. Notable from these results, is also that though farmers appreciated the DTSVs, they deemed it was also necessary to be trained and be informed of other CSA technologies, other than DTSVs. These results are in line with Katengeza et al. (2012) and Mulaudzi and Oyekale (2015), who note that trait preferences of farmers form the basis of their selection of varieties.

Gender

The variable Gender in first and second contrasts is negative, but statistically significant in the first contrast at the 10% level of significance. Therefore, the estimated results of Gender imply a unit increase in the number of male smallholder farmers reduces the likelihood of using "Hybrids and Hybrids with OPVs or traditional seeds" by 6.6%, relative to the reference or base category. These results contradict with Ikheloa et al. (2013) who noted that male-headed households have the tendency to adopt climate adaptation strategies much more than female-headed households. However, our results concurred with Bayard et al. (2007) and Mugi-Ngenga et al. (2016) who found that female farmers are more likely to adopt strategies to adapt to climate variability. Although previously, female farmers were inclined to and managed to save seeds for the next farming season as compared to their male counter parts, the changing climate have seen households headed by women taking up climate adaptation strategies (Nhemachena and Hassan, 2007; Kom et al., 2020).

Marital status

The variable Marital status is negative in both contrasts, but statistically significant in the first contrast at the 5% level of significance. Therefore, the estimated results of Marital status imply a unit increase in the number of married smallholder farmers reduces the likelihood of using "Hybrids and Hybrids with OPVs or traditional seeds" by 10.3%, relative to the reference or base category. Marital status has previously been found to be insignificant in influencing the choice of adaptation strategies and technology adoption (Matata et al., 2010; Mugi-Ngenga et al., 2016; Ubisi et al., 2017). Our results however relate with the findings of Mulaudzi and Oyekale (2015) who found a statistically significant, but positive relationship between marital status and adoption of improved seeds varieties. Oluwatayo and Ojo (2016) also found a positive relationship between marital status and the likelihood of choosing diversification as an adaptation strategy. Furthermore, the highest percentages of married farmers observed in the study suggest that adoption of DTSVs in the study depends on the perception of the technology by males, as it may be common that women do not own land and/or other resources to take autonomous adoption decisions.

Credit access

The variable Credit access in first and second contrasts is positive and negative, respectively, but statistically significant in the first contrast at the 5% level of significance. This result implies that a unit increase in farmers' access to credit will yield a 0.014 (1.4%) increase in probability of using "Hybrids and Hybrids with OPVs or traditional seeds", relative to the reference or base category. These results corroborate research that found that access to credit facilities positively increased the use of different adaptation strategies (Ikheloa et al., 2013; Oluwatayo and Ojo, 2016). Thus, as access to credit increases, so does the financial capacity of the smallholder farmers to employ various technologies that are climate smart and profit driven. It should be noted that the discussion was limited to independent variables that were significant in distinguishing the 2 categories of the dependent variable related to the "traditional seeds" category (that is, base category). The reason for this was that looking at the characteristics of DTSVs as perceived by the farmers and other socio-economic factors; knowledge and experience on non-agricultural activities, age, household size, farming experience, education, income, reason for farming, land size, government support and cooperative membership; were found not to be significant in distinguishing both categories related to "traditional seeds" within their crop farming. Therefore, these variables were not included in the interpretation (Table 7).

While, MNLR computes correlation measures to estimate the strength of the relationship (Pseudo R^2 utility of the MNLR model, classification accuracy is more

Table 7. Classification table from the multinomial logit model.

Observed	Predicted			
	Hybrids and hybrids with OPVs or traditional seeds	OPVs and OPVs with traditional seeds	Traditional seeds	Percent correct
Hybrids and hybrids with OPVs or traditional seeds	**125**	3	8	91.9
OPVs and OPVs with traditional seeds	16	**7**	1	29.2
Traditional seeds	13	0	**23**	63.9
Overall percentage	**78.6**	**5.1**	**16.3**	**79.1**

useful and compares predicted group membership based on the logistic model to the actual, known group membership, which was the value for the dependent variable. Even if the predictor variables had no relationship to the groups defined by the dependent variable, the predictions would still be expected to be correct for group membership some percentage of the time. This is referred to as by chance accuracy (Petrucci, 2009). Correctly classified cases are on the diagonal in Table 7 (that is, "Hybrids and Hybrids with OPVs or traditional seeds" category, "OPVs and OPVs with traditional seeds" category, and "traditional seeds" category). Overall, the final model accurately predicted 79.1% of the cases. However, we see that the "Hybrids and Hybrids with OPVs or traditional seeds" category had a much higher prediction at 91.9% compared to other 2 categories. The estimate of by chance accuracy is computed by summing the squared percentage of cases in each group. The difference between by chance accuracy for binary logistic models and by chance accuracy for multinomial logistic models is the number of groups defined by the dependent variable. The proportional-by-chance accuracy rate was computed by calculating the proportion of cases for each group based on the number of cases in each group in the 'Case Processing Summary' (see Table 4), and then squaring and summing the proportion of cases in each group ($0.694^2+0.122^2+0.184^2=0.531$). The proportion by chance accuracy criteria is 66.4% (1.25 × 53.1% = 66.4%). Since the classification accuracy rate of 79.1% (Table 7) was greater than the proportional-by-chance accuracy criteria of 66.4%, the model improves on chance 25% or more and is considered adequate.

CONCLUSIONS, IMPLICATIONS FOR POLICY AND FURTHER RESEARCH

DTSVs are CSA technologies for addressing moisture stress and water scarcity related to climate change and variability. Results showed smallholder farmers in the study area were using three seed varieties namely: CSA technologies (Hybrids and improved OPVs) and traditional seeds. Thus, results from the survey of 196 farmers showed 136 (69.4%) used Hybrids and Hybrids with Open Pollinated Varieties (OPVs) or Traditional seeds, followed by 24 (12.2%) who were using "OPVs and OPVs with Traditional seeds", with the remaining 36 (18.4%) who did not adopt any DTSVs and were using Traditional seeds. We find that despite the acknowledged potential of such technologies as DTSVs, drivers and barriers exist, which impact their adoption and use. For instance, variables "Training and demonstration related to DTSVs", "Knowledge possession and benefits related to DTSVs" and "Enabling factors" (that is, referring to empowering elements such as additional training on DTSVs and information as well as knowledge about other CSA technologies, other than DTSVs) were significant in distinguishing both categories ("Hybrids seeds and Hybrids with OPVs or traditional seeds" and "OPVs seeds and OPVs with traditional seeds" of the dependent at 5 and 1% as well as 1 10, and 5% as well as 5% significance levels respectively, when compared with "Traditional seeds". Furthermore, the following variables: "necessary requirements" (that is, combination of essentials such as farmers receiving tractor services on time, possessing knowledge on better planting dates of DTSVs and weather information), gender, marital status and credit access were significant in distinguishing category 1 of the dependent variable. These results are valuable to policymakers and technology developers as they highlight the key factors that impact farmers' adoption decisions. Farmers in the study area report that enabling factors such as additional training and information would increase their ability to adopt DTSVs. Our results highlight that training and demonstration related to DTSVs, knowledge possession and awareness of benefits related DTSVs and enabling factors were important for all the categories of the dependent variable. It can be recommended that Department of Agriculture, Forestry and Fisheries (DAFF), Provincial Departments of Agriculture (PDsA) and Agricultural Research Council as well as private companies work together to improve adoption of DTSVs to establish functional regulatory board in order to work closely with the farmers and to educate them about the seeds and their benefits so as to safeguard food security and to improve farm incomes. Working closely with farmers will enable them to assess the most suitable seed varieties for a given area and farming system, together with farmers' ability to adequately adopt seeds in question.

The results also indicate that training and demonstration were significant in impacting farmers' adoption of DTSVs relative to traditional seeds. In this instance, policymakers and other stakeholders can mobilize their resources and coordinate their efforts to provide training and demonstration to farmers regarding the DTSVs to enhance adoption of these technologies. The results also highlight that farmers in rural areas are heterogeneous, with some having better capabilities to adopt different CSA technologies; therefore, how other stakeholders engage farmers through education, training and any form of assistance related to CSA technologies should be tailored to suit farmers' different needs and capabilities. Furthermore, the results highlight that access to effective training, agricultural advisory service and weather forecasting impacted adoption. The strengthening of existing extension services as well as engagement with the private sector (e.g. technology providers), could help overcome the barriers of lack of knowledge and finances, thereby safeguarding adequate adoption by farmers.

Results indicated that variable necessary requirements related to DTSVs were significant when the outcome variable "Hybrids and Hybrids with OPVs or traditional seeds" was being compared to outcome variable "traditional seeds". Thus, farmers highlighted the importance of being informed about weather information and better planting dates in their area and to receive tractor services on time to plant DTSVs. Despite the importance of timing regarding inputs and services delivery in agriculture, during FGDs farmers indicated their frustration of receiving tractor services and other inputs late in the season which in turn impacts planting dates recommended for DTSVs. Therefore, PDsA in South Africa need to relook into their planning and supply chain processes in order to improve the effectiveness of their input delivery system to smallholder farmers.

Our results indicated that unit increase in the number of male smallholder farmers reduces the likelihood of using "Hybrids and Hybrids with OPVs or traditional seeds" by 6.6%, relative to the use of traditional seeds. Gender issues within climate change related studies are not new and continue to yield mixed results. In Ikheloa et al. (2013) male-headed households showed a tendency to adopt climate adaptation strategies, while in Bayard et al. (2007) and Mugi-Ngenga et al. (2016) female famers were more likely to adopt strategies for climate variability adaptation. Perhaps potential issues arise during survey processes. It can be recommended that a specific study be conducted in South Africa and pay attention to potential gender issues during survey process to ascertain the conditions which hinder or enable various genders to adopt CSA technologies such as DTSVs.

Credit access was also a significant factor, again illustrating the difficulty of farmers' access to agricultural production credit. It can therefore be recommended that farmers' access to credit be enhanced so as to beef-up their financial capacity to adopt CSA technologies such as DTSVs. Ikheloa et al. (2013) alluded that improving farmers' access to credit and extension will boost farmers capability to use various adaptation strategies to respond to climate variability. This is important given that affordability of DTSVs remains a challenge. Department of Land Reform and Rural Development in partnership with DAFF could work to together to fast-track the pillar of land reform responsible for provision of title deeds and adequate post-settlement support that farmers will need to ensure transferred farms remain viable. Ownership of land accompanied by adequate sufficient support will empower the farmers in several ways that include ability to produce food and to use the land as a collateral to obtain production credit which is a necessity for commercial production. Policymakers could help farmers obtain title deeds of the land they use for agriculture, so this land can be used as collateral to obtain production credit in formal institutions. Some farmers in the study area sourced their credit from informal institutions, often even considered 'illegal'; as they see these as alternative options in the absence of support from formal institutions such as commercial banks, government, and the private companies. Further research could unpack other sources of production credit and how they function, to complement the provision by formal institutions.

Although it is undeniable that local provision of seeds has the potential to reduce the higher transaction costs of procuring DTSVs, the concern raised by some farmers over issues of trust regarding production and marketing of quality seeds at local level demand further attention. Therefore, government, private sector and universities should join forces and mobilize resources to invest in organizing and empowering more farmers to engage in community-based seed production that farmers can all trust. Furthermore, knowledge of these enabling and hindering factors to adopting CSA technologies such as DTSVs will also contribute to the emerging literature as well as the global research and policy debate regarding CSA.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors are appreciative for the financial support offered by NUFFIC NFP PHD Programme, NFP-PhD, grand award CF9421/2014 and other support provided by Wageningen University (WUR) and University of Limpopo that enabled the PhD research project upon which this paper is based and also thank the respondents of the study for their time and for sharing their insights with us.

REFERENCES

Adesina AA, Chianu J (2002). Determinants of farmers' adoption and adaptation of alley farming technology in Nigeria. Agroforestry systems 55(2):99-112.

Adesina AA, Zinnah MM (1993). Technology characteristics, farmers' perceptions and adoption decisions: A Tobit model application in Sierra Leone. Agricultural economics 9(4):297-311.

Akinola AA, Alene AD, Adeyemo R, Sanogo D, Olanrewaju AS, Nwoke C, Nziguheba G (2010). Determinants of adoption and intensity of use of balance nutrient management systems technologies in the northern Guinea savanna of Nigeria. Quarterly Journal of International Agriculture 49(1):25.

Arslan A, McCarthy N, Lipper L, Asfaw S, Cattaneo A, Kokwe M (2015). Climate smart agriculture? Assessing the adaptation implications in Zambia. Journal of Agricultural Economics 66(3):753-780.

Asayehegn K, Iglesias A, Triomphe B, Pédelahore P, Temple L (2017). The role of systems of innovation in adapting to climate change: The case of the Kenyan coffee and dairy sectors. Journal of Innovation Economics and Management 3:127-149.

Baiyegunhi LJS (2015). Determinants of rainwater harvesting technology (RWHT) adoption for home gardening in Msinga, KwaZulu-Natal, South Africa. Water SA 41(1):33-40.

Barnard J, Manyire H, Tambi E, Bangali S (2015). Barriers to scaling up/out climate smart agriculture and strategies to enhance adoption in Africa. In Forum for Agricultural Research in Africa, Accra, Ghana.

Bayard B, Jolly CM, Shannon DA (2007). The economics of adoption and management of alley cropping in Haiti. Journal of Environmental Management 84(1):62-70.

Below T, Artner A, Siebert R, Sieber S (2010). Micro-level practices to adapt to climate change for African small-scale farmers. A Review of Selected Literature 953:1-20.

Bidogeza J, Berentsen P, De Graaff J, Lansink AO (2009). A typology of farm households for the Umutara Province in Rwanda. Food Security 1(3):321-335.

Bonabana-Wabbi J (2002). Assessing factors affecting adoption of agricultural technologies: The case of Integrated Pest Management (IPM) in Kumi District, Eastern Uganda. (Doctoral Dissertation), Virginia Tech.

Botha N, Atkins K (2005). An assessment of five different theoretical frameworks to study the uptake of innovations. Paper presented at the New Zealand Agricultural and Resource Economics Society.

Bryan E, Deressa TT, Gbetibouo GA, Ringler C (2009). Adaptation to climate change in Ethiopia and South Africa: options and constraints. Environmental Science and Policy 12(4):413-426.

Chami DE, Moujabber ME (2016). Drought, climate change and sustainability of water in agriculture: A roadmap towards the NWRS2. South African Journal of Science 112(9-10):1-4.

Chaminuka P, Senyolo G, Makhura MN, Belete A (2008). A factor analysis of access to and use of service infrastructure amongst emerging farmers in South Africa. Agrekon 47(3):365-378.

Creswell JW (1994). Research design: Qualitative, quantitative, and mixed methods approaches. Sage publications,

Deressa TT, Hassan RM, Ringler C, Alemu T, Yesuf M (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. Global Environmental Change 19(2):248-255.

Diale N (2011). Socio-economic indicators influencing the adoption of hybrid Sorghum: The Sekhukhune District perspective. South African Journal of Agricultural Extension 39(1):75-85.

Doss CR (2006). Analyzing technology adoption using microstudies: limitations, challenges, and opportunities for improvement. Agricultural Economics 34(3):207-219.

Drechsel P, Olaleye A, Adeoti A, Thiombiano L, Barry B, Vohland K (2005). Adoption driver and constraints of resource conservation technologies in sub-Saharan Africa. Berlin: FAO, IWMI, Humbold Universitaet pp. 1-21.

Edge M, Oikeh SO, Kyetere D, Mugo S, Mashingaidze K (2018). Water Efficient Maize for Africa: A Public-Private Partnership in Technology Transfer to Smallholder Farmers in Sub-Saharan Africa. In From Agriscience to Agribusiness (pp. 391-412): Springer.

Elum ZA, Modise DM, Marr A. (2017). Farmer's perception of climate change and responsive strategies in three selected provinces of South Africa. Climate Risk Management 16:246-257.

Falaki AA, Akangbe J, Ayinde O (2013). Analysis of climate change and rural farmers' perception in North Central Nigeria. Journal of Human Ecology 43(2):133-140.

FAO (2010). "Climate-Smart" Agriculture. Policies, Practises and Financing for Food Security, Adaptation and Mitigation. Retrieved from Rome, Italy: http://www.fao.org/docrep/013/i1881e/i1881e00.pdf

FAO (2013). Climate-Smart Agriculture Sourcebook [Press release]

Feder G, Umali DL (1993). The adoption of agricultural innovations: a review. Technological Forecasting and Social Change 43(3-4):215-239.

Fischer K, Van den Berg J, Mutengwa C (2015). Is Bt maize effective in improving South African smallholder agriculture? South African Journal of Science 111(1-2):01-02.

Gandure S, Walker S, Botha J (2013). Farmers' perceptions of adaptation to climate change and water stress in a South African rural community. Environmental Development 5:39-53.

Ghane F, Samah BA, Ahmad A, Idris K (2011). The role of social influence and innovation characteristics in the adoption of Integrated Pest Management (IPM) practices by paddy farmers in Iran. Paper presented at the Proceedings of the International Conference on Social Science and Humanity.

Grainger-Jones E (2011). Climate-smart smallholder agriculture: What's different (ISBN 978-92-9072-282-3). Retrieved from Rome, Italy: https://www.donorplatform.org/files/content/Media/Agenda_2030/Latest/SAFIN/IFAD_CSA.pdf

Hair JF, Anderson RE, Tatham RL, Black WC (1995). Multivariate Data Analysis with Readings (4th ed.). Englewood: N.J: Prentice-Hall.

Harvey CA, Chacón M, Donatti CI, Garen E, Hannah L, Andrade A, Chara J (2014). Climate-smart landscapes: opportunities and challenges for integrating adaptation and mitigation in tropical agriculture. Conservation Letters, 7(2):77-90.

Ikheloa E, Ikpi A, Ikpi V, Oluwatayo I (2013). Understanding farmers' response to climate variability in Nigeria: a multinomial logit approach. Ethiopian Journal of Environmental Studies and Management 6(6):630-369.

Jiri O, Mafongoya P, Chivenge P (2015). Smallholder farmer perceptions on climate change and variability: A predisposition for their subsequent adaptation strategies. Journal of Earth Science and Climatic Change, 6(5):1-7.

Kariyasa K, Dewi YA (2013). Analysis of factors affecting adoption of integrated crop management farmer field school (icm-ffs) in swampy areas. International Journal of Food and Agricultural Economics 1(2):29-38.

Katengeza S, Mangisoni JH, Kassie GT, Sutcliffe C, Langyintuo A, La Rovere R, Mwangi W (2012). Drivers of improved maize variety adoption in drought prone areas of Malawi.

Khatri-Chhetri A, Aggarwal PK, Joshi P, Vyas S (2017). Farmers' prioritization of climate-smart agriculture (CSA) technologies. Agricultural Systems 151:184-191.

Khatri-Chhetri A, Aryal JP, Sapkota TB, Khurana R (2016). Economic benefits of climate-smart agricultural practices to smallholder farmers in the Indo-Gangetic Plains of India. Retrieved from Bangalore, India.

Kielbasa B (2016). Driving and limiting factors in the farm management by young farmers in the context of survey research. Journal of Agribusiness and Rural Development (1[39]).

Kom Z, Nthethengwe NS, Mpandeli S, Chikoore H (2020). Determninants od smallscale farmers' choice and adaptive strategies in response to climatic shocks in Vhembe District, South Africa. GeoJournal pp. 1-24.https://doi.org/10.1007/s10708-020-10272-7

Langat B, Ngéno V, Nyangweso PM, Mutwol M, Kipsat M, Gohole L, Yaninek S (2013). Drivers of Technology Adoption in a Subsistence Economy: The case of Tissue Culture Bananas in Western Kenya. Paper presented at the Invited Paper Presented at the 4th International Conference of the African Association of Agricultural Economists.

Long TB, Blok V, Coninx I (2016). Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: evidence from the Netherlands, France, Switzerland and Italy. Journal of Cleaner production 112:9-21.

Lybbert T, Sumner D (2010). Agricultural technologies for climate change mitigation and adaptation in developing countries: policy options for innovation and technology diffusion. Retrieved from www.ictsd.org

Mackrell D, Kerr D, Von Hellens L (2009). A qualitative case study of the adoption and use of an agricultural decision support system in the Australian cotton industry: The socio-technical view. Decision Support Systems 47(2):143-153.

Mannan S, Nordin SM (2014). The Influence of Innovation Attributes on New Technologies Adoption by Paddy Farmers. International Review of Management and Business Research 3(3):1379.

Maponya P, Mpandeli S (2012). Climate change and agricultural production in South Africa: Impacts and adaptation options. Journal of Agricultural Science, 4(10):48.

Matata P, Ajay O, Oduol P, Agumya A (2010). Socio-economic factors influencing adoption of improved fallow practices among smallholder farmers in western Tanzania. African Journal of Agricultural Research 5(9):818-823.

Mdungela NM, Bahta YT, Jordaan AJ (2017). Indicators for economic vulnerability to drought in South Africa. Development in Practice 27(8):1050-1063.

Meijer SS, Catacutan D, Ajayi OC, Sileshi GW, Nieuwenhuis M (2015). The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. International Journal of Agricultural Sustainability 13(1):40-54.

Mekoya A, Oosting SJ, Fernandez-Rivera S, Van der Zijpp AJ (2008). Farmers' perceptions about exotic multipurpose fodder trees and constraints to their adoption. Agroforestry systems, 73(2):141-153.

Mignouna D, Manyong V, Mutabazi K, Senkondo E (2011). Determinants of adopting imazapyr-resistant maize for Striga control in Western Kenya: A double-hurdle approach. Journal of Development and Agricultural Economics, 3(11):572-580.

Mpandeli S, Nesamvuni E, Maponya P (2015). Adapting to the impacts of drought by smallholder farmers in Sekhukhune district in Limpopo province, South Africa. Journal of Agricultural Science 7(2):115.

Msangi S, Utah A, Batka M (2012). African Agricultural Future: Opportunities, Challenges and Priorities. Prepared for Food Security in Africa: Bridging Research and Practice, Sydney., Sydney.

Mugi-Ngenga E, Mucheru-Muna M, Mugwe J, Ngetich F, Mairura F, Mugendi D (2016). Household's socio-economic factors influencing the level of adaptation to climate variability in the dry zones of Eastern Kenya. Journal of Rural Studies 43:49-60.

Mulaudzi VS, Oyekale AS (2015). Smallholder farmer's adoption intensity of genetically modified maize varieties in Thulamela municipality, Limpopo province, South Africa. Environmental Economics 6(1):104-112.

Mushunje A, Muchaonyerwa P, Taruvinga A. (2011). Smallholder farmers perceptions on Bt maize and their relative influence towards its adoption: The case of Mqanduli communal area, South Africa. African Journal of Agricultural Research 6(27):5918-5923.

Mutamba M, Mugoya M (2014). Climate-Smart Agriculture: Farmers' Perspectives. Retrieved from https://cgspace.cgiar.org/bitstream/handle/10568/42433/Farmers%27%20Perspectives%20for%20web.pdf

Mwangi M, Kariuki S (2015). Factors determining adoption of new agricultural technology by smallholder farmers in developing countries. Journal of Economics and Sustainable Development 6(5).

Nhemachena C, Hassan RM (2007). Micro-level analysis of farmers' adaptations to climate change in Southern Africa. IFPRI Discussion Study No 714, Washington D.C, IFPRI.

Nyasimi M, Kimeli P, Sayula G, Radeny M, Kinyangi J, Mungai C (2017). Adoption and Dissemination Pathways for Climate-Smart Agriculture Technologies and Practices for Climate-Resilient Livelihoods in Lushoto, Northeast Tanzania. Climate 5(3):63.

Oluwatayo IB, Ojo AO (2016). Awareness and adaptation to climate change among yam-based farmers in rural Oyo state, Nigeria. The Journal of Developing Areas 50(2):97-108.

Palanisami K, Haileslassie A, Kakumanu K, Ranganathan C, Wani S, Craufurd P, Shalander K (2015). Climate Change, Gender and Adaptation Strategies in Dryland Systems of South Asia: A Household Level Analysis in Andhra Pradesh, Karnataka and Rajasthan States of India; Research Report No. 65 (65).

Pannell DJ, Marshall GR, Barr N, Curtis A, Vanclay F, Wilkinson R (2006). Understanding and promoting adoption of conservation practices by rural landholders. Australian Journal of Experimental Agriculture 46(11):1407-1424.

Partey ST, Zougmoré RB, Ouédraogo M, Campbell BM (2018). Developing climate-smart agriculture to face climate variability in West Africa: Challenges and lessons learnt. Journal of Cleaner Production 187:285-295. doi:10.1016/j.jclepro.2018.03.199.

Petrucci CJ (2009). A primer for social worker researchers on how to conduct a multinomial logistic regression. Journal of Social Service Research 35(2):193-205.

Rankoana SA (2016). Perceptions of climate change and the potential for adaptation in a rural community in Limpopo Province, South Africa. Sustainability 8(8):672.

Rogers EM (2003). Diffusion of Innovations, fifth ed. New York: The Free Press, New York.

Senyolo MP, Long TB, Blok V, Omta O (2018). How the characteristics of innovations impact their adoption: An exploration of climate-smart agricultural innovations in South Africa. Journal of Cleaner Production 172, 3825-3840. doi:10.1016/j.jclepro.2017.06.019.

Suleman KK (2017). UPSCALING CLIMATE-SMART AGRICULTURE IN SUB-SAHARAN AFRICA (48). Retrieved from University of the Witwatersrand, Johannesburg, South Africa:

Tessema YA (2018). Drivers of Climate Sensitive Farm Level Adjustments: Climate Change, Economic and Technical Factors, and Resource Availability. ETH Zurich,

Tessema YA, Aweke CS, Endris GS (2013). Understanding the process of adaptation to climate change by small-holder farmers: the case of east Hararghe Zone, Ethiopia. Agricultural and Food Economics 1(1):13.

Tshiala FM, Olwoch JM, Engelbrecht FA (2011). Analysis of temperature trends over Limpopo province, South Africa. Journal of Geography and Geology 3(1):13.

Ubisi NR, Mafongoya PL, Kolanisi U, Jiri O (2017). Smallholder farmer's perceived effects of climate change on crop production and household livelihoods in rural Limpopo province, South Africa. Change and Adaptation in Socio-Ecological Systems 3(1):27-38.

Wanigasundera W, Alahakoon P (2014). Perceptions of climate change and adaptation of climate-smart technology by the paddy farmers: a case study of Kandy District in Sri Lanka. International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering 8(4):1088-1100.

Weisenfeld P, Wetterberg A (2015). Technological Advances to Improve Food Security: Addressing Challenges to Adoption [Press release]. Retrieved from https://www.rti.org/rti-press.../technological-advances-improve-food-security

Wekesa BM, Ayuya OI, Lagat JK (2018). Effect of climate-smart agricultural practices on household food security in smallholder production systems: micro-level evidence from Kenya. Agriculture and Food Security 7(1):80.

Zizinga A, Kangalawe RY, Ainslie A, Tenywa MM, Majaliwa J, Saronga NJ, Amoako EE (2017). Analysis of Farmer's Choices for Climate Change Adaptation Practices in South-Western Uganda, 1980–2009. Climate 5(4):89.

Zubair M, Garforth C (2006). Farm level tree planting in Pakistan: the role of farmers' perceptions and attitudes. Agroforestry Systems 66(3):217-229.