Enabling acceptance and use of ecological intensification options through engaging smallholder farmers in semi-arid rural Limpopo and Eastern Cape, South Africa

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Abstract

Ecological intensification is being promoted to address food security and environmental challenges. It has shown potential to improve yields as well as adapt and mitigate the effects of climate variability and change. Despite the great potential, smallholder farmers continue to shun the latter. Apart from this, limited research has been conducted focussing on their acceptance and use in smallholder sub Saharan African agricultural systems. In this study, a qualitative approach using the Unified Theory of Acceptance and Use of Technology (UTAUT) four constructs (performance, ease of use, social influence and enablers) was used to assess behavioural intention to accept and use ecological intensification options. A total of 97 smallholder farmers from diverse farm types in rural Limpopo and Eastern Cape, South Africa participated in focus group discussions to assess behavioural intention to accept and use ecological intensification options. Smallholder farmers revealed that they were exposed to a plethora of ecological intensification options. However, acceptance and utilisation of these options were low, mainly due to lack of awareness, germplasm and technical support. The four constructs of the UTAUT framework, revealed locally relevant knowledge that must be considered for effective acceptance and use of ecological intensification options.

Key words: ecological intensification, unified theory of acceptance and use of technology, smallholder farming systems

1.0 Introduction

South Africa as a nation is food secure, but most rural households that depend on agriculture as a livelihood are food insecure (De Cock et al. 2013; Musemwa et al. 2015). Debates on how to revitalise smallholder agriculture to improve food security in rural South Africa are gaining momentum (Thamaga-Chitja and Morojele 2014). Around four million smallholder households are still largely confined on 13% of the country's land (Louw 2013). Much of this land is severely overcrowded (Edward and Cousins 2005), with average land holdings of 0.5 to 1.5 ha per household (Aliber and Hart 2009). As in many African countries, South African smallholder farmers practice rainfed subsistence agriculture (Thamaga-Chitja and Morojele 2014), in areas with low agricultural potential. It is anticipated that these areas will be severely affected by negative impacts of climate change and variability (Turpie and Visser 2015). Cropping takes place in gardens and demarcated fields, consisting of staple and vegetable crops for household consumption. The farms are not well developed or resourced and rely on traditional methods of production generally characterised by low input-low production systems (Thamaga-Chitja and Morojele 2014). As a result, food insecurity is a challenge that still persist in these smallholder farms (Masipa 2017).

According to Food and Agriculture Organisation (FAO) (2015), South Africa achieved its millennium development goal target of halving undernourishment and food insecurity by 2015. Yet, the lack of sustainability in both the commercial and smallholder farming sectors is increasingly worsening (Laan et al. 2017). Also, several studies have shown that the ever increasing population densities in rural areas are leading to shrinking of farms (Jayne et al. 2014). Environmental conditions within the smallholder areas continue to deteriorate because of continuous cropping of fields, land degradation due to natural and anthropogenic factors, and poor state support for land users, amongst other causes, are all contributing to unsustainable forms of agricultural intensification (Timm Hoffman 2014). Unavailability of land for cropland expansion in these areas (Aliber 2003) means that South Africa should adopt a sustainable approach to intensify smallholder food production systems (Laan et al. 2017). If not done, current and future generations are at risk of household food insecurity (De Cock et al. 2013). Scarcity of farmland, high levels of environmental degradation and increased vulnerability of smallholder farmers to climate variability and change calls for new pathways to sustainably improve and intensify food production systems. Mismanaged agricultural intensification might compromise food production and food security, leading to increased poverty and environmental degradation. This situation calls for the development of appropriate methods of intensification as well as enabling conditions for successful implementation.

Ecological intensification is being recognised for enhancing ecosystem services and improving crop yields (Bommarco et al. 2018). A recent review shows a predominance of win-win situations from ecologically intensified cropping, compared to conventional farming, particularly in terms of maintaining or increasing yields and public goods (Garbach et al. 2017). Whether deliberately or not, much of African smallholder agriculture has remained rather ‘ecological’. Basic supportive and regulatory ecological processes steered through local indigenous knowledge still form the backbone of smallholder agriculture in many places (Tittonell and Giller 2013). Although, there are many ecological intensification options associated with yield gains, African smallholder farmers are resource constrained and face important trade-offs in resource allocation due to the interconnectedness of farming systems

(Tittonell et al. 2009). Smallholder farmers are unable to benefit from the potential yield gains emanating from the options because they come with varying costs, socioeconomic impacts and also require conducive environments for their uptake (Tittonell and Giller 2013; Harris and Orr 2014). These pressures shape farmers' decision making in accepting and using particular agricultural technologies, as they may have both short and long-term consequences on farm livelihoods. Thus, implementation of ecological intensification options requires engaging with farmers and other stakeholders to understand trade-offs and synergies that arise among them. Smallholder farmers are heterogenous in nature (Vanlauwe, Coe, and Giller 2016); they operate under various agroecological, socioeconomic and market conditions (Caron, Bienabe, and Hainzelin 2014). This makes it crucial to generate more information on the feasibility and viability of these options at farm scale.

This paper focuses on what can be done to improve acceptance and use of ecological intensification options in a context applicable to smallholder farmers. The specific objectives of this paper are therefore to understand farmer perceptions on:

(i) relevance of ecological intensification options;
(ii) how ecological intensification could apply within the main livelihood and socioeconomic context; and
(iii) what can be done to enable implementation of ecological intensification?

To achieve the objectives specified above, the following questions were formulated. (i) How relevant are ecological intensifications options in their farming efforts? (ii) How well does ecological intensification apply and fit within the main livelihood and socioeconomic context of smallholder farmers? (iii) What can be done to enable implementation of ecological intensification options in smallholder farming systems?

2.0 Materials and methods

2. 1 Conceptual and theoretical framework

To answer the research questions, we took a qualitative and deductive approach. We employ both farmer perceptions and theory to guide us, using key factors for enhancing technology use and acceptance. We identify options for ecological intensification and explore their relevance directly with farmers, utilising their lived experience of the context within which they are used in smallholder agriculture in South Africa. We then use and apply the Unified Theory of Acceptance and Use of Technology (UTAUT) conceptual framework (Venkatesh et al. 2003) to explain how ecological intensification options could be accepted and used in smallholder farming communities. The UTAUT framework has four key constructs that influence behavioural intention to use or accept a technology (namely, performance expectancy, effort expectancy, social influence, and facilitating conditions). In line with the UTAUT, performance expectancy is defined as the degree to which using a technology or practice will help improve productivity (performance) of a system; effort expectancy is the degree of ease or difficulty associated with the use of the technology or practice; social influence is the extent to which individuals perceive the usefulness of a particular technology due to others' persistent use of the technology; and enabling conditions are defined as the extent to which farmers believe that organisational and technical support exist to use the technology or practice (Brown and Venkatesh 2005; Venkatesh et al. 2003). Various scholars have used the UTAUT conceptual model extensively to explain technology acceptance and use in agricultural systems (Rose et al. 2016; Beza et al. 2018). In our case, the model allowed rigour to be brought to the process of assessing acceptance and use of ecological intensification options by smallholder farmers, with an expectation for out-scaling.

2.2 Description of study regions

This study was conducted in Amathole and Vhembe Districts in the Eastern Cape and Limpopo Provinces of South Africa, respectively (see Figure 1). Both provinces are predominantly rural and classified as the poorest in the country. Compared to other provinces, they are also home to the largest number of smallholder farmers who are highly dependent on rainfed agriculture (De Cock et al. 2013; Musemwa et al. 2015). In addition, each smallholder farmer cultivates less than 2 ha on average. Maize, legumes and vegetables are the most commonly cultivated crops. Depending on their level of resource endowments, farmers own cattle, donkeys, goats, sheep, pigs and poultry. In Amathole District, the study was conducted in Raymond Mhlaba Local Municipality which is located at 34°47´S, 26°38´E. Amathole is a semi-arid area, with mean minimum and maximum monthly temperatures ranging from 6.2°C to 20.8°C in July and 17.2°C to 36.0°C in February. The District experiences a bi-modal rainfall pattern. Thus, it receives both summer and winter rainfall, with an average annual rainfall not exceeding 600 mm. The months of October to March have the most rainfall with 75 to 100 mm monthly averages, while May to September experience the least rainfall averaging 25 to 75 mm monthly (Chari, Hamandawana, and Zhou 2018). The highly variable climate makes it difficult to project climate change in this area (Wintola, Otang, and Afolayan 2017). The challenges posed by highly variable semi-arid climate, compounded by factors such as poverty, inequality, and low income levels, among others, compromise the adaptive capacity of local communities (Chari, Hamandawana, and Zhou 2018).

In Limpopo Province, the study was conducted in Ha Lambani village of Vhembe District, which is about 180 km to the north of Polokwane at 22°58´S, 30°26´E. It is a semi-arid area found to the north of the Province. The area receives most of its rainfall between October and January, and is frequently affected by dry spells, often escalating into severe drought (Ubisi et al. 2017). Projections in the South African National Climate Change Response Strategy reveal that, in Vhembe District, temperature is expected to increase by 1 to 3°C by the mid-21st century (Department of Environmental Affairs and Tourism: [DEAT] 2004). It is projected that rainfall amounts will be reduced by 5–10% (DEAT, 2004). These stressors are another trait of importance to the study of acceptance and use, further highlighting the suitability of these communities for assessment of the potential of implementing ecological intensification options.

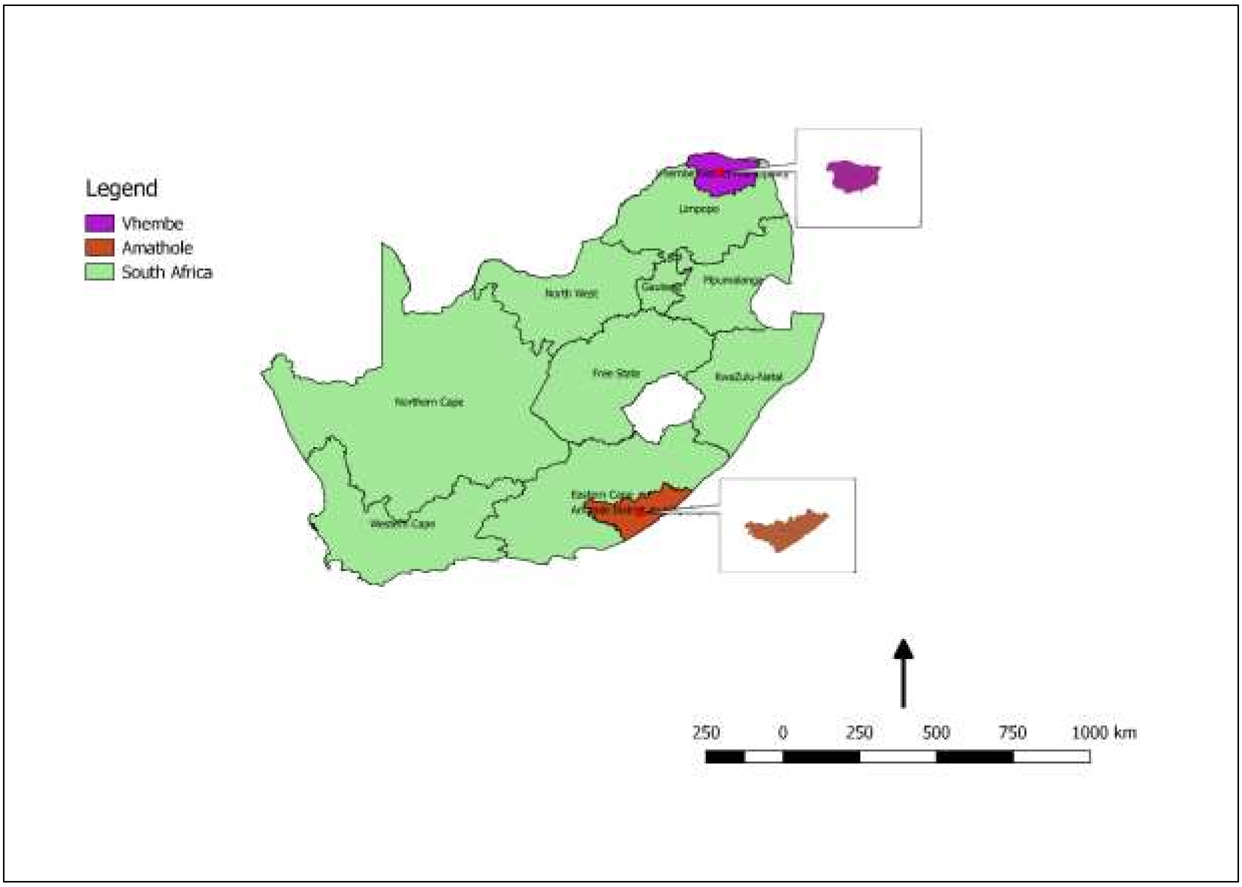

Figure 1. Map of South Africa showing the location of the study sites in Limpopo and Eastern Cape Provinces.

2.3 Data collection methods and approach

This research was a qualitative case study analysis of ecological intensification options used by smallholder farmers in the study areas. The data collection approach involved two stages which were as follows:

(i) Stage 1: Identifying context specific ecological intensification options through literature review

(ii) Stage 2: Participatory action research through focus group discussions with local experts and smallholder farmers on the acceptance and use of ecological intensification options.

Our study was based on a mixed methodology centred on literature review and participatory action research (PAR) as data collection approaches. Participatory action research has been recognised as an effective strategy to identify needs, institutional capacity and to catalyse change in smallholder farming systems (Shames et al. 2016). Participatory action research is an approach in which project stakeholders are engaged in a process that allows them to play an active role in the development of research questions, research methodology as well as data collection and analysis (Ernesto et al. 2017). We selected participatory action research in this case because it is context specific, participatory, it develops reflection based on interpretations made by the participants and is based on evidence gathered.

2.3.1 Diagnosis and identification of potential ecological intensification options

Literature review was carried out to identify ecological intensification options common in South African smallholder agriculture. While this paper does not purport to be exhaustive in documenting every ecological intensification option practised in the smallholder agricultural sector in South Africa, it attempts to provide a comprehensive overview of ecological intensification options used in smallholder agriculture in South Africa. These options/practices are listed in Table 1.

Table 1 Description of ecological intensification options for smallholder farmers in South Africa.

Option	Description of the practice	Source
Crop rotation	The growing of different crops in succession on the same piece of land	Ndwandwe and Mudhara, 2008; Bloem et al. 2009; Thierfelder et al. 2013
Trap crops	A crop planted to attract insect pests from another crop	Finch and Collier 2012; Phophi and Mafongoya, 2017
Natural enemies	Control of insects by other living insects	Grzywacz et al. 2014
Plant extracts	Using extracts from certain plant species to control pests	Grzywacz et al. 2014
Field sanitation	Procedures aimed at the prevention or eradication of sources and vectors of pests and diseases.	Mdluli et al. 2014
Intercropping	Growing a crop among plants of a different kind	Bloem et al. 2009; Rusinamhodzi et al. 2012; Masvaya et al. 2017
Cover cropping	Growing a crop for the protection and enrichment of the soil	Tsubo et al. 2003; Bloem et al. 2009; Murungu et al. 2011; Dube et al. 2012
Polycultures	The simultaneous cultivation or exploitation of several crops	Hitayezu et al. 2016
Inclusion of legumes	Growing of leguminous crops in space and time	Gwata and Mzezewa 2013
Varietal mixtures	Several varieties of the same species, such as maize, sown mixed together	Mnkeni and Mutengwa 2014; van Niekerk and Wynberg 2017
Agroforestry	A system of land use in which harvestable trees or shrubs are grown among or around crops or on pastureland as a means of preserving or enhancing the productivity of the land	Paumgarten, Shackleton, and Cocks 2005; Kelso and Jacobson 2011; Zerihun, Muchie, and Worku 2014
Conservation agriculture (CA)	A practice that comprises three components applied simultaneously in the field on: namely, planting basins, crop residue retention and crop associations through rotations	Sithole et al. 2016; Muzangwa et al. 2017
Gelesha	A means of hoeing or the tilling of soil after a crop harvest	Denison and Wotshela 2009; Gandure, Walker, and Botha 2013
In field water harvesting	A technique of maximising infiltration, reducing surface runoff and soil evaporation, and improving soil water availability to the crop	Mwenge Kahinda and Taigbenu 2011; Biazin et al. 2012
Rooftop water harvesting	Water is collected from rooftops, courtyards and similar compacted surfaces and used for domestic purpose or garden crops	Mwenge Kahinda and Taigbenu 2011; Denison and Wotshela 2012
Application of animal manure/ compost	Animal waste (predominantly urine and faeces) typically applied to soils as fertilizer for agricultural production	Mkhabela 2017; Materechera 2010
Land fallowing	A piece of land that is normally used for farming but that is left with no crops on it for a season to let it recover	Shisanya and Mafongoya 2016
Mulching	A process whereby a layer of grass or crop residues is applied to the surface of soil	Botha et al. 2012; Maponya and Mpandeli 2013

2.3.2 Focus group discussions to explore the uptake of the options

Fieldwork for this research was carried out from September 2017 to November 2017. During this time frame, the lead author spent three months collecting qualitative data through focus group discussions with agricultural extension officers and smallholder farmers from villages in the study locations. Focus group discussions were conducted in two steps. During the first phase, four agricultural extension officers in each local Municipality, namely Raymond Mhlaba and Thulamela were identified as key informants and meetings were organised with the key informants to supply missing information, eliminate bias and validate our preliminary literature-based findings. This helped present a general depiction of the validity and relevance of the 18 ecological intensification options identified in the two municipalities. Critical context information on government initiatives and efforts to identify, promote and implement ecological intensification options was gathered. The discussions with the agricultural extension officials clarified several relevant ecological intensification options. Moreover, the discussions were enabled and facilitated subsequent focus group discussions in the two study areas. Definitions were tailored for the farming communities (Table 1) the focus group discussions.

During the second phase, focus group discussions were conducted involving smallholder farmers in the study areas. In each study location, smallholder farmers who fitted in into typologies developed by Mkuhlani et al. (2018) and Rusere et al. (2019) were selected. The Mkuhlani et al. (2018) and Rusere et al. (2019) typologies of smallholder farm types in Vhembe District, Limpopo Province were cereal-and-livestock-based, horticulture-based and off-farm-income-based farms. Similarly, in Amathole District, Eastern Cape, mixed cereal-and-livestock, horticulture-based, social welfare-dependent, struggling subsistence and cooperative farms were the identified five smallholder farm types. The snowball sampling approach was used to identify 40 and 57 farmers in Raymond Mahlaba and Thulamela Municipalities, respectively, to participate in the focus group discussions. In Raymond Mahlaba Municipality, Eastern Cape, extension officers identified agroecology farmers and farmers who fitted into the horticulture-based and cereal and livestock-based farm typologies. Five focus group discussions took place in five villages, namely Amathola Basin with 7 farmers, in Mazotsheni with 5 farmers, in Tyali with 9 farmers, in Krwakrwa with 12 farmers and Adelaide with 7 farmers. In Adelaide and Tyali the farmers specialised in the production of horticultural crops, while in Krwakrwa farmers specialised in growing cereals and legumes with rearing of livestock. In Amathola Basin and Mzotsheni, the farmers receive training and technical support in agroecology from Oxfam South Africa. In Limpopo, Thulamela Municipality, three focus group discussions took place, in three villages namely, Saselamani, Mhinga and Ha Lambani with 27 cereal-and-livestock based, 13 horticulture-based and 17 off-farm-income-dependent farmers, respectively.

Agricultural extension officers served as translators from English to either Xhosa or Tshivenda languages in the Eastern Cape and Limpopo Provinces, respectively. Farmers were asked the following questions relating to their familiarity with and use of any of the above-mentioned ecological intensification options.

(i) Are you familiar with the following option? (Yes/No)
(ii) Do you use this option in your cropping activities? (Yes/No)
(iii) What role does the option play in your farming activities?

The responses to these questions were used to gain a general depiction of relevance, use and farmer knowledge of these ecological intensification options. Apart from this, the UTAUT conceptual framework outlined above, its key constructs of performance expectancy, effort expectancy, social influence and enabling actors were used as themes to solicit information on aspects farmers consider before accepting and using a technology. Farmers were asked the question below to assess each of the above-mentioned ecological intensification options in terms of the four key themes of UTAUT framework.

The following questions were asked in relation to performance expectancy:

(i) Does the option perform a beneficial function in your cropping activities?
(ii) State the benefits derived from the use of the option in your cropping activities?

The following questions where asked in relation to ease of use:

(i) Is the option labour intensive?
(ii) Is there a cost associated with the option or is the initial cost high?

The following questions were asked in relation to social influence:

(i) How well does the option fit within the farmers environment?
(ii) How applicable is the option to all scales of farming?

The following questions were asked in relation to enabling actors:

(i) What can be done to improve acceptance and use of the option?

2.4 Data analysis

The data from the focus group discussions with farmers were analysed using iterative coding. The transcripts were coded manually with text, phrases, and statements and these were subsequently linked and mapped against the four key constructs of the UTAUT framework namely performance, ease of use, social influence and enabling actors. The authors performed moderate editing of interview quotes and questionnaire responses to enhance readability. This paper, therefore, reports on findings pertaining to the focus group discussions with smallholder farmers and it is not intended to make any statistical inferences for the study region. Its contribution is scope limited in this respect but transparent with respect to a detailed account of smallholder perspectives.

3.0 Results

First, we present focus group discussion results on smallholder farmers familiarity and the use of these ecological intensification options in their farming activities. We then present the results on smallholder farmers behavioural intention to accept and use ecological intensification options under the four key constructs of the UTAUT framework namely, performance, ease of use, social influence and enablers.

3.1 Familiarity and use of ecological intensification options by smallholder farmers

In both Municipalities, smallholder farmers were knowledgeable about the ecological intensification options presented in Table 2. The use of these ecological intensification options varied according to smallholder farmers production objectives. We present the results under three thematic areas namely pest suppression, soil management and intra-and-inter seasonal climate variability management.

3.1.1 Pest suppression

Pest and diseases were not regarded as major challenges in the production of cereal crops and legumes. The cereal and livestock farmers revealed that pests and diseases only affected their small home gardens only. Crop sanitation and land fallowing were practiced in arable fields. In contrast, horticulture-based farmers cited incidence of pest and diseases as major obstacles to successful production. They noted the importance of crop diversification options in crop protection. Among the crop diversification options, polycultures, varietal mixtures intercropping and crop rotations, helped break pest, diseases and weed cycles in horticultural cropping systems. Cereal and livestock, horticultural and agroecology farmers used plant extracts for example from onion and garlic to control crop insects' pests in their gardens on small scale. This was not a common practice in the other type of farming systems. It was observed that use of natural enemies as biological control agents for pest suppression was rare because most farmers were unaware of the methods. Nevertheless, agroecology farmers in Raymond Mahlaba Local Municipality indicated that they were aware of the potential of lady birds in the control of insect pest.

3.1.2 Soil management

Farmers across all the farm types highlighted soil fertility and soil moisture deficits as major challenges. It was indicated that organic resources, such as animal manure, crop residues and compost, were widely used to improve soil fertility and water conservation. Legumes were regarded crucial in cropping systems through crop diversification options, such as intercropping, cover cropping, rotations and polycultures. Their importance related to their ability to fix nitrogen and improve soil fertility, which ultimately reduced the need for high exogenous application of inorganic fertilizers. The crop diversification options reduced runoff and increased infiltration resulting in enhanced water harvesting and conservation. Cereal-and-livestock and agroecology-based famers confirmed their exposure to conservation agriculture (CA) and in situ water harvesting techniques. In addition, they highlighted the potential benefits of improving soil fertility as well as soil and water conservation. However, uptake was limited due to socio-economic and technical constraints. In the Eastern Cape, an indigenous practice of water harvesting, and soil conservation called *gelesha* was said to be common among farmers. it involved tilling the land immediately after harvest. This was done to ensure increased infiltration of rain, dew and frost, in addition to reducing runoff. Thus, the practice was crucial in increasing availability of water for the next crop.

3.1.3 Management of intra-and-inter seasonal climate variability

Farmers were aware and wary of inter-and-intra seasonal droughts, which increased the risk of crop failure. Mitigation measures included investing variety and cultivar mixtures, cultivating multiple types of crops with the aim of increasing overall farm productivity and ensure that there would be harvest security within unpredictable climatic patterns. Polycultures, intercropping and crop rotations with vegetables and legumes, were crop diversification options utilised to help to reduce the risks of production failure in case of dry spells and droughts being experienced. These practices helped reduce overall sensitivity of the farming systems to both intra-and-inter seasonal climate variations.

Roof top water harvesting techniques were also relied on. This made it possible to grow legumes and vegetables especially in small spaces, such as backyard or home gardens, with minimal use of resources. As a result, they were direct benefits with respect to household diets. Agroforestry played a multi-seasonal long-term role in diversifying livelihoods. Consequently, reduced sensitivity and increased adaptive capacity of farmers in household consumption. Surplus fruits were sold to generate income and reduce financial vulnerability to current and future climate risk. Non-fruit trees, such as Acacia species, were a source of forage fodder in livestock farming systems during the dry season and drought years. Because of this critical role, tree species helped build resilience of the farming systems to climate variability and change induced challenges.

3.2 Utilising the UTAUT framework in analysing ecological intensification options

The UTAUT theoretical framework suggest that acceptance and use of technology is explained by four key constructs namely, performance expectancy, effort expectancy social influence and enabling actors. We explored farmer perception on how ecological intensification options would apply under these four key constructs that influence technology acceptance and use. Table 3 is a summary of the farmer perceptions taking in to account the options performance, ease of use, compatibility with the socio-economic context and enabling conditions for acceptance and use of ecological intensification in smallholder farming systems.

3.2.1 Performance expectancy

According to farmers' perceptions (Table 3), increased crop yields, soil fertility improvement, enhancement of soil water conservation, pest suppression and harvest security were the major performance indicators and are major drivers for enabling acceptance and use of ecological intensification options. Farmer perceptions varied according to the role the option play in their farming activities. For example, use of organic animal manure which was common practice across farmers expressed the following testimony in relation to increased crop yields and harvest security:

"Use of animal manure improves our crop yield. If you do not apply animal manure you will not get anything."

Other farmers expressed the following testimony in relation to soil fertility improvement:

"Use of animal manure increases soil organic matter hence increase microbial activity and ultimately improve soil fertility."

Other farmers expressed the following in relation to enhancement of soil water conservation:

"If you apply animal manure it enables the soil to hold more water and enable the crops to survive during long dry spell period."

Other options that were common where use of crop rotations, polycultures and varietal mixtures. Farmers expressed the following comments in relation to pest suppression:

"If you keep on growing the same crop pest and disease will build up so u have to grow different crops or varieties to help minimise pest and diseases."

3.2.2 Effort expectancy

According to farmers perceptions (Table 3), labour intensity, availability of resources and production costs are the major indicators for effort expectancy and are the major drivers towards enabling acceptance and use of ecological intensification options. Farmer perception varied among options. For example, use of organic animal manure farmers expressed mixed feeling in relation to its ease of use:

"It is easy to use animal manure because it is locally available and cheap, but it is difficult to get it to field and also to have adequate amounts to support the whole field sufficiently".

Other options such as use of conservation agriculture and in situ rain water harvesting, farmers expressed the following testimony in relation to its labour demand:

"Conservation agriculture and in situ rain water harvesting has been promoted but some of us are too old. It will be too much work for some of us".

Other options such as varietal mixtures, crop rotations and intercropping some farmers expressed similar comments such as the following were made:

"It is very difficult to grow different crops on the same piece of land, they have different requirements and that become too much work for us. Also, it is very expensive to buy different types of seed of the same crop or for other crops. Seed is too expensive".

3.2.3 Social influence

According to farmers' perceptions (Table 3), social referents such as compatibility with the socioeconomic environment are the major indicators of social influence and are the major drivers towards enabling acceptance and use of ecological intensification options. Farmer perceptions varied according to option. For example, the following testimonies were made regarding conservation agriculture:

"Conservation agriculture is complex, we can not retain crop residues to the soil. We have livestock to feed and we use those crop residues to feed our livestock during the dry season".

This means that farmers were faced with trade-offs for crop residue use making acceptance and use of CA practices difficult in such an environment. Regarding crop rotations and polycultures, the following testimonies were made:

"We have to grow maize every season, that is what we eat".

This means that farmers have their preferred crops thus makes it difficult to introduce other crops or implement crop rotations.

Regarding agroforestry the following testimonies were made:

"We just grow fruit trees around our fields and our homes we learnt this for from our parents and grandparents. We do not know that trees and crops can be mixed together".

Regarding *gelesha* the following testimonies were made:

"That would be too much work. We also have other things to do after harvesting"

3.2.4 Enabling actors

According to farmers' perceptions (Table 3), training, technical knowhow, resource availability, markets, and legislation are the major enablers and are the major drivers towards enabling acceptance and use of ecological intensification options. Farmer perceptions mainly focused on the above-mentioned enablers. For example, the following perception were made regarding polycultures and integrating legumes in their cropping systems:

"Where will we sell those other crops? We do not have markets for those other crops. Once markets and prices are good we will grow those crops".

This means that farmers lack access to markets as well prices of the other non-preferred crops are not lucrative to them to enable them to accept and use such options.

Regarding other options such as intercropping, agroforestry farmers expressed the need for skills, training and technical knowhow. The following comments were made:

"We do not even know which crops to intercrop and when to intercrop?"

Some farmers expressed knowledge of these options but have never seen the options being used practically. For example, the following comment was made by agroecology farmers in the eastern cape:

"We have heard that lady birds can used to control pest, but we have never been exposed to such technologies"

This show that farmers need skills training and technical know to enable acceptance and use of ecological intensification options.

Regarding options such as polycultures and varietal mixtures, some farmers expressed the following:

"We are not allowed to retain seed by law. This makes it difficult to grow different crops and varieties because seed is very expensive hence we just only buy one variety for our main crop."

Table 2: Ecological intensification options exposed to and/or used by different farm types in smallholder agriculture in Limpopo and Eastern Cape.

Study area	Farm type	Pest suppression strategies	Soil management	Inter-and-intra seasonal climate variability management
Limpopo & Eastern Cape	Cereal-&-livestock-based	- Field sanitation - Land fallowing - Plant extracts	- Intercropping - Crop rotations - Inclusion of legumes - Application of animal manure - Mulching - In situ rain water harvesting - Gelesha - Conservation agriculture (CA)	- Varietal mixtures - Polycultures - Agroforestry - Roof top water harvesting
Limpopo & Eastern Cape	Horticulture-based	- Plant extracts - Polycultures - Varietal mixtures - Intercropping - Crop rotations - Field sanitation	- Application of compost - Application of manure - Crop rotations - Mulching - In situ rain water harvesting	- Varietal mixtures - Polycultures - Agroforestry - Roof top water harvesting
Eastern Cape	Agroecology	- Field sanitation - Intercropping - Polycultures - Crop rotations - Plant extracts - Natural enemies e.g lady bugs	- Application of compost - Application of manure - Cover cropping - Intercropping - Crop Rotations - Inclusion of legumes - Mulching - Conservation agriculture (CA) - Gelesha - In situ rain water harvesting	- Varietal mixtures - Polycultures - Agroforestry - Roof top water harvesting
Limpopo	Off farm-income-based	- Field sanitation - Land fallowing	- Application of manure - Intercropping - Inclusion of legumes	- Varietal mixtures - Agroforestry - Roof top water harvesting

Table 3: Key factors influencing potential adoption and or use of ecological intensification options in smallholder agriculture.

Option	Agronomic performance	Ease of use	Social influence	Enabling conditions
Land fallowing	- Breaks pest and disease cycles - Improves soil fertility	- No costs	- Resource under utilisation - Land underutilisation - Simple	- Land availability
Conservation agriculture (CA)	- Increases crop yields - Ensures harvest security - Improves soil fertility - Promotes soil and water conservation	- labour intensive	- Complex - Trade-off for mulch use - Lack of experience	- Training - Technical knowhow and support
In situ rain water harvesting	- Increase crop yields - Ensures harvest security - Promotes soil and water conservation	- High investment costs - Labour intensive	- Complex - Trade-off for mulch use - Lack of experience	- Training - Technical know and support
Gelesha	- Promotes soil and water conservation	- Labour intensive	- Competition with off season activities	- Training - Technical support
Roof top water harvesting	- Promotes soil and water conservation	- Low investment costs	- Simple	
Application of organic manures	- Increases crop yields - Ensures harvest security - Improves soil fertility - Promotes soil and water conservation	- Resources locally available - Low investment cost - Labour intensive - Insufficient quantities - Handling and transportation challenges	- Simple	- Resource availability - Technical knowhow and support
Mulching	- Promotes soil and water conservation - Improves soil fertility	- Resources locally available - Labour intensive - Insufficient quantities - handling and transportation challenges	- Simple - Trade-off for mulch use	- Resource availability - Training - Technical knowhow and support
Crop rotation	- Increases crop yields - Ensures harvest security - Improves soil fertility	- Labour intensive - High germplasm cost and limited access	- Complex - Food diversity - Crop preference trade-offs	- Land availability - Markets - Resource availability

	- Promotes soil and water conservation - Breaks pest and diseases life cycles		- Competition for resources - Lack of experience - Land limitation	- Technical knowhow and support
Intercropping	- Increases crop yields - Ensures harvest security - Improves soil fertility - Promote soil and water conservation	- Labour intensive	- Complex - Food diversity - Crop preference trade offs - Competition for resource - Lack of experience	- Markets - Technical knowhow and support - Resource availability
Cover cropping	- Increases crop yields - Improves soil fertility - Promote soil and water conservation	- Labour intensive - Limited access to germplasm	- Food diversity - Crop preference trade offs - Competition for resources - Lack of experience	- Markets - Technical knowhow and support - Resource availability
Polycultures & varietal mixtures	- Increases crop yields - Ensures harvest security - Breaks pest and diseases life cycles - Improves soil fertility - Promotes soil and water conservation	- Labour intensive - Limited access to germplasm - Land limitation	- High investment cost - Lack of experience - Food diversity - Competition for resources - Crop preference trade offs	- Markets - Technical knowhow and support - Resource availability - Legislation
Agroforestry	- Ensures harvest security	- Limited access to germplasm	- Complex - Food diversity - Lack of experience	- Technical knowhow and support - Training - Resource availability
Plant extracts, natural enemies and trap crops	- Breaks pest and diseases life cycles - Ensures harvest security	- Cheap - Resources locally available	- Complex - Lack of experience	- Technical knowhow and support - Training
Field sanitation	- Breaks pest and diseases like cycles - Ensures harvest security	- Labour intensive - Cheap	- Complex - Lack of experience	- Technical knowhow

4.0 Discussion

4.1 Relevance of ecological intensification options in smallholder farming systems in South Africa

Ecological intensification is a pathway designed to improve productivity, increase adaptive capacity and reduce vulnerability in these smallholder farming communities. Ecological intensification advocates for strategies that are rooted in crop diversity. Crop diversity lowers the risk of crop failure and increases resilience to extreme weather events (Mccord et al. 2015). For example, while most smallholders prefer to grow cereal crops, such as maize and sorghum, with long cropping cycles, staple cereal crops tend to be more vulnerable to environmental threats and risk of crop failure. In contrast, vegetables and legumes have shorter cycles, are faster growing, require little space, and, thus, can be considered less prone to climate variability. Using indigenous knowledge is an additional advantage, allowing farmers to favour varieties well-adapted to local conditions. This has potential to increase overall farm productivity, yield stability and resilience to changing climatic patterns.

Nowadays, the issue of environmental sustainability is clearly embedded within the discourse of agricultural intensification. Where environmental sustainability and intensification could seem incompatible and contradictory (Garnett et al. 2013), ecological intensification could provide a win-win situation in terms of productivity and environmental sustainability (Garbach et al. 2017). Soil fertility is a major constraint in South African smallholder systems (Materechera 2010). Farm level management decisions, such as continuous mono-cropping on the same plot, result in both loss of soil and loss of soil fertility, resulting in land degradation and shrinkage of the natural resource base. In addition, most smallholder farmers lack knowledge on pesticide use and disposal, leading to misuse and improper disposal of agricultural pesticides with serious environmental consequences (Njeru 2013; Sheahan and Barrett 2017). Any form of degradation tends to reduce their agricultural productivity and income, which often amplifies the cycle of poverty and environmental deterioration. The implementing of ecological intensification options enhances pest suppression ecosystem services through crop diversification options, such as polycultures including intercropping and rotations (Gurr et al. 2016). It helps reduce the need for pesticides thus reducing environmental contamination, degradation and crop losses. Through crop diversification-based options, soil structure and soil biological biodiversity are inherently improved, thus enhancing nutrient recycling (Tiemann et al. 2015). Ecological intensification, hence, has the potential to break this cycle of poverty and environmental deterioration.

Options for ecological intensification fits well within the contrasting biophysical and socio-economic conditions of the heterogenous smallholder farms. It is a low-cost intensification pathway, it requires few external inputs, and makes use of local resources, hence, it is particularly suited to South African smallholder farmers. Furthermore, the reliance on local and indigenous knowledge can improve social capacity and gradually increase the quality and quantity of natural resources within the community. Ecological intensification maybe a relevant option for intensification, thus may play a key role in smallholder farming systems to enhance agricultural production and contribute to sustainable development in the poorest rural areas of South Africa.

4.2 Smallholder farmers' acceptance and use of ecological intensification in South Africa

Implementing ecological intensification is knowledge intensive and is a complex process (Garibaldi et al. 2016). According to our findings, working with farmers could increase acceptance and use of ecological intensification options in their farming systems because technology adoption depends on a range of personal, social, cultural and economic factors. Mutual learning between farmers and researchers could overcome these complexities (Landis 2016). The discussion of trade-offs at farm level is still largely missing from the ongoing discussions on how to improve smallholder agricultural productivity through ecological intensification. Trade-offs can occur between productive, environmental and social performance indicators, for example, between agricultural production and environmental impact. Such trade-offs influence acceptance and use of technologies, impact and sustainability of possible innovations and future pathways (Giller et al. 2011).

We used a four key constructs framework to assess behavioural intention to accept and use a technology and highlight issues that must be addressed if ecological intensification is to be accepted and successfully implemented in smallholder farming systems in South Africa. The actual implementation of our framework leads to a better understanding of the situation to be transformed for both researchers and farmers. We explicitly make the effort to go beyond performance to consider other aspects, such as effort, social influence and enabling actors needed, which play an indiscernible role in influencing the acceptance and use of different technologies.

4.2.1 Performance expectancy

Performance of an agricultural technology is a critical determinant of acceptance and use in farming systems. When evaluating the performance of cropping systems and technologies, attention is placed on direct or indirect outcomes. Typically, indicators such as productivity (yield), resource use efficiency or profitability, which are direct outcomes, to smallholder households, are usually employed in the evaluation process. In addition, indirect outcomes, such as improved soil fertility, decreased erosion, pest suppression among others are also used to assess the performance of cropping systems. Scientists and researchers tend to focus on yield as a key metric for assessing performance agricultural technologies. While it gives a numerical proxy for cropping system potential, it often lacks accounting for household constraints and limitations. For instance, our results showed that, for many farmers, ecological intensification options were highly useful and impacted positively on yield and resource use efficiency of inputs. Yet, this is not sufficient to ensure acceptance, as it does not necessary match with priorities of farmers, who may value food quantity more than productivity, or production stability over time more than yield maximization.

Many studies of agricultural intensification hypothesize that smallholder livelihoods will improve as agricultural productivity increases (Trimmer et al. 2017; Liao and Brown 2018). Yet, meeting home consumption requirements is a top priority for most smallholder farmers across much of Africa, often putting consistency ahead of productivity. Even if those are not necessarily conflicting, they are not clearly aligning with the original hypothesis that one implies the other. The yield stabilising effect brought about by ecological intensification options through nutrient recycling, pest suppression, and soil and water conservation ecosystem services, makes the cropping systems more resilient, thus enhancing food security. For example, our results show that crop diversification options lead to consistent and reliable harvest, thus increasing their acceptance and use in smallholder farming systems.

4.2.2 Effort expectancy

Decisions on the use of technologies are dependent on farmers' strategies (defined as a consistent set of practices aimed at reaching a particular goal) which are defined according to available financial, labour and nutrient resources. For example, a farmer might choose not to accept and use a technology that is superior in terms of productivity because s/he cannot satisfy the increased labour demands. The ease of use of ecological intensification options is consequently an important factor, which widely differs among farmers and options. Some ecological intensification, such as conservation agriculture and in situ rain water harvesting, which are promoted in rural South Africa, were noted to be complex, in addition to being management and labour intensive. Many farms are headed by elderly farmers with limited physical capacity and access to manual labour; this complexity makes those options less likely to be accepted and used. Early engagement with smallholder farmers during the design process allows to interrogation and definition of those contrasting priorities and proceeding with better tailored assessments. This could enhance acceptance and use of ecological intensification options by identifying and addressing adoption and out-scaling barriers. For example, the creation of innovation platforms that are farmer-centred, gives farmers a chance to learn, experience and exchange knowledge with other farmers and stakeholders, facilitating exchange of relatable experiences and solutions.

4.2.3 Social influence on the use of ecological intensification options

Values, degree of trust, norms and attitudes are social aspects that do influence technology acceptance and use, beyond productivity and effort of specific options. For instance, maize is a commonly grown crop and the main food staple in the study areas despite repeated low yields and low returns. The dominance of maize in this area is enormous relative to its low potential, which is motivated by food preference and strong social support. This and other social norms present a challenge for smallholders to accept and use ecological intensification options. In the maize case, it challenges the promotion of crop diversification options, such as crop rotations, intercropping or polycultures, which offer more competition for resources to maize to realise yield, over limited land availability.

The heterogenous nature of smallholder agricultural systems also results from the diverse social systems. These translate into different trade-offs, likely to influence technology acceptance and use differently through farm types. In our study areas, livestock is highly valued, especially cattle, because of the major roles it plays at farm level. Farmers keep livestock even under scarcity of feed, adapting feed practices to what is locally and seasonally available. Crop residues for instance are normally harvested, removed from the fields and used as supplementary livestock feed during the dry season when feed availability and quality are limited. In the communities surveyed, trade-offs exist between crop residue retention for soil cover and use as a supplementary livestock feed. The limited production of crop residue, subject to competing demands, emerged as a key issue and constraint for acceptance and use of some ecological intensification options. Conservation agriculture (CA) and in situ rain water harvesting options for instance, emphasize the retention of surface mulch with crop residues in smallholder farming systems, making no clear provision for supplementary feed. It is doubtful that smallholder farmers can produce sufficient crop residues to satisfy concurrently improved crop production and supplementary feed for sustained livestock production. This shows that technologies must be carefully tested on how varying social factors impact their acceptance and use given the socio-economic context of farmers.

4.2.4 Enabling conditions for acceptance and use of ecological intensification options

Several routes can be pursued to enable ecological intensification in smallholder agriculture. Increased access to information and improved knowledge on the use and potential benefits of ecological intensification options allows farmers to properly assess the impact of these options on their farming systems. Most farmers acknowledged being aware of the above ecological intensification options, but lacked knowledge and skills needed for their integration and implementation. These observations concur with other studies which asserted that smallholder farmers in South Africa lacked knowledge and skills on CA and climate smart agricultural practices (Muzangwa et al. 2017; Senyolo et al. 2017). Awareness, knowledge and training are particularly critical in crop diversification options, such as crop rotations, intercropping, trap crops and polycultures, and in our case, farmers were unaware of ideal cultivars/varieties or crops to use for such options or another practice. Facilitating tailored education programs and initiatives and providing adequate access to locally relevant technical and extension support services, is a locally relevant direction to improve smallholder farmers' access to locally relevant information and knowledge, and consequently improve the acceptance and use of ecological intensification options.

We found that increased affordability and availability of farm input resources could enable significant increase of the acceptance and use of ecological intensification options and new agricultural technologies. Studies on crop diversification options by Waha et al. (2018) and Hitayezu, Zegeye, and Ortmann (2016) noted that resource-poor smallholder farming households appear willing to grow different crops, but high cost needed for inputs such as seed and other production related costs, strongly de-incentivise farmers. Although studies by Zerihun et al. (2014) asserted that agroforestry is common in South African smallholder farming systems mainly through fruit tree production around their homesteads and cropping fields. However, the lack of high-quality agroforestry germplasm has long been recognized as a major challenge to a wider uptake of agroforestry for soil fertility and soil and water conservation in such smallholder systems (Mbow et al. 2014; Meijer et al. 2015). In our findings smallholder' farmers access resources such as seed (germplasm) through savings and exchange. Buying locally approved varieties is a common constraint due to limited financial and technical know-how on suitable varieties. In Eastern Cape, for example, farmers revealed that issues relating to laws prohibiting the retaining of seed by farmers are a major obstacle in implementing crop diversification options. Consequently, the potential of crop diversification in smallholder farming communities is limited due to legislation, limited access, availability and affordability of germplasm of other non-preferred crops in smallholder farming communities. Policies and institutions need to be put in place to enable better access to, and affordability of, farm input resources in smallholder farming communities.

Institutional accessibility, for instance the distance to input and output markets also has a significant effect on technology acceptance and use. When input and output markets are far from farms, it is difficult for farmers to access the required crop production inputs or to sell their products. It is further reported by Mariano et al. (2012) and Tessema et al. (2013) that, despite the desirable positive impacts of new technologies and considerable energies put into persuading farmers to adopt them, technology adoption is also affected by institutional factors, such as lack of input and output markets. For example, the promotion of leguminous crops, which increase fertility of nutrient deficient soils, remains limited due to limited access and availability of leguminous markets. Therefore, rapid transformation of smallholder agriculture towards ecological intensification is highly dependent on the availability of markets of the other non-preferred crops.

4.3 Transition towards acceptance and use of ecological intensification in smallholder farming systems

Through the concurrent assessment of the four key constructs of the UTAUT framework, we were able to gain a depiction of smallholder farming communities' priorities and trade-offs towards the acceptance and use of ecological intensification. Most farmers were familiar with, and appreciated, ecological intensification options, for instance in terms of soil fertility improvement, pests and diseases suppression, yield improvement and stability. In our study areas, smallholder farmers currently benefit or could benefit from ecological intensification options, making ecological intensification an attractive, promising, feasible and viable option for intensification in smallholder farming communities.

Although farmers recognised the value of ecological intensification options and associated them with yield and productivity gains, other factors they consider before accepting and using a technology are hindering their acceptance and use. Factors such as land constraints, labour, lack of knowledge, lack of technical or extension support, lack of markets, socio-economic issues, resources, and farmers consequent trade-offs need to be explored beyond mere productivity benefits. Smallholder farmers are not willing to invest in options which are costly, labour intensive or which conflict with other farmer's goals. Unless these concurrent goals and constraints are also addressed, the feasibility and viability of ecological intensification will be questionable, making its acceptance and use difficult. To enable ecological intensification acceptance and use, best-fit management practices must be tailored according to the socio-economic aspects of the communities, farming systems and their environmental context. In addition, there is a need for these efforts to be supported by institutions, for instance through increasing access to market opportunities for alternative crops resulting from diversification.

Smallholder farming communities are heterogenous in terms of resource endowments, production objectives and their biophysical environments, adding to the inherent complexity in enabling ecological intensification acceptance and use. Ecological intensification options which may be beneficial for one farmer may not always be beneficial to another. The heterogeneous nature of smallholder farming communities translates into different production objectives, synergies and trade-offs. These must be carefully considered to create conducive conditions for acceptance and effective use of ecological intensification in smallholder farming communities.

5.0 Conclusions

This study provides further evidence that ecological intensification practices and options are relevant to smallholder farming systems. They play a pivotal role in enhancing soil fertility, as well as soil and water conservation, productivity and impart stability of smallholder agroecosystems. The analysis of options for ecological intensification reported above has demonstrated the importance of assessing technologies in a holistic manner, in our case, through the application of the UTAUT framework. Overall, the analysis clarified the importance of trade-offs and synergies related to the diverse farm types, farmer objectives and the smallholder farming community more broadly. Working towards best-fit ecological intensification options requires participatory on-farm experimentation coupled with coordinated extension support. The latter should be carried out such that the smallholder farming communities are actively involved. Such an approach helps raise awareness and enables farmers to acquire agronomic skills in variety selection, planting time, cropping density and cropping patterns. Moreover, involvement of farmers would provide opportunities for them to tailor information transfer better than is the case at present. Ecologically inspired approaches rely on biodiversity to enhance resilience. Therefore, the observation of biodiversity patterns, through mapping their effectiveness, would promote the emergence of relevant agroecosystem services. Given the importance of crop diversity in ecological intensification, various crop cultivars, including native species and old landraces known among smallholder farmers should be explicitly considered taking into account factors of acceptance and use beyond productivity only.

List of Abbreviations

ACCESS: Alliance for Collaboration for Climate and Earth System Sciences

ADCI: African Climate Development Initiative

NRF: National Research Foundation

SSA: Sub Saharan Africa

UTAUT: Unified Theory of Acceptance and Use of Technology

WRC: Water Research Commission

FAO: Food and Agriculture Organisation

CA: Conservation Agriculture

Declarations

Ethics approval and consent to participate

Prior informed consent was sought from each interviewee respondent

Consent for publication

Not applicable

Availability of Data and materials

Not applicable

Competing interests

The authors declare that they have no financial or personal relationships which may have inappropriately influenced them in writing this article.

Funding

This research was supported with funding from National Research Foundation (NRF), Water Research Commission (WRC), Alliance for Collaboration for Climate and Earth System Sciences (ACCESS) and African Climate Development Initiative (ACDI). Lynn Dicks was funded by the Natural Environment Research Council (NERC) (grant code: NE/N014472/1). Interpretation of the findings and conclusion drawn from the study were the responsibilities of the authors and not on any part of National Research Foundation (NRF), Alliance for Collaboration for Climate and Earth System Sciences (ACCESS), Water Research Commission (WRC), African Climate Development Initiative (ACDI) and Natural Environment Research Council (NERC).

Authors contributions

Farirai Rusere and Siyabusa Mkuhlani developed the first draft of the manuscript, including literature search and colloation, data collection and analysis. Olivier Crespo, Lynn Dicks, Joseph Francis and Leocadia Zhou supervised the research. They provided guidance in terms of the article structure and directed the retrieval of relevant literature and finalization of the manuscript, including reviewing successive drafts.

Acknowledgements

The authors are very grateful to Alliance for Collaboration for Climate and Earth System Sciences (ACCESS), South African Water Research Commission (WRC), African Climate Development Initiative (ACDI) and Natural Environment Research Council (NERC) (grant code: NE/N014472/1) for funding the work. The authors are indebted to the Department of Rural Development and Agrarian Reform (DRDAR), in the Eastern Cape province and Limpopo Department of Agriculture and Rural Development (LDARD), Risk and Vulnerability Science Centre within the Faculty of Science and Agriculture, at the University of Fort Hare and Institute for Rural Development (IRD), at the University of Venda for providing both technical and logistical support.

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