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Exploring farmers' seasonal climate forecast needs: Co-producing forecasts for food security

Seasonal climate forecasts (SCFs) are explored as an additional tool for farmers to use to act against seasonal climate fluctuations and to support greater food security for themselves and their customers. In this study, we compared the SCF needs and possible emerging farming actions of commercial farmers and smallholder farmers while exploring the prospects for developing SCF tools to aid farmers. Our intent was not to produce a new SCF, but to improve the farmers' reception, understanding and uptake of existing SCFs. The results show that both farmer groups saw value in SCFs in improving their farming actions (and, by implication, improving their food security) and provided detailed information on their specific SCF needs to support their decision-making, such as how to improve trust, the type of information they would like to receive, how to make SCFs more understandable, and how to make SCFs relevant for their farming actions. The needs of the two groups differed marginally, but the major barrier for smallholder farmers was SCF access as a result of a lack of smartphones and network coverage.

Significance:
The findings help us to understand what farmers need to know to perceive a use and make use of SCFs, and to provide guidance in bridging the gap between existing SCF products and farmers taking more informed farming actions that will increase their resilience to climate change and improve their food security. This will enable us to build seasonal climate forecasting information tools that can be easily accessed and understood by commercial and smallholder farmers alike.

Introduction

While proportionally low in comparison to other African countries, malnourishment and perceptions of food insecurity are both on the rise in South Africa – 4.7 million South Africans are malnourished and 5.3 million report severe food insecurity.[1] While South Africa is often viewed as food secure, large-scale commercial farmers are often financially incentivised to favour exports, leaving millions with reduced access to affordable food. The largest proportion of farmers in South Africa are smallholders with limited access to technology, finances or information, and they rely largely on rain-fed agriculture. Crop yields have already been negatively impacted by climate change in southern Africa[2] and these are predicted to worsen by 2050 under current climate change predictions[3]. Reduced yields may have direct negative consequences for food security but will also impact the economy through the loss of income, job losses and the reduction of exports[4,5], further exacerbating food insecurity. Despite these early warning signs, South African farmers have yet to fully develop their resilience to climate change.

Significant research efforts have explored adaptation strategies to mitigate the long-term effects of the changing climate through modelling and remote sensing assimilation[6], but climate variability remains of near-immediate (i.e. this season) importance. In South Africa, climate variability affects the agricultural sector and results in fluctuating crop yields and the loss of crops on a seasonal timescale.[7] To address growing food insecurity, farmers can adopt precision agriculture methods to boost their yields and output. Seasonal climate forecasts (SCFs) provide one opportunity for farmers to gain insights into medium-term meteorological conditions and thus adapt their meteorological-related inputs to support their food security. Where SCFs have been used, they have been shown to improve food production.[8] SCFs offer crucial insights into potential climate anomalies expected in the upcoming season.[9] While weather forecasts predict the timing and intensity of events a day to several days ahead, SCFs provide estimates of average seasonal conditions over a specified period, typically 1–3 months.[10] While they cannot predict specific meteorological events, SCFs indicate whether the upcoming season is likely to be wetter, drier, hotter or cooler compared to typical regional averages. SCFs are therefore particularly useful in the agricultural sector because they may influence farmers' decisions regarding when and what to plant, what supplementary inputs to purchase or use, what yields to expect, and expected harvesting timing.[11,12] Effective SCFs are therefore valuable for the agricultural sector to support routine farming decisions as well as to manage risks (e.g. drier seasons, late seasonal onsets or likelihood of frost), and to implement risk-reduction strategies (e.g. the crop mix, seed choices, insurance or land management). These decisions are important, even for smallholder farmers with limited resources.[13] Hansen et al.[14] reported that farmers in sub-Saharan Africa who responded proactively to SCFs produced proportionately higher crop yields (i.e. reduced food insecurity) than those who did not.

Although the benefits of SCFs are clear, historically they have not been frequently adopted in the agricultural sector[15,16], apart from in the USA[17]. Farmers encounter challenges in accessing, interpreting and applying the forecasts.[18] Generally, Bruno Soares and Dessai[19] found that organisations in Europe failed to use SCFs because they were unaware of them, the skill and reliability were perceived as too low, there was a high level of perceived uncertainty in SCFs, and they often lacked the perceived relevance for their organisation. In a study on the value of SCFs for agriculture in Australia, Ash et al.[20] noted that they were limited by poor skill, short lead times, were difficult to access and understand, and farmers struggled with understanding their relevance to agricultural decision-making. In the USA, Briley et al.[21] reported that farmers experienced difficulties in understanding the information provided by SCF experts, were unrealistic in their expectations of what SCFs could produce, and were unsure when it was appropriate to make decisions based on SCFs.

While there is recent and ongoing work contributing to the development of knowledge on SCF production (i.e. how to produce better-suited and easier-to-understand information), this study purposefully explored the users' (farmers') needs and how existing accessible SCFs could be better accessed, understood and appropriately weighted in farmers' decision processes. Several literature reviews have summarised the problems experienced with SCF adoption by farmers across Africa. Hansen et al.[14] identified three broad categories faced by sub-Saharan African farmers: content limitations, accessibility problems and a lack of resources to address seasonal variability. Content limitations included spatial scales that were too broad, imprecise timing of meteorological events, unclear forecast periods, and poor forecast accuracy. Accessibility problems included not knowing where to access SCFs, inequitable access to SCFs with differential technology availability, and the SCF not being available in the local language. Resource limitations prevent necessary adjustments for the coming season. A lack of resources included financial resources to purchase preferred cultivars, insufficient access to lines of credit, unsuitable soils for the meteorological conditions, and insufficient credit to purchase soil enrichment resources. Chisadza et al.'s[22] review found similar issues being faced by African smallholder farmers. Muita et al.'s[23] review of SCF problems experienced by Kenyan farmers identified accessibility problems, limited access to farm inputs (e.g. appropriate seeds or fertiliser), language barriers, a lack of trust in SCFs, and spatial and temporal limitations of the forecasts.

Ebhuoma[8] provided the most comprehensive review of the problems experienced by South African farmers when considering SCFs. Some of the issues were similar to those identified elsewhere in Africa[13,22,23], such as the lack of access to SCFs (especially in a local language), poor forecast accuracy, difficulties in understanding probabilistic forecasts, and the same spatial and temporal problems. However, there were also issues that were not present in these other reviews. Specifically, the South African farmers expressed greater trust in Indigenous knowledge systems and did not trust the producers of SCFs or the intermediary disseminators of SCFs (usually extension officers).[8] Low literacy was a perceived barrier to SCF adoption, and younger farmers were more likely to consider adopting SCFs than older farmers.[8]

In summary, farmers expressed problems accessing SCFs, understanding the information on the SCFs if they could access them, and finding the relevance of SCFs for their farming decisions.

SCF tool co-production for South African farmers

Current SCF information available in South Africa is either produced in-country, either by the South African Weather Service for official dissemination or in an academic context (e.g. Forecast Worx), or is produced globally by, for example, the European Centre for Medium-Range Weather Forecasts or the International Research Institute for Climate and Society. Such products are largely developed as top-down data dissemination tools, although, for effective forecasting, the World Meteorological Organization[24] calls for co-design with clients. For the World Meteorological Organization, this means strengthening collaborations between the forecast scientists and social scientists to determine what to communicate and how to reveal actionable information to end-users. Muita et al.[23] made a similar recommendation based on their review of SCF use with farmers in Kenya. Other studies have shown the value of SCF co-design for end-users, such as Sanchez-Garcia et al.[25] who co-developed SCFs tools for moderate and advanced users in Europe, and Steinke et al.[26] who co-developed an SCF tool for a seed supply company in Zimbabwe. Bojovic et al.[27] defined co-production as an iterative, interactive and collaborative approach between forecast scientists and users that aims to improve the quality and relevance of climate forecasts by tailoring the forecasts to users' needs. For this study, we adopted an ergonomics/human factors participatory approach[28] to co-designing an SCF tool to assist farmers to access, explore, understand and facilitate the extraction of actionable information on existing SCFs for decision-making that underpins their food security.

This study initiates the co-production process for an SCF exploration platform for crop farmers, which intends to address the needs of both smallholder and commercial farmers in South Africa. These are often the two groups into which farmers are placed in South Africa.[29] Commercial farmers have access to land and their produce is predominantly sold for a profit. Smallholder farmers have limited access to land, produce food predominantly for their household, with small surpluses sold for commercial gain, and mainly use family or shared labour with neighbours.[29] In South Africa, both farmer groups are highly dependent on rainfed agriculture, which is susceptible to climate variability. The first step in the ergonomics/human factors approach[28], when designing a new exploration tool, is to gather information about users' needs and to understand the kinds of decisions that can be made.

The aims of this study were therefore twofold in comparing the smallholder and commercial crop farmers: (1) to compare the SCF exploration needs and (2) to compare the possible farming actions that enable sustainable food production. There are currently no studies comparing the SCF exploration needs of smallholder and commercial farmers in South Africa, or that have looked at how these two farmer groups might use SCFs to enhance their farming decision-making.

Methods

Procedure

The qualitative study followed ethical procedures for human participants approved by the respective ethics committees at the University of the Witwatersrand (MAORG/21/03 and MAORG/21/03) and the University of Cape Town (FSREC 064-2021). The data were collected in two stages. The sampling strategy was purposive, based on where the research team had contacts and access, to enable the comparison between commercial farmers and smallholder farmers, to be able to consider winter and summer crop farming, and to reflect experiences in locations known for differing SCF skills. Contacts in Overberg Agri helped identify potential interviewees and focus group participants in the Western Cape. Grain SA and extension officers helped identify potential interviewees and focus group participants in the Eastern Cape. The first stage involved semi-structured, in-depth interviews. Interviews took place in farmers' homes, offices or community halls, in September and October 2021. Interviews were conducted in English or Afrikaans (Western Cape) and English or Xhosa (Eastern Cape) and lasted approximately 1 hour. The interviews were audio-recorded and professionally translated/transcribed into English for analysis. The second stage involved focus group discussions to corroborate the interview data and to identify new issues. Focus groups were held in Caledon (Overberg district, Western Cape) and Moorreesburg (Swartland district, Western Cape) in July 2022 and in Nqanqarhu, Mount Fletcher (Gqabi district, Eastern Cape) and Bizana, eMaxesibeni (Alfred Nzo district, Eastern Cape) in November 2022. The focus groups took place in the Overberg Agri offices (Western Cape) and community halls (Eastern Cape). Each focus group lasted approximately 120 minutes. In the Western Cape, the focus group facilitator spoke Afrikaans, whereas in the Eastern Cape, the facilitator was assisted by a Xhosa-speaking extension officer using the Xhosa version of the focus group questions. The geographical areas from where participants were drawn are shown in Figure 1. Data were collected until saturation was noted in the responses. The researchers were constantly reflexive during data collection and data analysis to understand how their own assumptions, beliefs and judgements might bias the research process.

Instruments

The interview schedule started with biographical questions about the farmer, their farming activities, and their use of climate services, to establish a rapport. Next, farmers were asked about their SCF exploration needs with regard to their farming activities. Last, farmers were asked about the types of actions they could take based on SCFs.

The focus group discussions started with an explanation of SCFs and the issues of probability and forecasting skill. Next, the farmers' perceptions regarding the usefulness, understandability and trustworthiness of SCFs were probed, as well as suggested exploration capacity improvements. Finally, farmers were asked about the actions that they could adopt based on SCFs.

The interview and focus group schedules were developed in English and translated into Afrikaans and Xhosa.

Participants

Commercial farmers

Although the Western Cape encompasses commercial and smallholder farmers, all commercial farmers we interviewed were based in the Western Cape. In the Western Cape, 13 interviews were held with commercial grain farmers growing various winter rainfall grains, mostly wheat and barley, and 2 interviews were held with extension officers from Overberg Agri. All interviewees were white men who spoke Afrikaans as their home language. This was followed by two workshops with 52 commercial grain farmers and 2 extension officers as participants. Participants were assigned to smaller focus groups for the discussions and then each focus group reported back to the larger workshop (see Table 1). All participants were white Afrikaans speakers; 4 were women and 50 were men.

Smallholder farmers

Similarly, although the Eastern Cape encompasses commercial and smallholder farmers, all smallholder farmers we interviewed were based in the Eastern Cape. In the Eastern Cape, 16 interviews were held with smallholder crop farmers who grow a wide range of summer rainfall crops, including maize, cabbages, beans and potatoes. All interviewees were black and spoke Xhosa as their home language; 4 were women and 12 were men. Interviews were followed by four workshops with 93 smallholder crop farmers and 3 extension officers as participants. Participants were assigned to smaller focus groups as per the commercial farmers (Table 1). All participants were black Xhosa speakers; 51 were women and 45 were men.

Analysis

After transcribing the interview and focus group recordings, a random sample of the transcriptions was checked against the recordings by an independent reviewer for accuracy. The interview and focus group data were imported into Nvivo and analysed using thematic analysis. The six-phase approach to a thematic analysis was followed[30]: (1) familiarisation with the data; (2) generating initial codes; (3) searching for themes; (4) reviewing potential themes; (5) defining and naming themes; and (6) writing the report.

Results

Most interviewees had not used SCFs (77% of smallholder farmers and 77% of commercial farmers) and many had not even heard of SCFs (69% of smallholder farmers and 15% of commercial farmers), with some smallholder and commercial farmer interviewees sceptical that seasonal forecasting was even possible. For this reason, the focus groups started with a presentation on SCFs and what they were potentially capable of achieving. Attention was paid to the need to present SCF capacity as fairly as possible, including the various South African SCFs, and clarification of inherent uncertainties and skill variations.

SCF exploration needs

Six themes were identified from the interviews and focus groups regarding the needs of farmers from SCFs (see Table 2), although differences were noted between the commercial and smallholder farmers.



Figure 1: Geographical location of data collection sites.

Table 1: Breakdown of the participants of the focus group discussions

Commercial farmers	Farmers	Extension officers	Focus groups	Focus group sizes
Caledon	30	1	3	10, 10, 10
Moorreesburg	22	1	2	11,11
Smallholder farmers	**Farmers**	**Extension officers**	**Focus groups**	**Focus group sizes**
Bizana	25	0	3	8, 8, 9
eMaxesibeni	18	1	2	10, 9
Nqanqarhu	23	1	2	12, 11
Tlokeng	27	1	3	10, 9, 9

Table 2: Themes identified from the exploration of farmers' seasonal climate forecast (SCF) needs

Commercial farmers	Smallholder farmers
Reliability	**Reliability**
• Must be better than chance (60%; 70%+)	• Must be better than chance
Easier access	**Easier access**
• Through apps on mobile phones or a website	• Through extension officers
• Information in Afrikaans	• Through mobile phones (WhatsApp and text messages)
	• Through radio broadcasts
	• Information in Xhosa
A complete picture	**A complete picture**
• Rainfall and temperature	• Rainfall and temperature
• Wind (soil moisture)	• Wind (wildfires)
• Intensity of extreme events	• Hail
• Frequency/spread of rainfall	• Frost/snow
• Date of seasonal onset (e.g. date of first rains)	• Intensity of extreme event
	• Frequency/spread of rainfall
Relevance	**Relevance**
• Exact location of farm on map	• Weather stations are too far away to provide meaningful information in their area
• Historical comparison	• Exact location of farm on map
• Alignment with indigenous knowledge	• Historical comparison
	• Alignment with indigenous knowledge
Trust	**Trust**
• Understanding of underlying science behind SCFs	• Producers of SCFs must come and speak to them
• Reliability of source of SCFs	
• Demonstrate historical accuracy	
Understandability	**Understandability**
• Training in how to interpret SCFs	• Training in how to interpret SCFs
• 'Above' and 'below' normal is unclear (unless you know the normal range)	• Avoid or simplify academic jargon (e.g. uncertainty, probability)
• Actual values, not ranges	
• Less jargon (e.g. skill, probability)	
• Short and simple explanations	
• Colours are difficult to interpret	

Reliability

Both the commercial and smallholder farmers specified that they needed to appreciate SCF reliability for SCFs to be considered usable. The commercial farmers specified what they considered to be acceptable reliability levels (levels of either 60% or 70% accuracy), whereas the smallholder farmers indicated that reliability should be better than random chance (i.e. 50% or better).

Easier access

While accessibility of SCFs was a theme for both the commercial and smallholder farmers, their needs were different. Commercial farmers wanted access either through an application on their mobile phone or from a website. The smallholder farmers had poorer access to smartphones/computers and limited Internet/network connectivity, and therefore expressed a preference for access through their mobile phones either as text messages or WhatsApp messages or through radio broadcasts like weather forecasts. Smallholder farmers also expressed an interest in having SCFs explained to them by extension officers or other authority figures (e.g. by an experienced local farmer or by the SCF producers themselves). Both farmer groups wanted the information accessible in their home language.

A complete picture

To provide the necessary support for their farming operations, both groups of farmers felt that an SCF exploration tool should provide a "complete" picture of meteorological information. However, the two groups differed

in what was considered "complete". Both groups indicated that rainfall, temperature, the likelihood of extreme events (e.g. heavy rainfall, floods and drought), and the spread of rainfall across the season (e.g. how many days of rain and when the rain was expected during the forecast period) were important. Both groups felt that wind information was important, but for different reasons. The commercial farmers needed this information in conjunction with rainfall and temperature to determine soil moisture. The smallholder farmers needed temperature and wind information to determine the likelihood of wildfires that might threaten their crops. Smallholder farmers were interested in the likelihood of hail, frost and snow that might damage their crops. All the farmers were interested in the onset date of the rainfall season (particularly in anticipation of the planting) as well as the distribution of rain across the season (i.e. whether it would fall regularly or whether there was a likelihood of extreme rainfall events).

Relevance

Both farmer groups struggled to identify their own farms/locations on a larger map and wanted the functionality to zoom into the maps to more accurately identify their specific location (and therefore also their specific probabilistic estimates). The smallholder farmer group was also concerned that forecasts were being made based on data collection points that were far away and not relevant to their specific locality (e.g. the meteorological station was in a town 70 km away). Both groups of farmers expressed a need to consider the historical accuracy (i.e. against their own records or own recollections). This would allow the farmers to make a connection with the forecasts. Both farmer groups also wanted an SCF exploration tool aligned with their own indigenous knowledge experiences (e.g. March lilies flowering in March).

Trust

Generally, both farmer groups felt that more could be done to improve user trust in SCFs. The smallholder farmers felt that trust could be established by the SCF producers speaking to them in person. They valued a personal connection and the ability to be able to ask questions and engage in dialogue. The commercial farmers wanted information on the sources of the SCFs to be able to identify whether the information came from trustworthy sources. They thought that understanding the science underlying SCFs and that demonstrating the historical accuracy of predictions would increase their trust in SCFs.

Understandability

The smallholder farmers were aware that they would be unable to interpret the SCFs without some form of training or support (e.g. from extension officers, educated farmers, or younger farmers who would be familiar with technology). Commercial farmers also felt that they would benefit from training in how to interpret SCFs, but also suggested other ways to improve their understanding. Some of these issues relate to the existing SCF representations which are often presented as terciles (e.g. 'above normal', 'normal', or 'below normal' rainfall) using colours or colour gradients. The terms 'above' and 'below' normal were considered unhelpful unless the normal rainfall for the specific region and time of year were known. Instead, the commercial farmers wanted a short, simple explanation. The use of technical terms (e.g. ROC curves, skill, probability), which the farmers considered to be jargon, was also identified as problematic.

Actions available at a seasonal scale

Farmers need to know that SCFs will add value to their farming practices. It was therefore important to understand what actions the different farmer groups felt they could take based on information obtained from exploring SCFs. It is unsurprising that the actions available to smallholder farmers were fewer than those for commercial farmers (Table 3), although there were still many actions available to smallholder farmers.

Input costs

All the farmers indicated that they could use SCF information to regulate their input costs. The number and variety of these input costs was far greater for the commercial farmers. Both farmer groups could regulate the choice of cultivars (e.g. drought-resistant cultivars in a dry season, early or late maturing), the mix of crops (e.g. changing the proportion of different crops planted or the types of crops planted) to suit the expected conditions, and whether to buy fertiliser (i.e. if good rainfall was expected). The commercial farmers indicated that they could also switch to other types of farming (e.g. shifting to livestock farming). This might also have been possible for some smallholder farmers, although it was not mentioned. Related to this, commercial farmers could also decide how much seed to plant to optimise yields. Commercial farmers indicated that they could also make decisions about how much fertiliser, pesticide and fungicide (especially if rainfall was expected to be high) to purchase. Smallholder farmers were further limited to deciding whether to purchase insurance to secure against poor yields or crop failures. Presumably, this would also be available to commercial farmers, although it was not mentioned by them.

Timing

Both farmer groups could use SCF information to adjust the time of planting, the time of harvesting, and the time when fertiliser would be applied. While the flexibility to adjust some of these timings was limited, the information could also help farmers in preparing for these activities (e.g. ensuring equipment was ready, personnel were in place, or the land was prepared). The smallholder farmers also indicated that they could use SCF information to adjust when they would start preparing their land and when they would need to weed the land (if rains had been good). For smallholder farmers, these activities are usually manual and labour intensive because they generally do not have regular access to motorised technology. They would therefore benefit from advanced warnings to enable preparation. Smallholder farmers also indicated that they could decide to stagger their planting rather than planting all their seeds at the same time. For example, if a dry season was expected, they could plant less seed at the start of the season and if the rains arrived, they could plant more seed.

General planning

The commercial farmers also indicated that there were other general planning activities that would benefit from SCFs. If irrigation possibilities existed (e.g. if they had a water-use licence for extracting from a water source or for storing water), they could start planning the irrigation distribution (e.g. laying pipes or digging irrigation channels). Most commercial farmers also had contractual agreements with grain buyers. The SCF information could help these farmers to determine profitable and realistic delivery contracts. Additionally, the commercial farmers indicated that they could use the SCF information to make general farming decisions, such as whether to suspend farming operations (e.g. if the predicted conditions were highly unfavourable). None of the smallholder farmers mentioned any general farm planning activities.

Fatalistic attitude

Both farmer groups also expressed responses that suggested that there was little direct, physical action that could be taken. Both farmer groups indicated that SCF information only promoted an emotional response. Farmers suggested that their emotional responses could range from hope (e.g. hope that the SCF was wrong or that it was correct) to despair (e.g. it is going to be a bad year). Both farmer groups felt that there was nothing that they could do in response to the future weather. The smallholder farmers suggested that they could ask their extension officer what they could do. Commercial farmers were more likely to feel that the SCFs were interesting, but not necessarily informative. Nevertheless, the commercial farmers did feel that exploring SCFs more efficiently would be a further resource to their existing decision-making processes. Despite the limitations, both groups of farmers welcomed additional information, which could confirm (or disconfirm) the decisions and actions that they were already thinking of making and which would either increase their confidence or result in uncertainty.

Discussion

The identified needs and concerns were broadly similar to those identified in previous literature reviews[8,14,22,23]: the lack of access, the lack of SCF skill and accuracy, the problematic spatial and temporal scales, and wanting SCFs in their local language. The accuracy and reliability of SCFs is difficult

Table 3: Themes identified for actions that farmers could take to address seasonal fluctuations

Commercial farmers	Smallholder farmers
Input costs	**Input costs**
• Choice of cultivars	• Choice of cultivars
• Choice of crop mix	• Choice of crop mix
• Shift/diversification to other types of farming (e.g. livestock)	• Buying fertiliser
• How much seed to plant	• Purchase insurance
• Buying fertiliser	
• Buying fungicide	
• Buying pesticides	
Timing	**Timing**
• Adjust time of planting	• Adjust time to prepare the land
• Adjust time of harvesting	• Adjust time of planting
• Adjust time of applying fertiliser	• Stagger planting
• Fungicide application	• Adjust time of harvesting
• Adjust time of insecticide application	• Adjust time of applying fertiliser
	• Determine weeding time
General planning	
• Planning irrigation opportunities	
• Planning delivery contracts	
• Financial planning (when to cut losses)	
Fatalistic attitude	**Fatalistic attitude**
• Interesting rather than informing decision-making	• Ask extension officers what to do
• Emotions (hope/despair)	• Emotions (hope/despair)
• Nothing can be done, it's all down to rainfall	• Nothing can be done, it's all down to rainfall

to guarantee, but conveying these (and other) limitations of SCFs in an open and honest manner is crucial from the farmers' perspective. Both farmer groups could see the potential of a tailored exploration of SCFs and suggested several content parameters that would improve their decision-making, including the distribution of rainfall events (commercial farmers), and the likelihood of frost, snow or hail (smallholder farmers). Both farmer groups expressed an interest in being trained on how to interpret and use the SCFs, especially in order to understand concepts such as probability and uncertainty, and what they mean for farmers. Hansen et al.[14] and Hansen et al.[18] have been successful in developing training techniques enabling farmers to understand probabilistic forecasts, which could be applied for this purpose.

Both farmer groups expressed the need for greater trust in SCFs. Alexander and Block[15] also highlighted the importance of user trust in the adoption of SCFs. For the commercial farmers, trust needed to be built up through experience in seeing how the SCFs performed against real conditions. The smallholder farmers needed to develop trust through direct interactions with the SCF producers. Given the access issue, it is also possible that a trusted intermediary (e.g. an extension officer) might need to perform this role. This would mean improved training of extension officers to be able to translate the SCFs while applying local relevance. Much of the wariness appears to stem from the smallholders' distrust of authorities. For the older farmers, this distrust was related to their past experience of authority figures under apartheid and the continuation of misinformation under post-apartheid governance regimes. These farmers tended to trust indigenous knowledge systems more than scientific knowledge systems. The smallholder farmers also expressed concerns that the meteorological data stations were not co-located with their farms. They therefore doubted whether the SCFs would give them accurate information. Hansen et al.[14] also noted that the historical data coverage that informs SCF modelling tends to be sparser in remote rural areas, which would correspond to the lived experiences of these smallholder farmers.

While both farmer groups wanted to access the SCFs in their home language, how the two groups envisaged accessing SCFs differed. The commercial farmers were more technologically inclined, preferring to access the SCFs through mobile phones or a website. Access for the smallholder farmers was more complicated. If smallholder farmers had mobile phones, they wanted to receive the SCF information as text (either text messages or WhatsApp messages). This is probably related to the sporadic network coverage in many of the more geographically remote farming areas. Smallholder farmers also considered accessing SCFs from radio (and television) broadcasts, which is the usual way of accessing weather forecasts. Independently of the medium, it is highly likely that smallholder farmers would need some type of intermediary mechanism (or person) to access or pre-interpret the SCFs.

Similarly to Hansen et al.[14], we found that smallholder farmers were more limited than commercial farmers in their capacity to take up SCF information. While there were definite benefits from SCFs for early planning, from the pre-planting to the post-harvesting stages for smallholder farmers (e.g. given their heavy reliance on manual labour,

this gives them time to put the relevant resources in place), they were, however, more likely to feel that there was nothing that they could do and would rely on external inputs (e.g. from extension officers) to aid their decision-making. Commercial farmers already have more resources at their disposal and therefore have more alternatives. They could make a wide array of decisions based on SCFs, including more general planning for farming decisions such as financial planning.

Future developments and limitations

While it is not possible to address all the needs, seasonal climate information still offers some level of value that is largely unexploited. Without attempting to improve the inherent skill of SCFs, this study emphasises numerous avenues for improvement from a farmer's perspective. Such improvement could arise from a farmer's tailored exploration of SCFs to farmers' needs, offering local relevance, and expressing more honestly the success and failure potential of SCFs. Equipped with this increased explorative capacity of seasonal climate information, farmers would be better able to support their farming operations for improved food security. On the other end of the spectrum, research[31] has begun to look at the presentation format of SCF information from a producer's perspective (in response to farmers' needs) so that it can be correctly interpreted. Caution should also be taken in reading too much into the comparison of the two farmer groups. In addition to the differences in the sophistication of their farming practices, there are other parameters, such as the types of crops being farmed and the time of year when crops are grown, that makes them non-equivalent groups. It is not the claim that these respondents are representative of all commercial farmers and smallholder farmers in South Africa. The next steps would involve developing and testing prototypes that address the SCF exploration needs of each farmer group. It is important to consider what is possible with regard to the types of information that these farmers would consider useful. Some aspects such as the exact date of the seasonal onset, the distribution of rainfall events, and the intensity of extreme events are extremely difficult to represent with any degree of skill or accuracy. While improving the skill of SCFs in southern Africa would assist in increasing trust, skill will remain a challenge for physical reasons and we therefore advocate for a simpler and honest representation of reliability, which can help farmers appreciate this information. Other aspects, such as different language versions, pose their own challenges for the translation of highly specific scientific terms, but are arguably easier to implement. Given the high rate of technology adoption (especially mobile phones) in the commercial farming communities, access to SCFs for this group would be straightforward through a mobile phone application or web-based platform. There are considerable challenges around accessibility for smallholder farmers, especially in the more remote areas of the Eastern Cape which face the dual challenge of low smartphone ownership coupled with poor network coverage. Clearly, alternative methods of disseminating seasonal forecasting information to these farmers, through some intermediary person or organisation, would be preferred.

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Data availability

The data are available upon request to the corresponding author.

Authors' contributions

A.T.: Conceptualisation, methods, data collection, data analysis, writing – the original draft, student supervision, funding acquisition. O.C.: Conceptualisation, project leadership, methods, data collection, student supervision, writing – the original draft. P.J.: Conceptualisation, methods, data collection, data analysis, writing – the original draft. A.D.: Methods, data collection, data analysis, writing – the original draft. All authors read and approved the final manuscript.

Declarations

We have no competing interests to declare. We have no AI or LLM use to declare. The qualitative study followed ethical procedures for human participants approved by the respective ethics committees at the University of the Witwatersrand (MAORG/21/03 and MAORG/21/03) and the University of Cape Town (FSREC 064-2021).

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