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Delivering context specific, climate informed agro-advisories at scale: A case study of iSAT, an ICT linked platform piloted with rainfed groundnut farmers in a semi-arid environment

A.P. Ramaraj [a,b], K.P.C. Rao [a], G. Kishore Kumar [a], K. Ugalechumi [a], P. Sujatha [a], Suryachandra A. Rao [c], R.K. Dhulipala [a,d], A.M. Whitbread [e,*]

[a] International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, Telangana 502324, India
[b] Indian Meteorological Department (IMD), Mausam Bhawan, Lodhi Road, New Delhi 110003, India
[c] Indian Institute of Tropical Meteorology (IITM), Dr Homi Bhabha Rd, Pashan, Pune, Maharashtra 411008, India
[d] International Livestock Research Institute (ILRI), PO Box 30709, Nairobi 00100, Kenya
[e] International Livestock Research Institute (ILRI), C/- IITA East Africa Hub, PO Box 34441, Dar es Salaam, Tanzania

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A B S T R A C T

The influence of climate and weather-based advisories in planning and managing agricultural systems under highly variable conditions was evaluated to understand the potential benefits and challenges associated with the use of probabilistic climate and weather information. A pilot study, conducted with 720 farmers in Anantapur district of Andhra Pradesh, India over 3 cropping seasons in the period 2017–2020, used a semi-automated decision support tool, the "intelligent agricultural Systems Advisory Tool – iSAT" to generate and disseminate pre- and in-season advisories by integrating insights from historical trends in climate, current weather and climate and weather forecasts. The pre-season advisory was based on the seasonal climate forecast and aimed at improving the preparedness of farmers for the forthcoming season. The in-season advisories were aimed at providing advice on the various farm operations where weather may play a role in management, i.e., land preparation, timing of planting and harvesting, crop management etc. After piloting the advisory system over the 3 cropping systems, a survey was conducted to evaluate how and what operations were influenced by the advisories and how well iSAT performed in developing and disseminating context-specific advisories through the season. The results have indicated that the advisories have influenced both strategic and tactical management decisions made by farmers. Strategic decisions on crop diversification are evident from land allocation in the treatment compared to the control villages. The influence of tactical farm decisions varied between operations, villages and years. Overall, 80% of the farmers used the information for making decisions on harvesting, 79% for sowing while 65% of farmers used it for land preparation. Advisory information has impacted crop productivity positively, with increases in the climate-informed villages of between 1 and 56% over the uninformed. The results further indicate that the farmers considered advisories more useful during the normal and below normal seasons as compared to above normal seasons.

Practical implications

Coping with the impacts of climatic variability is one of the most complex challenges faced by smallholder farmers. Small changes in temperature, decreases in precipitation and higher variability can have huge impacts on agriculture, especially in the agro-ecologies of the semi-arid, where smallholder farming underpins the livelihoods of resource poor people. Climate variability which occurs at many temporal scales, from seasons to years to decades and beyond, has both direct and indirect impacts. Variability in the amount and distribution of seasonal rainfall has a direct impact on the productivity of agriculture, while the uncertainty and risk associated with this variability over the seasons and years make the process of decision making difficult and subjective,

* Corresponding authors at: International Livestock Research Institute (ILRI), C/- IITA East Africa Hub, PO Box 34441, Dar es Salaam, Tanzania
E-mail address: a.whitbread@cgiar.org (A.M. Whitbread).

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affecting the overall viability of the systems. Under these uncertainties, effective and efficient management of agricultural systems should aim at both reducing the risks and capitalizing on the opportunities through the adoption of proactive risk management practices.

It is evident from the study that, in the absence of science-based information, farmers tend to rely on their perceptions and experiences which may not match reality. Combining indigenous knowledge with scientific information can result in a better understanding of climate variability and better risk management. Climate services provided through iSAT played an important role in enabling farmers to take more informed management decisions leading to less risk and higher productivity. The results suggest that, for better utilization of climate services, building the awareness and capacity of farmers and their support agents is critical for understanding the probabilistic nature of the information, uncertainties associated and its potential outcome. Through actionable climate services, farmers can take advantage of a good season and avert the risk of crop loss in a poor season and manage the production system efficiently. This is extremely important for the continued and sustained use of climate information-based services.

Data availability

Data will be made available on request.

Introduction

Driven by the very high impact of climate and weather on agriculture, climate services are receiving increasing attention globally as an important component in making agriculture resilient to the impacts of climate variability and change (Zillman 2009; Hansen et al., 2014). Depending on the level of agricultural development and agroecology, FAO (2019) estimated that 20–80% of the inter-annual variability of crop production and 5–10% of national agricultural production losses could be associated with climate variability. Agriculture is also estimated to suffer 26% of the damage and loss during climate-related disasters in developing countries. Climate change is expected to further exacerbate these impacts and in the absence of ambitious climate action, yields may decline by up to 30% by 2050 (GCA, 2019). Smallholder farmers are expected to be more at risk because of their high dependence on agriculture for their livelihoods and limited capacity and resources to cope with shocks (Morton, 2007; Hertel and Rosch, 2010). Climate information-based services play an important role in managing agricultural systems productively, profitably, and with reduced risk (Selvaraju et al, 2011; Hansen et al., 2019). In most countries, past work on climate services was mainly focused on managing extreme events through early warning systems aimed at better preparedness and reacting in a way that reduces losses (Pulwarty and Sivakumar, 2014).

The production of forecast information on various time (from short range to seasonal) and space scales (resolution) has steadily grown and improved in accuracy, reliability and timeliness (WMO, 2021). The application of seasonal climate forecasts in planning and managing agricultural systems has also received significant attention and many pilot studies (Phillips et al., 2001, Ngugi, 2002, Tarhule and Lamb, 2003; Ziervogel, 2004, Roncoli et al., 2009, Rao et al., 2011) have demonstrated that substantial reduction in risk and improvement in productivity and profitability is possible (Hansen et al., 2011). Although forecasts at a seasonal scale are potential of most significance to farmers, short and medium-range forecasts remain important for many farm-level decisions.

Decision making in agriculture is a multistage dynamic process in which farmers make a series of decisions from pre-season planning to harvesting and many of these decisions are not straightforward (Edwards-Jones, 2006). Though a wide range of social, economic, and environmental factors influence farmer decisions, it is the variability in the prevailing weather conditions and the inability to anticipate or predict forthcoming events with some degree of certainty that makes the decision making misinformed and may lead to undesirable outcomes. Climate information services are expected to bridge this gap by providing relevant information which supports farmers in making informed decisions. Access to reliable intra-seasonal to seasonal climate forecasts (SCF) can lead to harmonized response options that might help reduce production risks by assisting farmers to make more informed decisions on what, when, and how to undertake farm management activities (Meinke et al., 2006; Crane et al., 2010; Hansen et al., 2011; Huda et al., 2004). SCF for example may be used to inform planning while in-season operational decisions on planting, agronomic practices, inputs and harvest may be informed by short-term and medium range (3–10 day) weather forecasts. The realization of these benefits requires meticulous efforts to design and implement effective mechanisms for the timely delivery of climate information in user-friendly formats (Mjelde et al 1998; Stern and Easterling, 1999; Agrawala et al., 2001).

An effective climate services system should provide tailored, contextual, and actionable advisories to the farming communities, based on all available climate products. This requires appropriate engagement to produce information that facilitates and guides early action and preparedness. (Tall and Njinga, 2013). Recent research suggests that the co-production of knowledge by scientists and users results in better uptake of climate information supporting management decisions (Lemos and Morehouse, 2005; Cash et al., 2006; Sarewitz and Pielke, 2007; O'Mahony and Bechky, 2008; McKinley et al., 2012; Briley et al., 2015; Meadow et al., 2015; Nidumolu et al., 2021; Streefkerk et al., 2022). Efforts aimed at narrowing down the 'usability gap' (Lemos et al., 2012), also require effective access and delivery mechanisms that enable a better response to user needs.

The need of the hour is therefore the ability to generate accurate, location-specific, timely and actionable information which can be disseminated to millions of farmers across diverse agroecological conditions utilizing a broadcast method that exploits the expansion of mobile phone use in rural areas (Perkins et al., 2015; Hudson et al., 2017). As described by Rao et al. (2019), the "Intelligent agricultural Systems Advisory Tool – iSAT" was developed as a process to conceptualise crop advisories which could be disseminated as short messages (SMS) to farmers' mobile phones at regular intervals through the crop season. The scientific challenge that iSAT has addressed has been to combine expert and indigenous knowledge with the analysis of historical, prevailing and forecasted climate and weather information to formulate tactical agronomic decisions. The iSAT system was piloted from 2016 to 2020 in four villages of the Anantapur district of India which is the second driest district in India with a highly variable climate and marginal resource endowment (Dharumarajan et al., 2018). This paper analyses the usefulness of climate and weather information (driven by iSAT advisories) in influencing strategic pre-season farm planning through to tactical in-season crop management decisions.

Materials and methods

This study was conducted to assess the role of climate and weather information-based agro-advisories in influencing farm-level decision making and efficient management of agricultural systems with reduced risk and enhanced productivity. The locations where this study was conducted are ideal for this type of assessment since the cropping season rainfall is not only low but highly variable (cv 50%) and is the major driver of productivity and profitability of groundnut production.

Study area

Four mandals (A mandal being a sub-district level administrative division) in Anantapur district in the state of Andhra Pradesh, India was selected for this study (Fig. 1). The district is predominantly agrarian with more than 60 percent of the total land area under agricultural use and with 80 percent of the total population deriving their livelihood from agriculture, either as land owner-farmers or agricultural labourers (Vasudeva Rao et al., 2018). According to the land capability classification, 69.3% of the land in the district falls in groups III and IV which are lands suitable for cultivation with intensive soil conservation practices (Rukmani and Manjula, 2009).

More than 80% of the 1.15 m ha area under agriculture in the district is rainfed. Farmers in the district are largely dependent on a single crop of groundnut which is cultivated on more than 80% of the land under rainfed agriculture. Due to its position in a rain shadow area, the district receives low and erratic rainfall making it highly vulnerable to inter- and intra-seasonal variability in rainfall. Two villages were selected in each of the four mandals (Fig. 1), of which one is a treatment village (climate-informed), and the other is a control village. The names of the selected mandals and villages are listed in Table 1 along with the number of farmers who took part in the study. Although all farmers in the village were invited to participate in the program, between 70 and 80% of the farmers participated in the study. In each year of the study, a minimum of 30 farmers in each of the treatment and control villages were randomly selected for the mid and end-of-season surveys.

Table 1
Study *mandals* and villages of Anantapur district.

Mandal	No. of Farmers registered	Treatment Village	Control Village
Kalyandurg	146	Gubanapalli	Kurabarahalli
Kanaganapalli	144	Ramapuram	Balepalem
Gooty	111	Turkapalli	Mamuduru
Singanamala	92	West Narsapuram	Chinna Maltigondi

Intelligent agricultural systems advisory tool (iSAT)

The development of iSAT was a collaboration between ICRISAT, the Indian Meteorological Department (IMD), Acharya NG Ranga Agricultural University (ANGRAU) and MICROSOFT. It is a methodology where the tasks of compiling the required data, including real-time weather data and forecast information from various sources, analysing the data, identifying relevant advisory and disseminating the same as short text messages are semi-automated (Rao et al., 2019). The process followed is outlined below (Fig. 2). iSAT provides climate and weather-based advisories to support pre-season planning as well as in-season management.

The pre-season advisory is based on the seasonal climate forecast issued by IMD along with the presence or absence of El Nino or La Nina conditions. Four different types of seasons with a varying probability of occurrence to receive a minimum of 300 mm rainfall were defined and for each season type potential cropping strategies were defined with due consideration to the risks and opportunities that these seasons offer. The threshold value of 300 mm is the minimum rainfall required to harvest

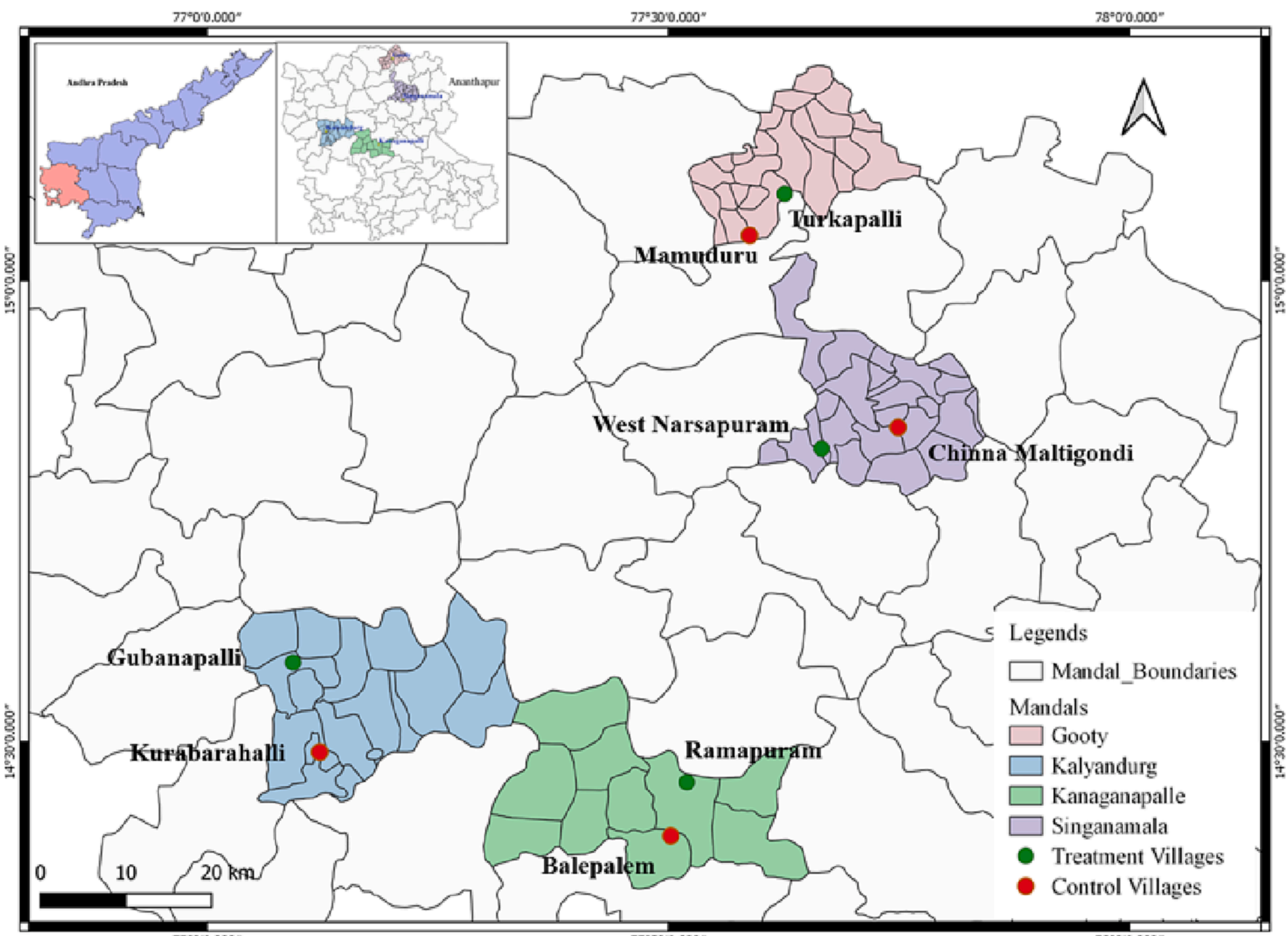

Fig. 1. Map representing the study *mandals* (colour shaded), treatment villages (green dot) and control villages (red dot). The inset image shows the location of Anantapur district in the Andhra Pradesh state, India.

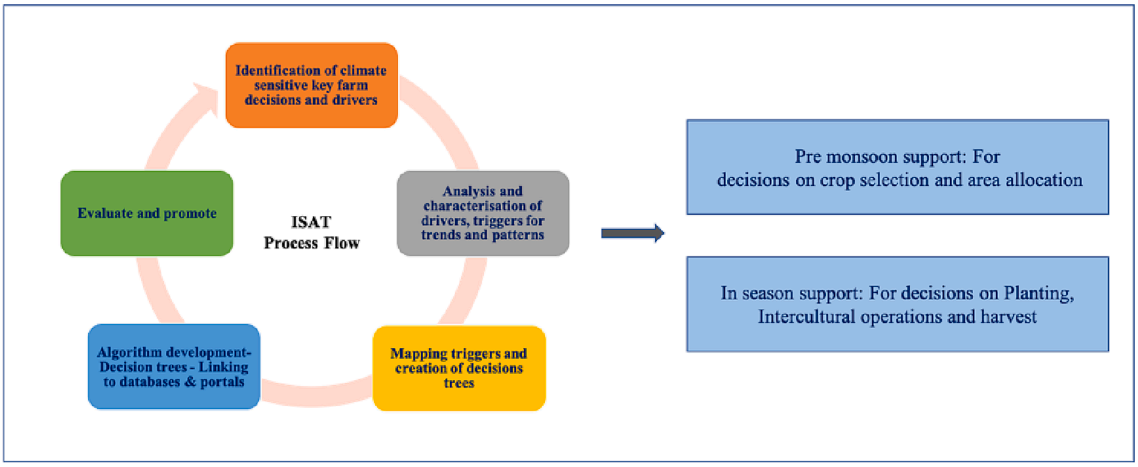

Fig. 2. Process followed in the development of decisions mapping for iSAT crop advisories.

at least one ton of groundnut which according to farmers is required for breakeven. This was derived from the analysis of historical climate data by conducting a what-if scenario analysis using the system simulation model APSIM. Among the four-season types, the risk of crop failure was found to be minimal during the seasons that the IMD seasonal climate forecasts indicate above normal rainfall with La Nina conditions while the risk of crop failure is high during the years in which seasonal climate forecast predicts below normal rainfall with the persistence of El Nino conditions in the equatorial Pacific Ocean. Using the logic defined below (Fig. 3), one of the four messages can be selected and disseminated depending on the type of season forecasted.

The pre-season advisory is followed by the dissemination of in-season advisories. The in-season advisories are issued at weekly intervals starting from at least one month before the actual start of the season in the first fortnight of June (Fig. 4) and cover all operations from land preparation, planting, weeding, fertilizer and pesticide applications, application of gypsum and other soil amendments and harvesting. Conducting such operations in a timely fashion will have a significant influence on the production and productivity of groundnut and other crops.

Using the decision tree approach, a well-structured decision process was developed for iSAT to pick an advisory from the database of messages created for all weeks until the crop is harvested. The decision process is driven by the amount of rainfall received during the past week and from the start of the season, the forecast for the next week and the outlook for the next two weeks which creates eight possible scenarios every week. Each scenario will lead to a specific advisory with information to support the key operations expected to be carried out during that week. A sample decision mapping with eight different messages for a time of sowing decision is presented in Table 2 (Rao et al., 2019). The

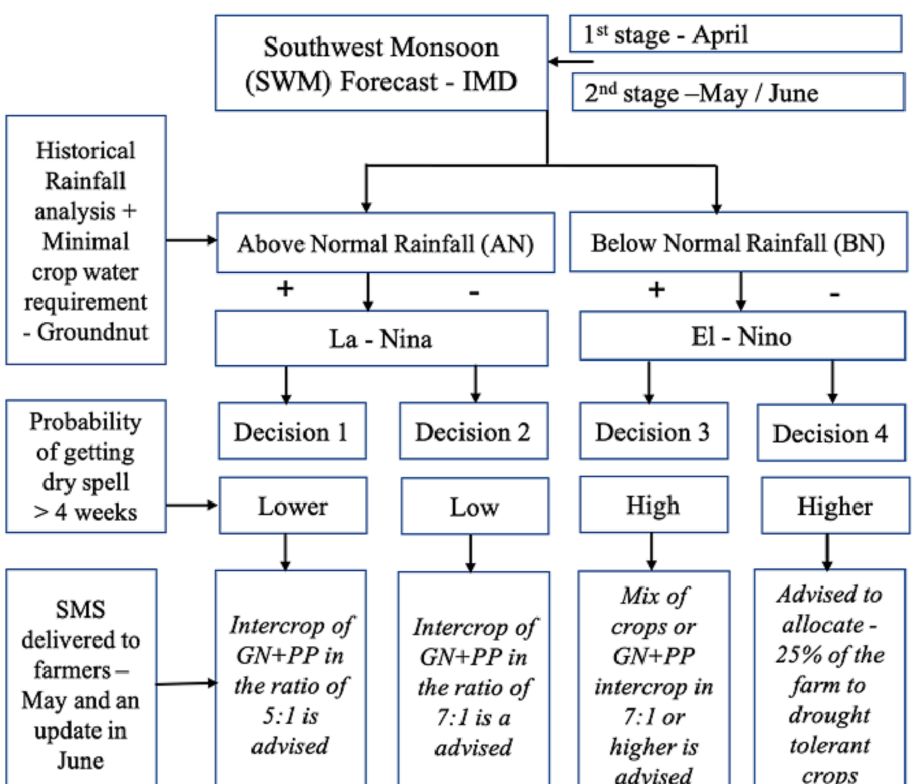

Fig. 3. Decision logic used for pre-season advisory using seasonal climate forecast and status of ENSO in the equatorial Pacific Ocean.

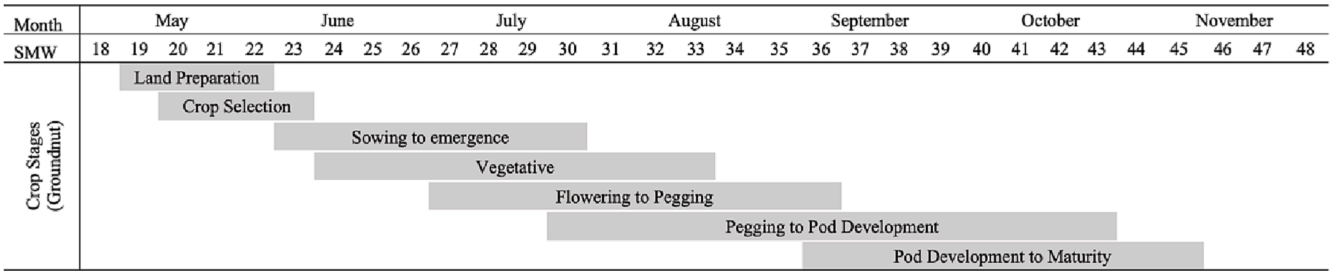

Fig. 4. Groundnut crop calendar followed by farmers in the study villages.

Table 2
Tactical pre-season decision mapping.

Decision	Last week rainfall (mm)	Next week rainfall (mm)	2 weeks outlook	Messages
1	<10 mm	<20 mm	BN	The monsoon is not yet active. Wait until a good rain is received
2	<10 mm	<20 mm	AN	The monsoon is not active yet, but the forecast for the next two weeks is positive. Time to plan for operations such as land preparation and application of farmyard manure (FYM)
3	<10 mm	>20 mm	BN	Though some rain is expected during the coming week, the forecast for the next two weeks is indicating limited rain. Wait and continue land preparation, preparing seed, transporting FYM and other preparations
4	<10 mm	>20 mm	AN	Some rain is expected during the coming week with a positive forecast for the next two weeks. Get ready with operations such as land preparation and application of FYM
5	>10 mm	<20 mm	BN	Some areas received rain last week, but the forecast for the next two weeks indicates not much rain is forthcoming. Wait and continue with land preparation, preparing seed, transporting FYM and other operations
6	>10 mm	<20 mm	AN	Some areas received rain with a possibility to get more rains during the coming two weeks. Get ready to perform operations such as land preparation and application of FYM
7	>10 mm	>20 mm	BN	Some areas received rain last week with a possibility for more rain this week. Since two weeks forecast is not positive, wait and continue with land preparation, preparing seed, transporting FYM and other operations.
8	>10 mm	>20 mm	AN	Some areas received rain last week with more rain forecasted for the next two weeks. Complete land preparation for early planting

advisory messages were disseminated as SMS (short message service) every Friday throughout the cropping season through an SMS gateway.

Data sources:

The seasonal climate forecasts and the medium and extended range forecasts are sourced from Indian Meteorological Department (IMD). The department issues seasonal climate forecasts for south west Monsoon Season (June- September) in two stages. The first stage forecast is issued in mid-April and the second stage forecast is towards the end of May/June which is an update for the forecast issued in April. The forecast is based on the operational statistical ensemble forecasting system (SEFS) developed by IMD (Pai et al., 2017). Regularly updated weekly weather forecasts (medium range) at the block level and monthly outlooks (extended range) at the district level are accessed from the website of IMD. The weekly weather forecast is quantitative while the monthly outlooks are probabilistic. The ENSO conditions are captured from the websites of the Bureau of Meteorology (BoM), Australia and the Climate Prediction Centre (CPC) of the National Oceanic and Atmospheric Administration (NOAA) which provide historical and current information on the status and forecast of Nino conditions.

The daily weather conditions in the selected study *mandals* were accessed through the Andhra Pradesh State Development Planning Society (APSDPS) website (https://apsdps.ap.gov.in/APSDPSNew/Rainfall.html) and complemented by the data collected in the target villages. In all the study villages rain gauges were installed and a local person was assigned the task of managing the same and reporting the rainfall data daily. The daily rainfall data was reported through a mobile-web based platform exclusively designed to collect real-time, geo-tagged data about farmers, farmland, livestock, other on-field interventions and other key indicators of agriculture research and extension. The data collected through the measure platform is directly linked to iSAT.

Evaluation of the iSAT services

A total of 493 farmers from the four treatment villages have registered to receive the advisory messages and expressed willingness to participate in the evaluation of the same. To assess the usefulness of the advisory messages, surveys were conducted during the years 2017, 2019 and 2020. The delivery of advisory messages was disrupted in 2018 due to technical and funding issues and hence is not considered in this study. Survey 1 was a telephonic survey conducted during the middle of the *kharif* season in the month of August to confirm whether the farmers are receiving the messages and to find out when the planting of crops was done. The second one is the end of the season survey conducted in the month of December or January. It is a formal survey using a survey instrument developed to evaluate farmers' access, timeliness and appropriateness of the advisory messages, reliability, and usefulness of the information in decision making, identify decisions influenced by the advisory and how crops performed during the season. In year one, the survey involved 125 randomly selected households from the farmers registered to the program in each of the four treatment and control villages (Table 1) and was conducted by a team of five trained enumerators and research assistants in the local language (Telugu). In subsequent surveys, the total number of surveyed households was reduced to 30 across the four treatment villages and 30 across the control villages to manage logistics and resourcing. The survey data were summarised and analysed using descriptive statistics and graphed in Microsoft Excel and R.

Results

Pre-season advisories

The seasonal climate forecast issued by IMD was compared with the rainfall realized during the corresponding season and examined the implications of the same on the advisory issued (Table 3). The forecast for the three years indicated three different season types leading to the delivery of three different pre-season advisories. The SWM during 2017 was predicted to be a normal season with no ENSO conditions, 2019 was forecasted to be normal to below normal season with weak El Nino and 2020 was forecasted to be a normal to above normal season with no ENSO signal.

Table 3
Monsoon rainfall profile of the study years and advisories mapped.

Year	2017	2019	2020	
Seasonal Forecast	Normal	Normal - Below Normal	Normal - Above Normal	
ENSO	Neutral	El-Nino (weak)	Neutral	
Pre-season advisory delivered	Groundnut-Pigeonpea intercrop in 7:1 ratio	Groundnut along with short duration millets and pulses	Groundnut-pigeonpea in 5:1 ratio	
Contingency advised	Green gram, Sorghum & Millets	Sorghum, Millets & Horse gram	Horse gram	
Standard week for contingency	33	33 & 38	37	
Monsoon Onset	Late (by 4—8 weeks)	Normal	Normal	
Actual rainfall (mm), rainy days (No.)	Gubanapalli	363 (20)	429 (17)	482 (27)
	Ramapuram	322 (13)	301 (15)	674 (34)
	Turkapalli	248 (10)	533, 25	946 (36)
	West Narsapuram	617 (25)	480 (25)	593 (34)
% Departure from mean	Gubanapalli	12	33	49
	Ramapuram	0	−7	109
	Turkapalli	−23	65	193
	West Narsapuram	91	49	84
Relevance of advisory (out of 4 villages)	3/4	4/4	4/4	
Dry spells > 14 days (No.)	Gubanapalli	1(22)	4 (20)	0
	Ramapuram	1(25)	3 (36)	0
	Turkapalli	1(25)	2 (21)	0
	West Narsapuram	2 (19)	3 (21)	0

IMD criterion for classification of seasonal rainfall as "Normal" = ± 10% LPA | "Above Normal" = > +10 LPA | "Below Normal" = < −10 LPA. LPA – Long period average (typically 30 years).

As forecasted, the SWM during 2017 received normal rainfall at two out of four study sites, Gubanapalli and Ramapuram. At Turkapalli the season was below normal with 23% less rain and at West Narsapuram the season was above normal with 91% more rain. A key feature of this season is more than a four-week delay in the onset of the rainy season. Despite the delayed onset, the season received well-distributed rainfall with only one dry spell of more than two weeks. The 2019 SWM was forecasted to be normal to below normal rainfall but received normal to above normal rainfall at all locations. However, the season is characterized by poor distribution of rainfall with 2–4 dry spells of more than two weeks. The SWM during the year 2020 was forecasted to receive normal to above normal rainfall and the same was realized at all the locations with 50–200% higher rainfall compared to the LPA. The distribution of rainfall is also good with no dry spells of two or more weeks at all the study locations. Pre-season advisories suggesting the best bet option for the type of season forecasted were issued in all three years. In the year 2017, due to delayed onset, a revised advisory was issued suggesting short season and drought tolerant contingency crops like green gram, millets and sorghum along with groundnut and pigeonpea intercrop. To minimize the risk from the below normal seasonal conditions predicted for the year 2019, the advisory suggested the use of drought-tolerant short duration crops along with groundnut. For the 2020 season which was forecasted to be normal to above normal rainfall, the advisory suggested intercropping of groundnut with pigeonpea in the ratio of 5:1.

Influence of pre-season advisory on crop choice and land allocation

Groundnut is the main crop grown in these villages followed by pulses. The pre-season advisories for groundnut farmers were delivered through a one-day on farm workshop, conducted ahead of the season, for a better understanding of forecast probabilities and to build farmers' trust. In the study villages, the choice of crops and allocation of land for (Fig. 5) different crops were found to be different in treatment villages compared to that in control villages. In the treatment villages, the area under groundnut varied from one year to the other depending on the season type and onset of the season. During the normal and below-normal seasons of 2017 and 2019, the area under groundnut was 20–30% lower in treatment villages when compared to control villages, which is in line with the advisory issued during those years. The 2017 pre-season advisory initially suggested an intercrop of groundnut and pigeon pea, but the same was revised to include green gram and millets as alternate crops in response to the delay in the onset of the rainy season by more than 45 days. Farmers responded to this advice by increasing the area under pulses which was reflected in the 30% higher proportion of the crop mix when compared to that in the control villages (Fig. 5b). The area under groundnut during the year is 25% lower in treatment villages (Fig. 5a) compared to that in control villages. Similarly, since the SCF for the 2019 season has indicated a below normal rainfall, farmers were advised to spread the risk by allocating at least 25 percent of the land area to short-duration crops such as millets and pulses. Farmers responded to this advisory by allocating about 47% of the planted area to these crops (Fig. 5c) which is 12% higher when compared to the area under these crops in control villages (Fig. 5d). During the year 2020, which was forecast to receive above normal rains, the pre-season advisory suggested an intercrop of groundnut and pigeonpea which is perceived by farmers to be the most profitable cropping system. It is interesting to note that no major difference was noticed between treatment (Fig. 5e) and control villages (Fig. 5f) during 2020 which is one of the wettest years on record. In the absence of advisory, farmers in the control villages followed the same cropping pattern with groundnut occupying 65 to 73% of the total cropped area.

Farmer expectation of a season

Farmers in Anantapur tend to prepare for the coming season with a certain expectation of how the season is going to be and this drives how they prepare for the season. This perception is influenced by

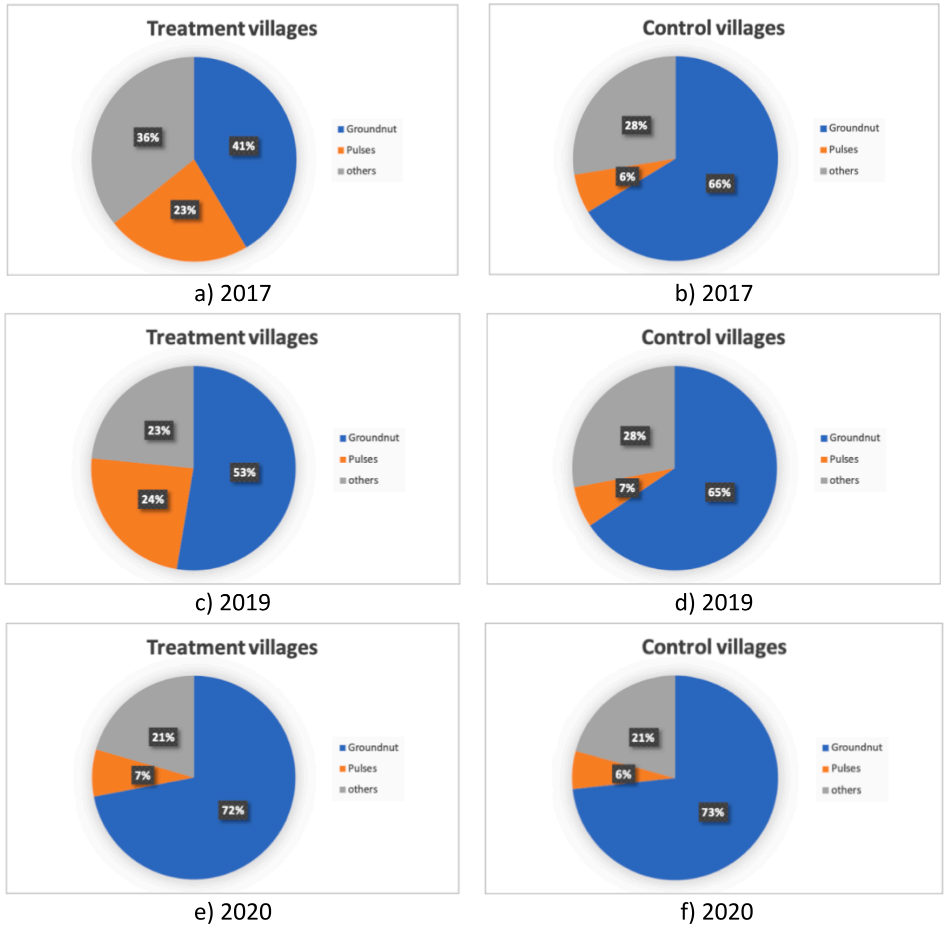

Fig. 5. Distribution of cropped area under different crops during the *kharif* seasons of 2017, 2019 and 2020.

observations, traditional beliefs, astrological predictions and/or based on the previous seasons' performance. To understand how well farmers perceive the seasonal conditions, we captured the farmer's perception at the start of the season and their assessment of the season at the end of the season by asking them to rate the season as good, average, or poor. Results indicated a big difference between the expectations before the start of the season and at the end of the season (Table 4). In 2017, about 58% of the farmers expected the season to be poor while the forecast by IMD has indicated it to be a normal season. During the end-season survey 75% of farmers rated the season as good. More than 70% of the farmers expected 2019 to be a good season while IMD forecast has indicated a high probability for the season to get normal to below normal rainfall. The end season ratings by farmers have indicated that the season was very similar to what they have expected at the beginning. The 2020 monsoon season stands out as an exception. About 56% of the farmers expected the season to be good and the IMD forecast also indicated a normal to an above normal season. As expected, the season was above normal and recorded very high rainfall. However, during the end season survey, about 85% of farmers rated it as a poor season. The results indicate that the farmer rating of the season is based on the performance of the crops and not on the amount of rainfall received. The amount of rainfall received during the 2020 season was very high with the performance of groundnut adversely affected by excess moisture, excessive vegetative growth and poor pod formation, leading to rating the season as poor.

Table 4
Farmer expectation about the monsoon at the start and end of the season.

Year	Expectation at the start (%)			Rating at the end (%)		
	Good	Average	Poor	Good	Average	Poor
2017	12	31	58	75	20	6
2019	70	20	10	63	32	5
2020	56	43	1	0	15	85

In-season advisories

The in-season advisories are issued at weekly intervals during the crop growing season which starts in the month of June in the target areas. The in-season advisory is aimed at supporting the farmers in making tactical decisions in a timely manner in response to the prevailing and forecasted weather conditions. A total of 26 messages in the year 2017, 27 messages in 2019 and 32 messages in 2020 were generated and disseminated to the farmers as SMS. The number of in-season messages varied from year to year depending on the length and rainfall distribution during the growing season. These messages included information that can support decision making in conducting various operations starting from land preparation and sowing to harvesting and were delivered to all the registered farmers. In general, the system worked very well and nearly 95% of the registered farmers received the messages without any problem. In a few cases, the delivery of the messages was affected due to the type of mobile phone used and the way message inboxes were configured. To understand the influence of these advisories on the decisions taken by farmers, the timeliness with which the farm operations were conducted, and the responses from farmers in treatment villages were compared with those from the farmers in control villages. Since the value of advisory depends on its contribution to making better decisions, attempts were made to capture the change in decisions in response to the information provided through advisory.

Major differences were observed in the way farmers in the treatment and control villages have performed various operations.

Influence of in-season advisory on sowing time and farm operations

The timing of planting is one of the most crucial decisions that farmers have to make during the early part of the season. This is an extremely important decision in the case of groundnut since the cost of seed accounts for one third of the total cost of groundnut cultivation. Hence, timely planting is crucial to establish a good crop stand and achieving good yields. The planting time suggested by the advisory is based on APSIM crop simulations and the availability of moisture in the soil. Availability of moisture is assessed based on the amount of rainfall since the onset of the season, the forecast for the coming week and the outlook for the following week. These conditions are more likely to help in avoiding early or late planting and in ensuring optimum germination and good crop establishment.

Results indicated significant differences between the treatment and control villages in the timing of planting of groundnut crops. During 2017, most farmers in the treatment villages completed planting in a short period within the optimal planting window when conditions are favourable (Fig. 6) except in West Narsapuram, where more farmers planted castor crops for which the optimal planting window is different. About 65 percent of groundnut area were sown during the optimum planting weeks in the treatment villages while only 41 percent of the area is sown in control villages. In 2019, the area sown during the optimal planting window is 62 percent in the treatment villages which is higher compared to 27 percent in the control villages. However, in 2020, the pattern of sowing is similar in both treatment (69%) and control villages (68%). This is mainly due to the good rainfall which is also well distributed throughout the season providing several planting opportunities for the farmers. Overall, up to 35 percent more area under groundnut is sown in optimal time in the treatment villages.

Most farmers have indicated that the advisories have provided the required information which helped them in the planning, preparation, and performing of various agricultural operations throughout the season. However, the magnitude of their contribution varied from one operation to the other depending on the type of information required to conduct that operation. About 90% of the surveyed farmers in all villages have acknowledged the contribution of advisories in performing different operations timely and efficiently during the season (Table 5). This is more evident in 2019 which was a difficult season with a highly erratic distribution of rainfall. Among the operations, about 80% of the farmers have indicated that the advisories have benefited them in the timely sowing and safe harvesting of the crop. The influence of advisory is relatively low in the case of operations such as land preparation (65%), inter-cultural operations (56%), and fertilizer and pesticide applications (54%). Since these operations are influenced by weather conditions over a short period, farmers paid less attention to advisory which is based on five-day forecasts. It is interesting to note the low levels of influence of advisory in the year 2020 which is an above-normal season with well-distributed rainfall. In addition, the utilization of advisory information is higher during the year 2019 compared to that in 2017 which indicates the increased acceptance of the information provided. The experiences during the first year have led to increased awareness, improved understanding, and growing confidence and are responsible for the observed positive impact on the use of advisories in the following years.

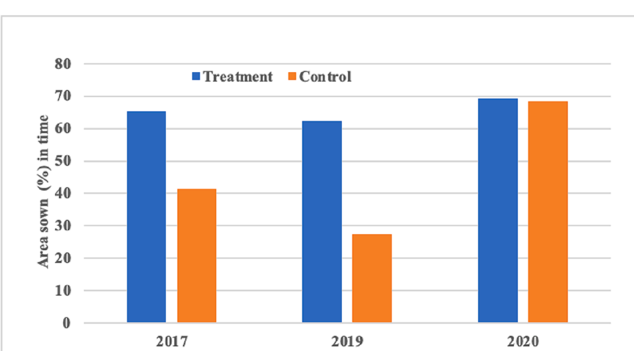

Fig. 6. Proportion of the area planted during the optimal planting window in treatment and control villages during the 2017, 2019 and 2020 crop seasons.

Level of influence of in-season advisory on decision making

To evaluate the extent to which decisions were influenced by advisory information, farmers were asked to rate the influence of advisory in making various decisions on a scale of 0–100%, where 0% indicates no influence and 100% indicates that the decision is entirely based on the advisory. Between 30 and 55% of farmers have indicated that the influence of information received through an advisory on decision making is more than 50% while the others rated it to be less than 50% (Fig. 7). No major differences were observed across the locations and the years, but differences were observed between the operations. Most farmers rated the influence of advisory on decisions related to the allocation of land to different crops as low and for operations that included the selection of crops, sowing, and harvesting as high. Some of the decisions that farmers have taken during the season included switching to other crops when the onset was delayed in 2017, adopting of more diversified crop options during 2019 which was forecasted to be a below-normal season and rescheduling harvesting in response to the forecast.

Contribution of advisory

Farmers were also asked to indicate how the information in the advisory has helped them in the decision-making process. According to farmers, the information helped them in four different ways. They include providing reliable climate and weather information, timely advice about various operations, enhanced confidence in making decisions, and assisting them to make informed decisions (Table 6). About 47% of farmers have indicated that the reliability of the information including forecasts was high and this helped them in making better decisions in managing the crops at different stages during the season. The second important contributor is the advice about various operations which 36% of the farmers found helpful in conducting the operations timely. Another 12% of farmers have indicated that the advisory has helped them make and implement decisions more confidently. A small (5%) percent of farmers have indicated that the messages made them think about “Other” alternatives while deciding. Overall, the results indicate that the reliability and quality of the information and suggestions about various operations in real-time are important for the advisories to be useful and make an impact at the farm level. The observed differences in the farmer responses across the years indicate that the advisories are more helpful in the normal to below normal years.

Efficiency of the iSAT system

The assessment also evaluated the functioning of the system in delivering the messages, the clarity, and understandability of the messages delivered and the benefits derived.

Access, timeliness, and relevance of the content advised

Nearly 95% of the registered farmers received the messages sent by iSAT indicating that the system worked well in delivering the messages every week (Fig. 8). About 91% of the farmers were satisfied with the weekly frequency of the messages and with the content of the message which matched well with their requirements. In terms of clarity and understandability of the messages, 95% of the farmers felt that the messages are clear and easy to understand. However, some differences were observed between the expectations of farmers and the issues covered by the messages. While most farmers, about 92%, felt that the messages are covering major issues relevant at that time, some farmers

Table 5
Utilization of iSAT advisory in planning various operations by farmers (% farmers) in the four villages.

Operations	Year	Gubanapalli	Ramapuram	Turkapalli	West Narsapuram	Overall
Planning and preparation	2017	97	46	97	79	
	2019	97	100	100	100	90
	2020	97	67	97	100	
Land Preparation	2017	9	2	8	5	
	2019	90	100	93	100	65
	2020	97	80	97	100	
Sowing	2017	71	30	80	6	
	2019	97	97	100	100	79
	2020	90	93	93	93	
Intercultural operations	2017	45	58	38	65	
	2019	93	87	90	93	56
	2020	17	50	13	23	
Spraying / Fertilizer application	2017	36	83	32	73	
	2019	90	87	80	83	54
	2020	20	33	13	20	
Harvesting	2017	85	61	97	22	
	2019	90	100	90	90	80
	2020	77	93	90	70	

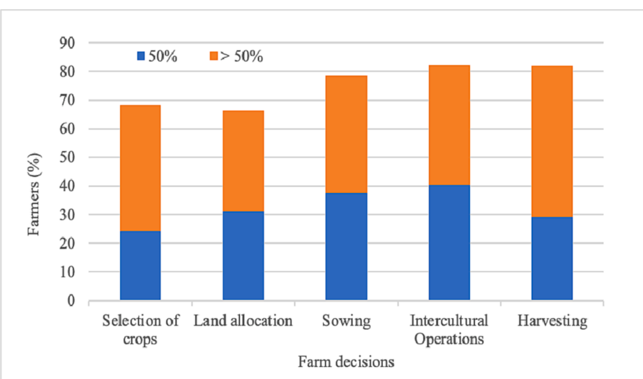

Fig. 7. Farmer assessment of percent influence of iSAT advisory in making crop management decisions.

felt that the messages should include information about the management of other crops such as vegetables with high commercial value. Currently, vegetables and other crops which are grown on small plots under irrigation are not included in the advisory. When it came to sharing the messages with others, the response of farmers varied widely over the years. On average, about 31% of the farmers shared their messages (Fig. 8), however, only 6 percent of the farmers shared the messages with others in 2020 which is a very wet year with low demand for climate information (data not shown). The uncertainty created by the delayed onset of monsoon in 2017 and by the occurrence of frequent dry spells of 14 days or longer in 2019 have created greater demand for information.

Benefits of iSAT based decisions

Making timely decisions, better management of crops, reducing cost of cultivation and better crop selection are the four ways by which farmers benefitted from the information received through the advisories (Table 7). The biggest contribution of the advisory was in assisting farmers to make timely decisions (about 36%) in conducting farm

Table 6
Farmer assessment (% farmers) of the contribution of iSAT information to decision making.

Reasons	Year	Gubanapalli	Ramapuram	Turkapalli	West Narsapuram	Overall
Advice about various operations	2017	26	15	20	43	
	2019	44	27	49	44	36
	2020	44	33	42	36	
More confident decision making	2017	24	14	19	24	
	2019	7	2	3	0	12
	2020	0	18	8	19	
Source of reliable information	2017	41	59	28	14	
	2019	47	67	46	56	47
	2020	56	49	48	45	
Others	2017	9	20	10	3	
	2019	2	4	2	0	5
	2020	0	0	2	0	

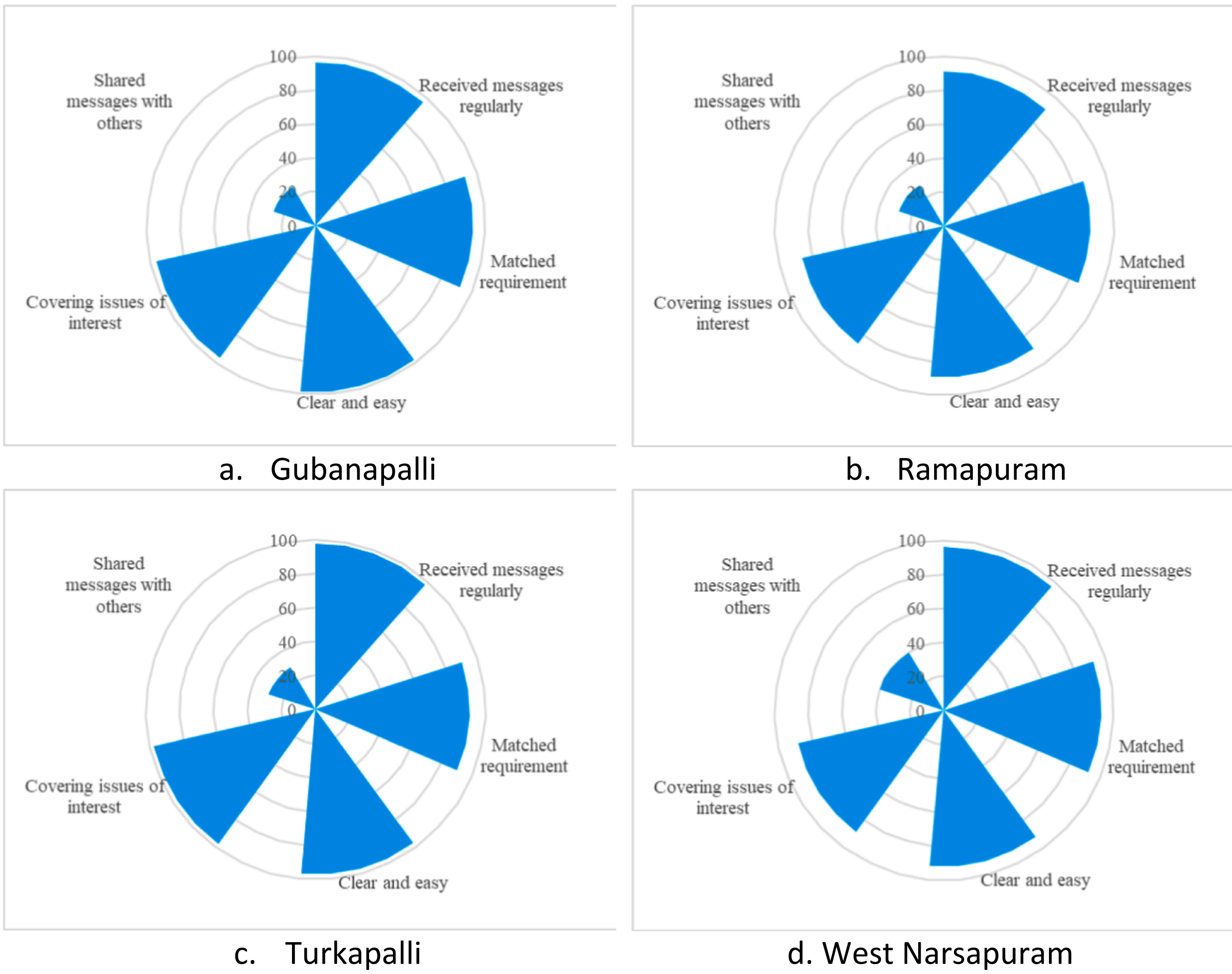

Fig. 8. Consolidated response of farmer's regarding the access, timeliness, and relevance of the content advised through the iSAT advisory.

Table 7
Farmer assessment (% farmers) of benefits from improved decision-making using iSAT advisories.

Options	Year	Gubanapalli	Ramapuram	Turkapalli	West Narsapuram	Overall
Selection of Crops	2017	4	18	4	0	
	2019	53	34	60	35	27
	2020	37	23	29	31	
Timely Decision Making	2017	45	32	53	37	
	2019	34	30	27	53	36
	2020	19	34	37	33	
Better Management	2017	26	27	25	27	
	2019	13	11	9	12	22
	2020	27	29	27	25	
Reduced cost of cultivation	2017	8	4	7	10	
	2019	0	11	0	0	4
	2020	3	5	1	0	

operations with little difference between the years and villages. Identification of this as the major contribution of advisory by a higher percentage of farmers during 2019 compared to 2017 and 2020 indicates the importance of advisory in below-normal seasons. Another important benefit derived by farmers (27%) was through helping select crops that are best suited for the type of season predicted. Only 4% of farmers have indicated that they are benefitted by reducing the cost of cultivation. Much of this reduction in the cost of cultivation is from plant protection activities. Though the advisories have no specific information on the occurrence of pests and diseases, farmers scheduled their spraying operations based on the forecast.

Influence of climate information on crop productivity

The grain yield of the groundnut crop achieved by farmers from both treatment and control villages was analysed (Table 8) to evaluate the impact of advisory-based decision making on its performance. Results

Table 8
Groundnut yield (kg/ha) achieved by farmers in climate informed villages and their control villages.

Villages	Year	Gubanapalli	Ramapuram	Turkapalli	West Narsapuram
Treatment	2017	939	695	1118	1305
Control		741	753	716	945
% Change		27	−8	56	38
Treatment	2019	1153	1036	1330	890
Control		1138	1176	1204	839
% Change		1	−12	10	6
Treatment	2020	422	724	423	329
Control		337	679	276	298
% Change		25	7	53	11

indicated an overall benefit of about 20% but it varied from 12% to 56% among the study villages and across the seasons, although no statistical significance was found. In 2017, the groundnut yield in treatment villages is 27 to 56 percent higher compared to that from control villages except in Ramapuram where the yield recorded in the control village is 8% higher. This village has shown no benefit due to advisory-based decision making in all three years. Though a similar trend was recorded in 2019, the gain is marginal and yields in the treatment village are on par with those from the control villages. This is partly due to the prolonged dry spell that has occurred during the critical flowering and pegging stage. During the above-normal season of 2020, yields in all treatment villages are higher than those achieved in control villages (not significant). It is interesting to note that the groundnut yields in 2020 were relatively low compared to the other two seasons. The extremely wet conditions have impacted the pod setting and pod filling during the year.

To test and understand the Influence of climate information on groundnut yield, the simple linear model ANOVA (Table 9) was worked out. Yield determinants considered in the test are season type (normal (N), below normal (BN), and above normal (AN)) and agro-advisory services (treatment and control villages).

The results suggest that the interaction between the impact of agroadvisory services and season type on groundnut yield was significant. However, only the main effect of season type on groundnut yield was statistically significant.

Further, to understand the significance of the effect of agro advisories, the Tukey post-hoc test was conducted and it revealed that the agro advisory services were useful (Fig. 9) during the below-normal season. From this analysis it is evident that climate information is influencing the groundnut yield.

Discussion

The successful adoption and usefulness of ICT-enabled advisory services in farm-level decision making depend on the timely availability, easy accessibility and potential for the information to influence decisions (Antle et al., 2017). iSAT was designed to address these issues through a decision tree approach that translates insights from the analysis of historical climate data, observations of the current weather and medium range (2 week) forecasts into actionable advisory information which is communicated to farmers for use in real-time decision making (Rao et al., 2019). This paper attempts to evaluate the extent to which the advisory information influenced the farmers in planning (strategic) and managing (tactical) various farm operations and their feedback on the effectiveness of the system.

Table 9
The general linear model ANOVA table for the groundnut yield determinants – season type and agroadvisory services.

Source	*df*	*Adj SS*	*Adj MS*	*F-Value*	*P-Value*
Agroadvisories	1	7414	7414	0.022	0.883
Season	2	40,284,821	20,142,410	58.646	0
Agroadvisories: Season	2	3,903,668	1,951,834	5.683	0.003
Residuals	600	2.06E+08	343,457	0.022	

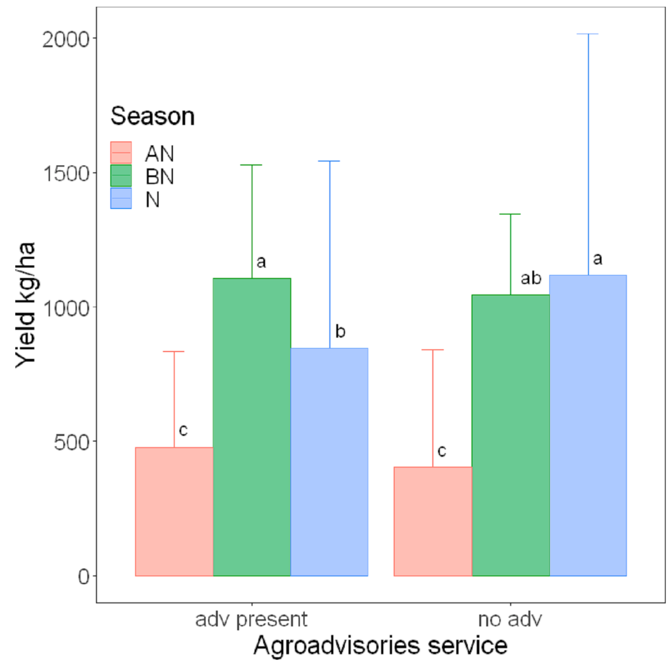

Fig. 9. Tukey post-hoc test results. Adv present = "Treatment" and no adv ="Control".

Pre-season advisory

Although several studies have evaluated and established the value of seasonal climate forecasts in farm-level decision making under a range of climatic conditions (Hammer et al., 1995; Hansen, 2002), large-scale adoption of the same is not yet taken place. Most studies either report limited use or evaluate their potential use (Dilling and Lemos, 2011). Apart from the lower reliability of SCF especially at the scale of small geographical areas, the other barriers for effective use include limited human, social, and financial capital (Eakin et al., 2014; Glantz, 1977; Ingram et al., 2002; Tall et al., 2018). Lack of knowledge of available products and their use is also one of the reasons for such low usage rates of adoption in many countries (Tschakert et al., 2010). Hansen (2002) and Nkiaka et al. (2019) argue that the probabilistic nature of SCFs requires farmer engagement and capacity development at various levels to effectively communicate such information (Meinke et al., 2006; Patt et al., 2005; Roncoli et al., 2009, 2011; Ziervogel, 2004). The pre-season advisory developed and disseminated in this study has addressed these limitations by following the approach suggested by Tall (2011).

The forecasts were evaluated against the rainfall requirement of the groundnut crop to give a positive economic return. Groundnut productivity and seasonal rainfall have indicated that the seasonal climate forecast-based advisories were useful in 3 out of 4 villages in 2017 and all the villages in 2019. The results clearly explains the relationship between seasonal climate forecast and the decisions made around crop choice and area allocation. Guido et al. (2020) also identified a similar association based on their study about farmers seasonal expectations on crop choice in Kenya. Though the forecast for the year 2020 turned out to be true, excess rain during the season had an adverse impact on the performance of the groundnut crop. Interestingly, farmer assessment of these seasons is very different when compared to our assessment. Almost all farmers rated the 2020 season as a poor season since the excess rainfall received during the year has adversely affected the groundnut crop resulting in lower yields compared to the other two seasons which received near-normal rainfall.

As noted earlier, the actual influence of seasonal rainfall on crop production is far more complex. Apart from rainfall, the onset of the season, length and distribution of dry spells also affect crop choices, cropping intensity, and crop performance (Lobell et al., 2008; Koide et al., 2013; Iizumi and Ramankutty, 2015). Though rainfall is a key determinant, it is not the sole determinant of strategic decisions taken by farmers. Researchers have identified that farmers access to seeds and farm machinery (Eakin et al., 2014; Ingram et al., 2002; Waldman et al., 2017), their risk perceptions and adaptive capacity (Rockström et al., 2002; Slovic and Peters, 2006) and household dynamics (Carr and Owusu-Daaku, 2016) also affect the strategic decisions.

There are deviations from the forecast in all three seasons that this study covered but some of them such as delayed onset can be responded to by closely monitoring the progress of the monsoon. Our results indicate that the seasonal climate forecast should be taken as an indication of how the season is going to be with corrective measures as required in response to the progress during the season.

In-season advisory

The majority of farmers in the study villages have indicated that the advisory information has helped them in deciding on tactical in-season adjustments and intercultural operations timely and efficient. Among the operations, the results strongly establish that information provided through advisories is extremely useful in deciding on planting time especially during the normal and below-normal seasons compared to the seasons with above normal and well-distributed rainfall which offers multiple sowing opportunities. Several studies (Gurav et al, 2010; Kumar et al, 2021; and Selvaraju et al, 2005) on the usefulness of advisories resonate with these findings. Farmers have also identified harvesting as another operation that is influenced by the information provided by the advisory. Selvaraju et al, (2005), Gurav et al, (2010), Ramachandrappa et al, (2018) and Gandhi et al, (2018) have also reported the dependence of farmers on climate information for harvest decisions. A smaller number of farmers have identified that the information also helped in planning and conducting land preparation, intercultural operations and in scheduling fertilizer and pesticide applications. This can be explained partly by the low sensitivity of these operations to weather variability and the limited role weather forecasts may play in informing the management of such operations. Land preparation is more influenced by the amount of moisture and workability of the soil at the time of conducting the operation than the expected rainfall. Similarly, intercultural operations such as weeding will be done based on the intensity of the weeds and availability of labor, pesticide and fertilizer applications are based on the stage of the crop and the extent of the damage. A similar difference in response to these operations based on advisory information was captured by Gurav et al, (2010), Nesheim et al, (2017), Gandhi et al, (2018) and Prasad et al, (2020) with varying levels of credibility.

Every season is unique in terms of rainfall amount and distribution, dry/wet spells that impact the productivity of crops. Invariably, in all seasons, the advisory information has impacted crop productivity positively. Results indicate that the demand and interest for climate information are higher in the years in which the season is more erratic than during the seasons in which the rainfall is high and well-distributed.

Efficiency of the iSAT system

Farmer's assessment of the efficiency of the iSAT system in delivering timely and context specific messages was highly encouraging. In all the years, more than 90% of the farmers have expressed that they have received the messages regularly and the messages are clear, easily understandable, and cover the issues of interest. They have also been satisfied with the weekly frequency of the advisory messages. This elucidates the success of tailored farmer friendly messages and its delivery. A similar assessment of farmers satisfaction with timeliness, accuracy, and frequency of the agromet advisories was reported by Gandhi et al, (2018); Ramachandrappa et al, (2018) and Kumar et al, (2021). The rating of iSAT advisories varied but improved over the years indicating farmers trust and the usefulness of the iSAT advisories. Overall, more than 80 percent of the farmers have rated it as 4 out of 5. Rana et al. (2005) and Ramachandrappa et al. (2018) also reported high farmers rating for the agromet advisory services in their assessment. Farmers response and rating validates the effectiveness of advisory delivery through SMS. The findings of Casaburi et al.. (2014); Maredia et al. (2018) and Sharma et al. (2021) resonate with the effectiveness of the delivery mechanism.

Conclusion

This study has demonstrated that climate information-based decision making will help in improving the productivity and profitability of small-holder farmers operating under variable weather conditions. However, the magnitude and distribution of benefits among farmers vary depending on the season type and resource condition of the farmer. Providing actionable advisories integrating historic and real-time climate information tailored to local conditions is still a challenge but the developments in technology have opened new opportunities. This case study has highlighted one such opportunity to harness the power of information and communication technologies to compile real-time information from different sources and analyse and interpret the same for end users to make informed decisions. For farmers operating under highly variable climatic conditions, this will make a significant contribution to reducing risks and capitalizing on opportunities.

This study has also demonstrated the potential for developing more advanced systems to deliver farmer-specific information once the required input datasets are built and made accessible. Such systems reduce the farmer's reliance on extension and other agencies, to access the information and enable farmers to make better and timely decisions.

CRediT authorship contribution statement

A.P. Ramaraj: Conceptualization, Data curation, Writing – review & editing. **K.P.C. Rao:** Conceptualization, Methodology, Investigation, Supervision. **G. Kishore Kumar:** Resources, Validation, Data curation. **K. Ugalechumi:** Visualization, Validation, Data curation. **P. Sujatha:** Software, Formal analysis. **Suryachandra A. Rao:** Funding acquisition, Supervision. **R.K. Dhulipala:** Software, Resources. **A.M. Whitbread:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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