International Journal of Computer Applications (0975 – 8887)
Volume 187 – No.85, February 2026

Decision Support System “*Krishidhare”* for Weather and Market Smart Agriculture

Chandre Gowda M.J.
ICAR-Agriculture Technology Application Research Institute (ICAR-ATARI),
Bengaluru-24, Karnataka, India

Dolli S.S.
Department of Agricultural Extension, University of Agricultural Sciences, Dharwad-580005,
Karnataka, India

Kedar K.
Department of Computer Science and Engg. Indian Institute of Technology, Dharwad-580011,
Karnataka, India

Kalpana M.
Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu- 641003, India

ABSTRACT
The paper investigates the shortcomings of Decision Support System (DSS) in the agricultural sector and presents a weather and market based DSS to strengthen the farming decisions. A systematic review of 804 research articles published across 78 journals during 2012–2023 indicated that existing expert systems were mostly on crop, irrigation, nutrient, weed, disease, and pest management, with little focus on weather and market- smart decision support. The secondary data on weather parameters and market prices for the period 2010–2023 showed an interesting trend between rainfall and market price for major crops. The primary data collected across project locations growing selected crops revealed inadequate and untimely access to weather and market information. In order to help farmers facing these problems, an Artificial Intelligence enabled, mobile based decision support system *“Krishidhare”* was developed to deliver real-time advisories on crop management based on weather and prices forecasts. The *Krishidhare* deploys MySQL database, Python Flask Framework, AI/ML service layer in data warehouse, software and system architecture. System implements a multi-tier distributed architecture comprising five principal layers, viz., data layer, application layer, AI/ML service layer, administrative interface layer, and presentation layer. Field test results confirmed an accuracy of 92 % for rainfall forecast. The diagnosis by AI application in the expert system found 100 % accuracy for pests and 90 % for diseases identification. After field testing, 350 farmers were registered and installed the *Krishidhare* expert system on their mobile devices. Analysis of the utility pattern of the expert system revealed that 73 % of farmers used the application for accessing weather information and market prices.

General Terms
Expert system, Decision Support System, Agricultural Information System.

Keywords
Artificial intelligence, decision making, market forecast, climate smart, sustainable farming.

1. INTRODUCTION
Agriculture is one of the oldest means of livelihood and the associated risks have been well documented world over. According to the Sustainable Development Goals (SDGs) report [1], most of the farmers in India fall into the smallholder category. The delayed onset of monsoon, intermittent dry spells and droughts largely affect the agriculture productivity and profitability in most parts of India. Unforeseen variations in temperatures, rainfall and pests being attributed to climate aberrations, have demanded for increased focus on development and demonstration of technologies that contribute to sustainable agriculture systems. Although the application of science and technology have helped to modernize farming and manage the risks involved, the risks and uncertainties associated with newer pests and diseases, market prices and unpredictable weather have continued to bother the farm practitioners and service providers. These risks are assuming serious dimensions due to increasing frequencies in extreme weather events [2], dynamic market systems and the shrinking holdings. Farmers’ decisions on the farm operations are difficult to be predicted, as the associated risks are many [3]. Precise and reliable information based rational decisions could reduce the consequences of the risk factors. Decision Support Systems (DSS) are emerging as the tools that help users with recommendations for specific situations. Decision support system is a computer-based system of models and databases, the outcome of which are used for decision making. The core components of DSS are database management, knowledgebase management and model management systems. Decision support systems have been attempted in all sectors including agriculture, computer science, engineering, environment, information technology, medicine etc., to help the people concerned to make better decisions. However, clarity is lacking on how many sectors have adopted the DSS and how each sector has been able to make use of the technological revolution in the information technology arena. In this backdrop, an attempt has been made to (i) review the recent evolution and development of decision support systems, (ii) to get an overview of decision support systems in agriculture, (iii) ascertain the less addressed yet more important domains within agricultural sector that could form the basis for the way forward, and (iv) explain the proposed models of decision support systems. The last part of the paper on the way forward is being pursued through an action project with financial support from National Agricultural Science Fund (NASF) of Indian Council of Agricultural Research (ICAR).

2. REVIEW AND THEORETICAL FRAMEWORK
To have an understanding of the decision support systems in use, the authors reviewed the published research papers with a focus on the following aspects.

2.1 Time frame
The priority was given to capture the trend in the development of decision support systems and their application at the field level. Since the digital aided decision making has been rapidly evolving, it was decided to review the latest, by confining to the work published during the last one decade (2012 onwards).

2.2 Article sample

Open source searching of articles with title having 'decision support system' or DSS or any model applying the previously developed DSS were accessed and analyzed for review purpose. A similar approach to meta-analyses was used by Arnott [4]. Articles which explicitly mentioned the DSS or its models only were considered for the sampling. A total of 804 articles that met the above criteria formed the sample of the study (Table 1).

Table 1. Sector-wise number of journals and articles on DSS published during 2012-2023

Sl. No.	Sector	Journals publishing articles on DSS		Articles published on DSS		Articles on DSS in Agriculture	
		No.	%	No.	%	No.	%
1	Agriculture	27	34.62	366	45.52	366	45.52
2	Computer	11	14.10	180	22.39	0	0.00
3	Environment	9	11.54	68	8.46	17	2.11
4	Engineering	5	6.41	21	2.61	2	0.25
5	General	20	25.64	120	14.93	8	1.00
6	Information Technology	4	5.13	7	0.87	0	0.00
7	Medicine	2	2.56	42	5.22	0	0.00
	Total	**78**	**100.00**	**804**	**100.00**	**393**	**48.88**

2.3 Classification of journals

The articles on DSS were published in seventy-eight journals, an average of 10.3 articles per journal in twelve years (2012-2023). Agriculture is the most dominating field, with twenty-seven journals (34.62 per cent) publishing a total of 366 articles (45.52 per cent). Twenty journals were not specific to any single domain and hence categorized as 'general' published 120 articles on DSS including eight on agriculture DSS. It was followed by computer sector journals with eleven journals publishing 180 articles on DSS, but none of these were related to agriculture. Nine journals belonged to environment sector published sixty-eight articles on DSS, with seventeen on DSS in agriculture. Overall, nearly half (48.88 per cent) of the published work on DSS was on agriculture.

Out of seventy-eight journals, top twenty-one journals with more than ten articles on DSS during the period accounted for 78.11 per cent (628 articles) of the published work (Table 2). Majority of these journals have been publishing articles on DSS regularly, with an exception of the Journal of Scientific Programming, which started publishing DSS articles 2020 onwards. Nine journals in agriculture sector emerged as the leading promoters of decision support systems, publishing an average of thirty-five articles per journal. Five journals in the computer sector published approximately thirty-two articles per journal (total 158) on DSS. There has been a steady increase in the articles published over the years, from thirty-four in 2012 to seventy-three in 2023.

Table 2. Major journals and year-wise number of articles published on DSS

Sector	Journal Name	Total
Agriculture	Agricultural water management	98
Computer	Procedia computer science	63
Agriculture	Computer and electronics in agriculture	56
Computer	Expert system with applications	44
Medicine	Journal of American Medical informatics	36
Agriculture	Field crops research	33
General	Journal of decision systems	32
Agriculture	Agronomy	29
General	Knowledge based systems	29
Agriculture	Agricultural systems	28
Computer	Computers and industrial engineering	25
Agriculture	European Journal of Agronomy	21
Agriculture	Irrigation and Drainage	21
Computer	Computers and industrial engineering	25
Agriculture	European Journal of Agronomy	21
Agriculture	Irrigation and Drainage	21
Environment	Environmental modelling and software	19
Environment	Journal of environmental management	19
Agriculture	Agricultural and forest meteorology	17
Computer	Procedia CIRP	14
Agriculture	Journal of Agro meteorology	12
Computer	Scientific programming	12

Engineering	Automation in construction	10
General	Interfaces	10
	21 Journals	**628**

Further probing into 366 articles related to the agriculture decision support systems indicated the progressive changes towards sophisticated instruments such as artificial intelligence, precision farming, remote sensing, and machine learning (Table 3).

Table 3. DSS and its types in agriculture

Sl.	Name of DSS	Purpose	References
A.	**Crop management**		
1.	CropSyst	DSS for nitrogen-water interaction, crop growth and development, crop yield and soil erosion by water and salinity	Stockle *et al.* [5]
2.	CROP-9- DSS	DSS for fertilizer, water, and pest and diseases management	Ganesan [6]
3.	DSS (Apollo)	Decision making on types of seed to be sown, crop yield, irrigation scheduling and fertilizer management.	Thorp *et al.* [7]
4	DSSAT-CERES (Wheat)	Decisions on water scheduling on wheat crop at various crop stages	Arora *et al.* [8]
5	DSSAT	DSSAT was applied through automation by crop simulation	Sachin *et al.* [9]
6	APSIM	DSS for crop management under climatic risk	Keating *et al.* [10]
B.	**Irrigation management**		
1.	CALEX	DSS for cotton irrigation	Plant *et al.* [11]
2.	SWASALT	To take decisions on the water requirement based on the salt content	Singh and Singh [12] and Singh [13]
3.	Plant Info irrigation Manager	Developed in Denmark, to schedule irrigation for crops such as potato, maize, spring, winter barley, rye, grass *etc*	Thysen and Detlefsen [14]
4.	HydroLOGIC	Designed in Australia to evaluate consequences of irrigation and to explore options to optimize yield in Cotton	Richards *et al.* [15]
5.	AquaCrop	Evolved from the FAO for irrigation scheduling in specific crops	Steduto *et al.* [16]
		Applications of AquaCROP in water management strategies for dry land areas	Berhane *et al.* [17]
		Applied for optimization of nitrogen fertilisers and water productivity in soybean	Adeboye *et al.* [18]
		Evaluated and applied for soil salinity and saline conditions	Zhai *et al.* [19]
6.	AQUATER	Developed in Italy for water optimization	Acutis *et al.* [20]
7.	CropIrri	Developed in China to optimize allocation of water resources	Zhang and Feng [21]
8.	IRRINET	Developed in Italy for irrigation management at field scale	Mannini *et al.* [22]
		Fuzzy DSS to improve water management and the model is tested in three crops namely corn kiwi and potato	Giusti and Marsili Libelli [23]
9.	SIDSS	Developed using the machine learning methods to provide accurate irrigation information.	Navarro-Hellin [24]
10.	WIDSSLI	Developed in North China Province for water management	Li *et al.* [25]
11.	IrrigDSS	DSS for site specific crop management	Todorovic *et al.* [26]
C.	**Nutrient management**		

1.	AmazieN	DSS for optimizing N fertilizer in maize	Li *et al.* [27]
D.	**Pest and disease management**		
1.	Weather based plant disease forecasting using fuzzy logic	Fuzzy inference system to overcome disease incidence	Tilva *et al.* [28]
	DSS for fungicide usage	DSS to reduce fungicide usage in Europe by using Meta analysis	Lazaro *et al.* [29]
2.	Weather based DSS to control cutworms	Developed in Poland to manage cutworms	Jakubowska *et al.* [30]
E.	**Weed management**		
1.	Crop protection online (CPO)	DSS was developed to suggest the herbicide applications and non-chemical weed control in cereals and sugarbeet.	Rydahl [31]
F.	**Weather**		
1.	Weather based DSS	Weather forecast linked crop and variety advisory	Ayubu *et al.* [32]
2	Weather based DSS	Weather based parameters was considered along with the category-based weather conditions.	Alugubelly *et al.* [33]
3	WeRise	Developed by International Rice Research Institute to improve rainfed rice productivity	Hayashi *et al.* [34]
4	Agromet DSS	Developed by Indian Meteorological Department in collaboration with Thailand based Regional Integrated Multi-Hazard Early Warning System for providing weather based ago advisories to farmers	Singh *et al.* [35]

A brief description of the above listed decision support systems is provided under six categories namely crop management, irrigation management, nutrient management, pest and disease management, weed management and weather.

DSS for crop management: The Decision Support System for Agro technology Transfer (DSSAT), was first developed in 1989 (DSSAT v 2.1) and since then more than eleven versions have been developed (latest version 4.8.2) by the DSSAT Foundation, which have been applied by various users on over forty-two crops (https://dssat.net). Recent studies and researches on DSSAT include other crop models such as SIMRIW, AquaCrop, APSIM, CROPSIM CERES model, DRAINMOD, DSSAT- SUBSTOR potato model, CROPGRO model. The DSSAT was used in integration with DRAINMOD, SALUS, PEST software, GLUE method and R software. Prediction of specific crops phenology was attempted in soybean, sugarbeet, rice using DSSAT. The Crop Environment and Resource Synthesis (CERES) decision support system developed in 1985, was further improved by Sachin [9] with an attempted automation of the CERES crop growth simulation model, wherein spatial database was created using PostgreSQL. The Agricultural Production Systems Simulator (APSIM) is a software tool developed in Australia for simulating farming systems. The framework is designed to help users understand the impact of different agricultural practices on crop yield, resource use, and the environment over the long term. APSIM consists of individual modules such as SOILN, RESIDUE, SOILP and MANURE, SOILpH, EROSION, and MANAGER representing different aspects of a farming system. APSIM has been extensively tested and used in various applications, showing its ability to provide valuable insights for agricultural decision-making [10].

DSS for Irrigation management: The AquaCrop, the FAO crop model, uses canopy ground cover instead of leaf area index (LAI) as the basis to calculate transpiration and to separate out soil evaporation from transpiration. AquaCrop was evolved from the previous [36] approach with relative Evapotranspiration (ET). Berhane [17] reviewed the applications of Aqua Crop model for improved field management and applied the model to evaluate the growth and production of various crops. Adeboye [18] applied the AquaCrop model for optimization of nitrogen fertilizer and water productivity of soybeans. Zhai *et al.* [19] evaluated and applied the updated version of AquaCrop.

AquaGIS is a new tool that is used to collect the information on the crop development and physiology by geo-spatial information system and other field data and incorporating the same into the AquaCrop.

Mannini *et al.* [22] applied IRRINET, a large scale DSS application for on farm irrigation scheduling. Guisti and Marsili Libelli [23] demonstrated a fuzzy decision support system (FDSS) for irrigation and water conservation in agriculture using IRRINET model.

Navarro *et al.* [24] developed an automatic “smart irrigation decision support system (SIDSS)” in agriculture.

Lie *et al.* [25] developed a web-based irrigation decision support system with limited inputs (WIDSSLI), which takes into account the day of sowing and water available at that point to start the decision process.

Todorovic *et al.* [26] developed IrrigDSS- Decision support system for irrigation scheduling for site specific data-driven irrigation scheduling.

DSS for nutrient management: Li *et al.* [27] developed AmaizeN, a decision support system for optimizing nitrogen management in maize, which collects the data of local weather stations, general soil types, and maize varieties.

DSS for Pest and disease management: Damos and Karabatakis [37] developed a web-based decision support system using the stored data on temperature to predict pest population phenology during the crop growth season. Tilva *et al.* [28] developed a weather-based plant diseases forecasting model using fuzzy logic. The fuzzy inference system (FIS) was developed using the information collected on the environment and the probability of occurrence of diseases. Jakubowska *et al.* [30] developed a weather-based decision support system for the control of cutworms in beets and cereal leaf beetles in cereals and their adoption in farming practice.

DSS for Weed management: Ryegrass integrated management decision support system helps to build the 10-year cropping scenarios and to evaluate the impacts of management choices on annual rigid ryegrass population and long-term profitability [38].

DSS based on Weather: Ayubu *et al.* [32] developed a weather-based decision support system using a MySQL database management system. Crop entity contains a forecast-code field to provide a mapping between the forecast and choice of crop, based on farmers preferences obtained during respondent's survey. The current weather data is converted into normal, above normal and below normal based on long-term averages and was used to advise farmers on choice of crop and related management practices.

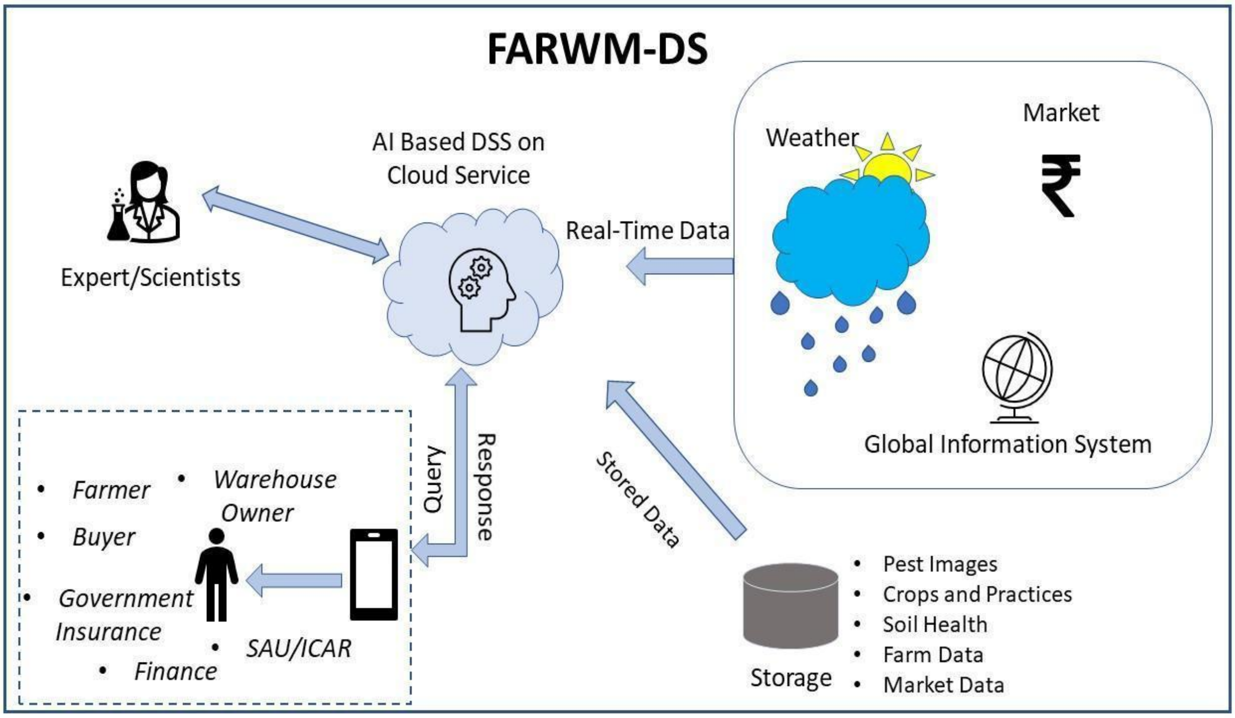

Figure 1. Framework of *Krishidhare* App

Hayashi *et al.* [34] evaluated the predictive accuracy of the weather rice nutrient integrated decision support system (WeRise) developed by the International Rice Research Institute. ORYZA v3 was used to simulate grain yields for rainfed rice ecosystems.

Agromet Decision Support System was developed by Indian Meteorological Department in collaboration with the Thailand based Regional Integrated Multi-Hazard Early Warning System (RIMES) (Agro-DSS: https://agromet.imd.gov.in/). It has a three-tier structure *viz.*, web-based front-end module, application layer using PHP / Python and data layer. Agromet Advisory Services are provided to farmers and other users using the dedicated App Meghdoot. An important feature of the Agromet DSS is the automation of agromet advisory using AI/ML technique [35].

Weather and prices are the two key factors that have been adversely affecting the financial performance and the morale of farmers. However, the decision support systems reviewed by the authors revealed inadequate and dedicated applications of DSS for guiding farmers on managing the uncertainties resulting from the extreme climatic factors. The decision support systems developed so far have focused on any one of the nutrient, irrigation or plant protection, but not comprehensive. More glaring by its absence is the non-existence of any initiative to fit in the market related information to decision support systems that are crucial for sustainable production and income from agriculture.

Development of Weather and Market information based Decision Support System (*Krishdhare*) for use by the farmers and other stakeholders in the Indian farming contexts is based on the theoretical framework depicted in figure 1. The framework is built on a meta analysis of reviews related to decision support systems in general and agriculture in particular, followed by a trend analysis of secondary data on weather and prices in the project areas. These two components are further strengthened by primary data related to benchmark crop practices from seed to market on the selected crops. Farmers' decision-making process is facilitated based on data processing, problem recognition and solution generation with well structured components such as Central Intelligent Unit, Data/Model Base Management System, Control System, Interface System_and Communications Unit that allows the DSS to communicate with other systems, including databases and external data sources. Operating System provides the basic software environment for the DSS to run on [39] and [40].

3. METHODOLOGY

Realizing the importance of the field level decision support systems related to weather and markets, a research project has been initiated. As part of the development of weather and price based decision support systems, benchmark survey of farmers growing the identified crops *viz*., groundnut, cotton, pigeonpea and tomato was conducted. The survey area (depicted in Fig. 2) was decided based on the criteria of "higher area under each crop" during the previous year as per the records of State Agriculture Department. As per these criteria, Dharwad district was identified for groundnut and cotton crops, in which two taluks namely Kundgol and Hubballi for groundnut and Kundgol and Navalgund taluks for cotton were shortlisted. For pigeonpea crop, Gulbarga district had the largest area under which Aland and Gulbarga were the leading taluks for further sampling. In case of tomato crop, Mulabagal and Srinivasapura taluks of Kolar district were considered for the survey as the major tomato growing areas. With the support of local office of the state department of agriculture, two villages in each selected taluk having more area under cultivation of respective crops were identified for the next stage of sampling. In the selected villages, farmers who cultivated the project crops were listed alphabetically to enable random selection process. Fifteen farmers from each village were identified using the random selection process, which included marginal, small, medium and large farmers, without proportionate sampling. Thus the benchmark survey was conducted for primary data collection with a minimum of sixty farmers for each crop. A pre-tested questionnaire was used for collecting data on farmers' personal details, farm size, crops grown, cost of crop production, the sources of weather and price information, perceived yield and income loss due to weather and market prices and the farmers' coping mechanisms to tide-over these losses.

The Government of India has launched a Krishi DSS which provides the information about weather, soil quality, moisture level, crop health, but not related to prices. In this scenario, it became even more important to create a user-friendly mobile application providing a farmer-specific data dissemination platform which allows them to receive advisories related to crop production based on weather and market aspects. The app featured in regional language coupled with audio formats aids in proper utilization of the application by all the categories of farmers (including illiterates).

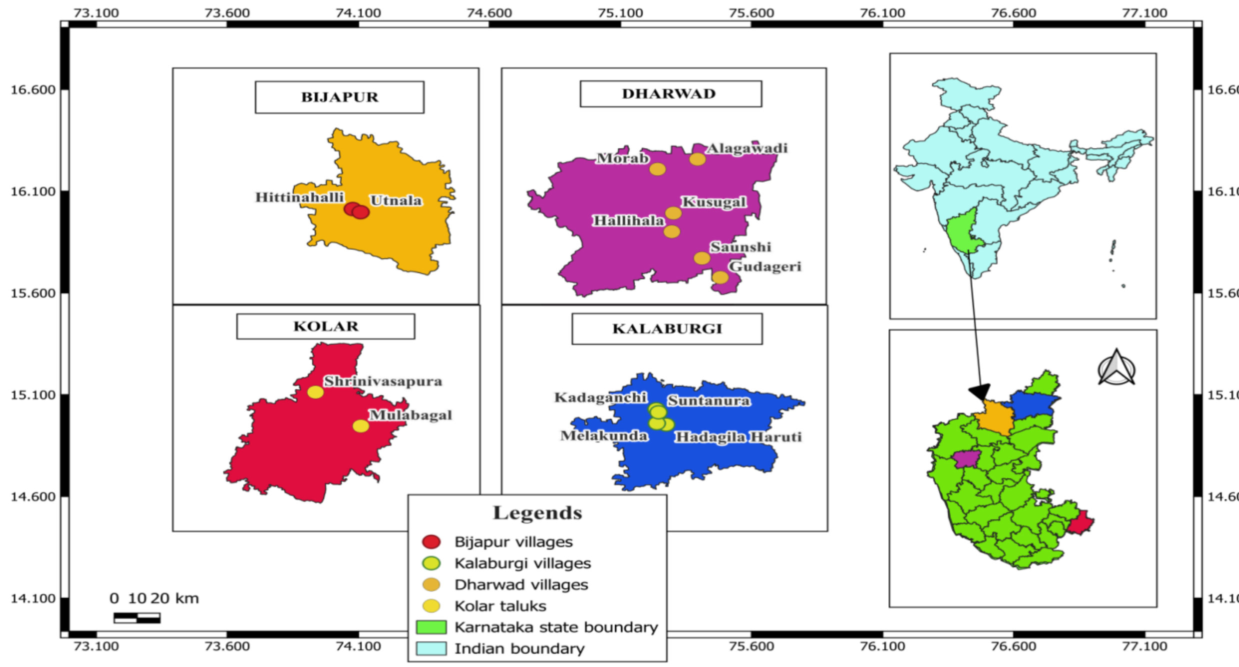

Figure 2. Map of survey area and project villages

In order to make the decision support system farmer-friendly, we developed a mobile phone application "*Krishidhare*" which can provide real-time responses with shorter response time for the farmer queries. Three V's namely, Volume, Velocity, and Variety are ubiquitous with data and are considered in the design of the DBMS. Static data on farmland, crop details, *etc.* has volume and variety, the real-time data has all the 3 V's such as the market price, weather conditions and crop management. Any DSS can be effective, only when the limitations with users in terms of language, digital literacy etc. [41] and [19] are overcome. The research team has taken cognisance of these challenges in development of *Krishidhare* DSS. Various data sources are organized in a suitable manner to be efficiently used for decision making. Each of the data sources has a different format, volume and rate. Thus, the choice of storage platforms such as MySQL or No-SQL databases along with schema design plays a crucial role.

The *Krishidhare* system implements a multi-tier distributed architecture comprising five principal layers: Data layer, Application layer, AI/ML service layer, Administrative interface layer, and Presentation layer. The data layer consists of a centralized MySQL database, containing three core tables (users, user_profiles, and crops) that maintain referential integrity and support efficient query operations. The application layer utilizes Python Flask framework to expose RESTful API endpoints across three distinct ports, enabling microservices-inspired architecture that facilitates independent scaling, service isolation, and simplified maintenance procedures. The system architecture depicted in figure 3 is briefly explained below.

The AI/ML service layer operates on a dedicated endpoint hosting trained deep learning models for automated crop disease identification across eight categories: Cotton Disease, Pigeonpea Disease, Groundnut Disease, Tomato Disease, and their corresponding pest detection models. These models process image inputs from mobile devices and return classification results with confidence scores, supporting model versioning and hot-swapping capabilities for continuous improvement. A separate asset management server efficiently handles static resources including diagnostic images, advisory sheets in Excel format, and forecast models through optimized content delivery with caching strategies.

The administrative interface layer provides authorized personnel with comprehensive database access for real-time system monitoring, data analysis, and management operations. The administrative interface maintains comprehensive audit logs of all actions, ensuring data security while facilitating data quality maintenance and system optimization insights.

The presentation layer consists of the *Krishidhare* mobile application developed for Android platforms, implementing responsive design that accommodates varying network conditions in rural settings. A central server orchestrates communication between all components through API gateway functionality, providing unified authentication, request throttling, protocol translation, and SSL/TLS termination. The system demonstrates robust performance with API response times under 200ms, disease detection inference within 1-2 seconds, and support for over 10,000+ concurrent user sessions, while maintaining scalability through containerization and horizontal scaling capabilities.

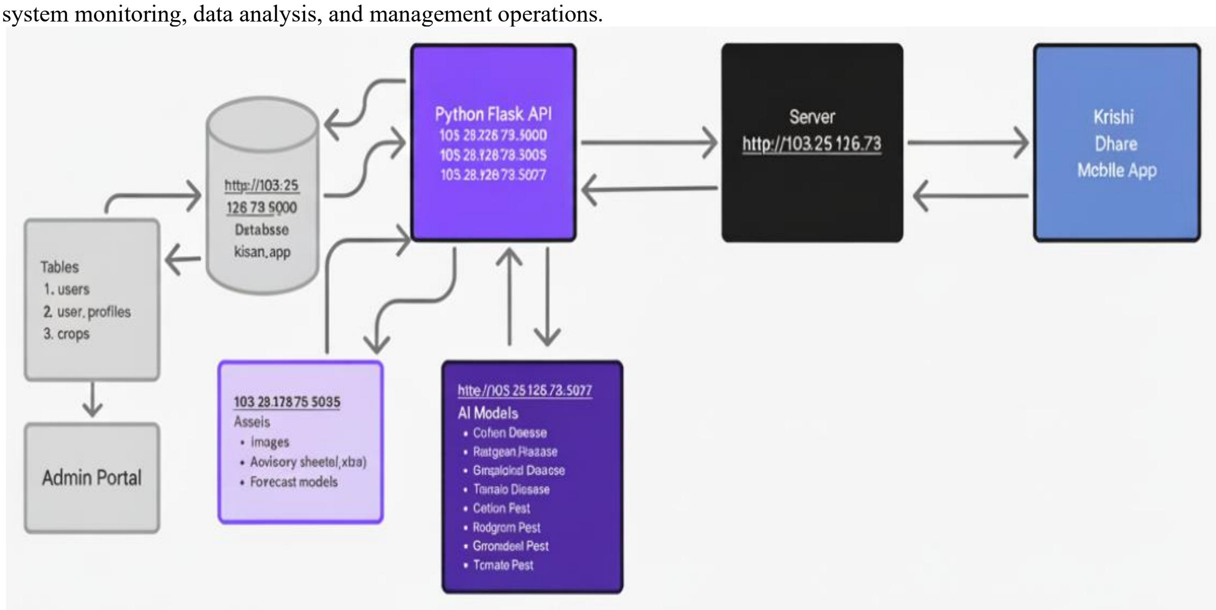

Figure 3. System Architecture of *Krishidhare* Mobile Application

4. RESULTS AND DISCUSSIONS

4.1 Secondary data

The weather-based DSS module (*Krishidhare* App) on weather and market is developed using the weather data on rainfall, temperature (max. & min.) and relative humidity for the project locations captured from the secondary sources for the period 2010 to 2023. Based on the data, current weather parameters are compared with long term averages and classified as 'normal', 'above normal' and 'below normal' to design the advisories on a weekly basis. Project farmers accessing the information are guided in the selection of crops and subsequently on crop cultivation practices at each stage.

Similarly, on market prices, fifteen years data are captured for the nearby/ most frequented market places for each of the select crops/ commodities. Based on which, most probable price scenario at the time of harvesting in the selected market places are forecasted right at the time of sowing so that farmers take calculated decisions of choosing a particular crop. The DSS offers a scope to provide data on demand for inputs, requirement of storage and processing facilities *etc*. Thus, an innovative weather and market information-based decision support system is designed for guiding farmers while choosing the project crop (cotton, groundnut, tomato and pigeonpea), optimum sowing time to harvest a good crop and also to harness maximum price.

The secondary data on rainfall and prices for one of the crops (Groundnut) in the project location areas are depicted in figure 4, which shows an inverse relation between rainfall and market prices. Rainfall in groundnut growing areas and its prices in three nearby markets (Mundargi, Lakshmeshwara and Rona) revealed that, in good rainfall years the average prices were less and the converse was true for less rainfall years. The trend seems to be logical as good rainfall results in higher production, leading to market glut and eventual low prices. It makes a strong case for a decision support system to break the trend by enabling the farmers to achieve higher productivity in low rainfall years and get benefited from the higher local prices. On the other hand, enable the farmers to explore the other/distant markets for better prices during higher production achieved in a good rainfall year.

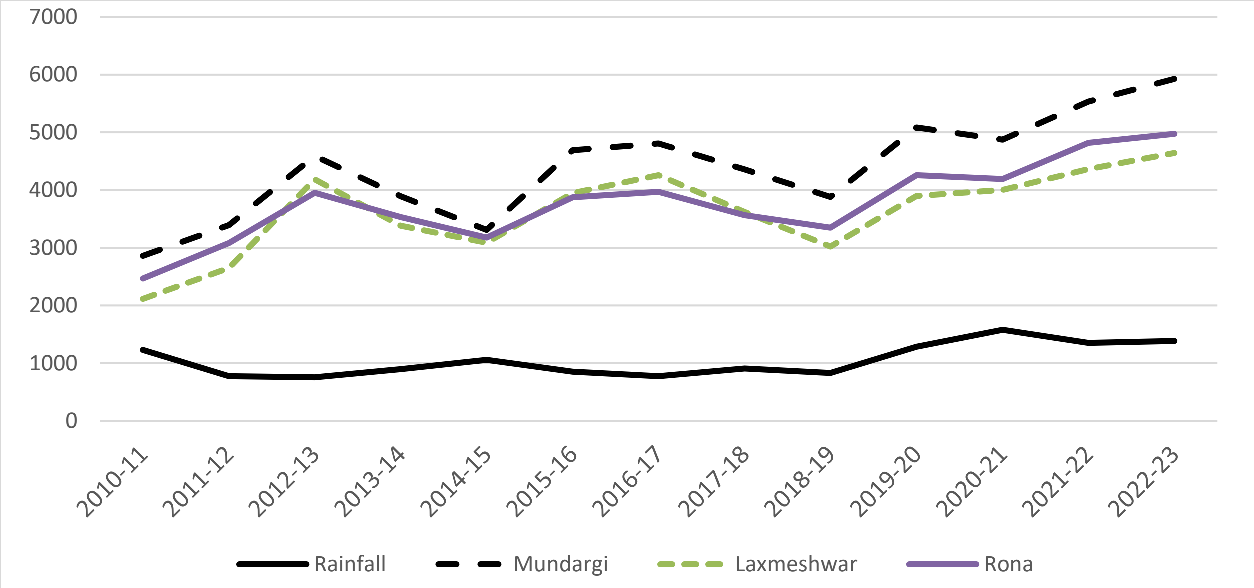

Figure 4. Groundnut prices (Rs/q) in three local markets compared with rainfall (mm) in the project area

4.2 Primary data on the baseline pattern of information access and use

(In order to have an assessment of ground realities, a survey of the project area was conducted with 204 farmers during February to July 2024) There is a huge gap between the weather and price information available and its proper usage by the farmers due to lack of awareness and access. Twenty-five per cent of farmers did not use any source of information and relied on the past experiences for crop production activities (Fig. 5). Forty-nine per cent of the farmers depended on newspaper, radio and television media for weather information. These media are known to have positive effect on adoption of agricultural technologies [42]. Television media also plays a major role in providing updates on weather forecast [43], [44] and [45]. However, majority of smallholders judge rainfall possibilities based on their past experiences [46] and [47].

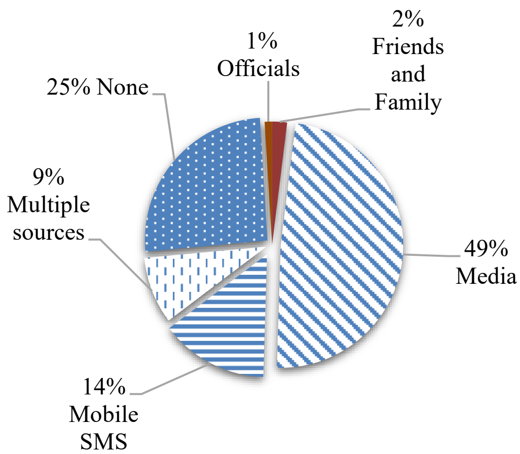

Figure 5. Sources of weather information

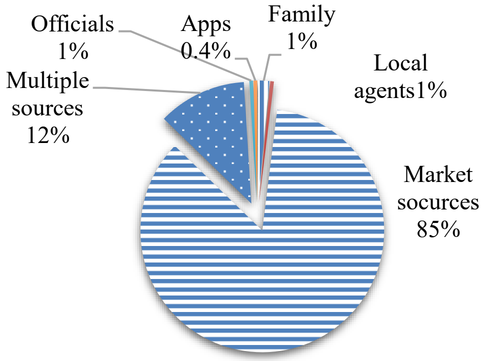

Figure 6. Source of price information for farmers

A large majority (85 %) of farmers obtained the price information from nearby markets and preferred local markets to sell their produce. Only 1 to 3 per cent of the farmers received information through local agents, officials and mobile applications (Fig. 6). The results are in line with previous studies [48] and [49]. Irrespective of the sources used by the farmers, farmers are unable to get the market information in required form [50]. Past researches have proved that households with access to right market information got better prices [51] and higher income. Weather and price information thus become most important factors for the farmers to increase their productivity and income.

4.3 Contextualization of the *Krishidhare* App and its utilities

The problems faced by farmers, consequences of these problems on yield and income, solutions needed to overcome and the potential utility of *Krishidhare* App to tackle these problems are consolidated in the table 4. The weather forecast on current, weekly, fortnightly, monthly and seasonal could impact the way farmers adapt themselves to weather and rainfall pattern. Similarly weather based forecasts of pest and diseases could equip farmers to face the challenges of pest and diseases occurrences. Market price forecasts equip farmers with knowledge of price trends in various markets, thus providing the psychological confidence of harvesting and transporting to chosen markets.

Table 4. Matrix of problems, impacts, expected solutions and potential utility of *Krishidhare* App

Problems	**Impacts of the problems**	**Expected solutions to overcome problems**	**Potential utility of *Krishidhare* App**
Limited or no knowledge about weather and rainfall pattern at the time of sowing and throughout the crop duration	Crop loss due to unexpected changes in weather and rainfall pattern	Information in advance on at regular intervals on rainfall pattern for the entire season, including post harvest operations	Weather forecasting on current, weekly, fortnightly, monthly and seasonal basis
Limited knowledge about time of pests and disease occurance	Affects the quality and yield, make farmer to grow maximum fetching less income	Alerts before the likely incidences of pests and diseases to take up precautionary measures	Forecasting time of pest and disease occurrences by taking into account of date of sowing
No information about market prices in the nearest markets at harvesting times	Farmers sell to wholesaler or middlemen, receive lower prices and lesser share in consumer price	Provide market prices for respective crops and markets. Predict price scenarios in different markets and guide	Forecasting current market prices and minimum, maximum and expected market prices for 90 days
Difficulty in selecting appropriate varieties for weather, climate and region suitability	Wrong choice of varieties Inappropriate agronomical practices Low yield High cost Possible pest and disease incidence	Advice farmers on most appropriate varieties Guide farmers on seed rate, method of sowing/planting, and spacing	Recommending suitable varieties/ hybrids, seed rate, method of sowing/planting and spacing
Lack of knowledge about seed treatment practices	Possible early disease incidence Susceptibility to pest attack Poor germination and low population	Advice farmers on the suitable biological/chemicals to be used for seed treatment	Advisory on both biological and chemical methods of seed treatment
Lack of knowledge about nutrient application during crucial stages of the crop growth period	Wrong choice of nutrient sources Excess/under-use of quantity of nutrient High cost due to above Soil and environmental pollution Chances of pest and disease incidence Affects the quality and yield	Guide farmers about nutrient application during critical stages of the crop Right combination and quantity of nutrients required Time and method of application	Information on selection and application of nutrients, fertilizers for specific crop, stage and their quantification based on area
No or less knowledge of causal organism specific pesticide, insecticide, fungicide application	Inappropriate use and inadequate use of chemicals	Guiding farmers on appropriate and adequate use of chemicals	Information on problem specific formulation and application of insecticides, pesticides, fungicides etc.
Lack of knowledge on weed management practices	Increase in weed population Yield reduction High labour cost High chemical cost Alternate hosts for pests and diseases	Advice farmers to take up Best preventive/ pre emergent weed control Post emergent weed control Mechanical practices Cultural practices	Information on selection, quantification and application of weedicides at different intervals
Difficulty in identification of pests and	Wrong selection of control methods	Information on actual pest and diseases, their symptoms,	AI based pest and disease detection from the

diseases in a crop	High cost of production Resistance development Reduction in quality and yield	remedial measures	uploaded pictures of the specimens and advices on their control measures

4.4 Field testing and validation of *Krishidhare*

The accuracy and consistency of expert system were tested at field level. The field validation of pest and disease forecasts revealed varying levels of accuracy across crops. The forecast of rainfall was 92 % accurate. Pest forecasts showed comparatively higher accuracy than disease forecasts, with the highest accuracy observed in pigeonpea pests (100 %) and cotton pests (89 %). Disease forecast accuracy ranged from 50 to 80 per cent, with cotton diseases recording the highest accuracy (80 %).

4.5 Preliminary utilization pattern of *Krishidhare* App

4.5.1 Forecasting

From the figure 7, it can be noticed that majority (73 %) of the farmers accessed *Krishidhare* app for forecasted information regarding weather, market prices, pest and disease incidences. Farmers are able to keep track of market and weather conditions which directly affect the yield and income. *Krishidhare* app forecasts current, minimum, maximum and expected market prices for 90 days. Additionally, it forecasts current, weekly fortnightly, monthly, seasonal weather conditions easing farmers to make decisions in farming during crucial times.

4.5.2 Advisory on agronomical practices

About 8 % of the farmers have utilized the app for advisories on agronomical practices such as seed, weed and nutrient (Fig. 7). Farmers get knowledge about best nutrient, weed, pest and disease management practices due to which quality, quantity of the yield are enhanced at lower management costs. Farmers are provided with information regarding nutrient, weed, pests and disease management and other agronomical practices through *Krishidhare* app.

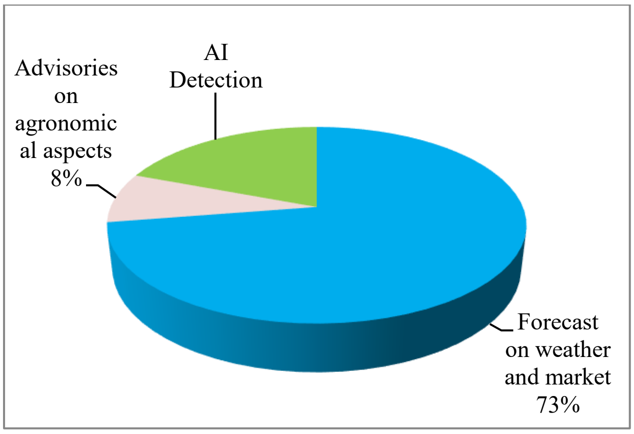

Figure 7. Proportion of farmers using different components of the Mobile-based *KrishiDhare* App

4.5.3 AI application

Pests and diseases can be diagnosed accurately through AI detection along with the recommendations for remedial measures. About 19 % of the farmers have utilized the *Krishidhare* App for accurate diagnosis of the pests and diseases through AI detection from the app. Though farmers have some knowledge about pests and diseases, still face difficulties in accurate identifications in early stages of a standing crop. This has impacted their yield and income, by minimizing the loss and expenditure on pesticides and chemicals.

5. CONCLUSIONS

Review of research work done in the last decade on decision support systems reveals the dominance of agriculture sector in terms of number of journals and the number of articles published. However, there is a clear shortfall of decision support systems on weather and market prices based applications. The decision support systems in agriculture have infinite relevance because of the unpredictable and erratic weather patterns and highly volatile markets. A successful farmer must be equipped to manage both these limiting factors with well-informed decisions using the DSS proposed to be built on artificial intelligence and machine learning. The secondary data on amount of rainfall and average market prices for the major crops grown revealed that good rainfall and higher prices have rarely occurred together. The current pattern of information accessed on weather and market prices point out the huge scope for mobile based applications for advising farmers based on forecasted weather and market prices information. Majority of farmers continue to depend on conventional media sources and personal experience, while the modern ICT tools and AI based mobile apps remains under-utilized due to lack of awareness among farmers. AI-enabled Krishidhare mobile application addresses the gap by integrating real-time weather forecasting, 90-day price forecasting, and AI-based pest and disease diagnostics. The field level testing confirmed its accuracy in selected pest detection, rainfall and disease forecasting. The positive utilization patterns indicate strong farmer preference for forecast-based modules, while AI-based diagnostics and agronomic advisories show promising but on evolving trends. Exclusive AI-enabled Krishidhare mobile application serves as an effective information delivery tool to combat the uncertain weather conditions, such tools and mechanisms can be used to provide information in other prioritized major crops.

Amidst frequent price fluctuations and pest disease incidences, the mobile application could build the resilience capacity and hence should be upscaled in other major crops and areas. In terms of information delivery to the farmers, considering the shortage of extension personnel trained in market intelligence, pest and disease diagnostic and weather mechanisms, the exclusive mobile application offers a personal guide and as a potential AI- enabled ICT tool in the era of digital dominance.

6. ACKNOWLEDGEMENTS

The work is part of the research project entitled "Development and Demonstration of AI enabled Weather and Market information-based Decision Support System (FARWM-DS) for sustainable farm productivity and profitability and evolve profitable cropping pattern". The research project is financially supported by Indian Council of Agricultural Research (ICAR) - National Agriculture Science Fund (NASF), Government of India for the period 2023 to 2026.

7. REFERENCES

[1] UN DESA. (2021). The Sustainable Development Goals report 2021. United Nations. https://unstats.un.org/sdgs/report/2021/The-Sustainable-Development-Goals-Report-2021.pdf

[2] Deutsch, C. A., Joshua, J. T., Michelle, T., David, D. B., Scott, C. M., Raymond, B. H., & Rosamond, L. N. (2018). Increase in crop losses to insect pests in a warming climate. Science, 361(6405), 916-919.

[3] Kahan, D. (2013) Farm management extension guide – Managing risk in farming. Food and Agriculture Organization of the United Nations. https://www.fao.org/4/i0412e/i0412e.pdf

[4] Arnott, D., Pervan, G., O'Donnel, P., & Dodson. G. (2004). An analysis of decision support systems research: Preliminary results. In Proceedings of IFIP International Conference on Decision Support Systems (DSS2004) (pp. 25-38). Monash University https://www.researchgate.net/publication/228739250

[5] Stockle, C. O., Donatelli, M., & Nelson, R. (2003). CropSyst, a cropping systems simulation model. European Journal of Agronomy, 18, 289-307.

[6] Ganesan, V. (2007). Decision support system "Crop-9-DSS" for identified crops. International Journal of Computer Systems Engineering, 1(12), 186-188.

[7] Thorp, K. R., DeJonge, K. C., Kaleita, A. L., Batchelor, W. D., & Paz, J. O. (2008). Methodology for the use of DSSAT models for precision agriculture decision support. Computers and Electronics in Agriculture, 64(2), 276-285.

[8] Arora,V. K., Singh, H., & Singh. B. (2007). Analysing wheat productivity responses to climatic, irrigation and fertilizer-nitrogen regimes in a semi-arid sub-tropical environment using the CERES-Wheat Model. Agricultural Water Management, 94, 22-30.

[9] Sachin, G., Mohammed, A. J., Nagajothi, K., Mamta, R., & Murugan, B. S. (2019). Automation of the DSSAT crop growth simulation model. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 52(3), 251-255.

[10] Keating, B. A., Carberry, B. S., Hammer, G. L., Probert, M. E., Robertson, M. J., & Holzworth, D. (2003). An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy,18, 3-4.

[11] Plant, R. E., Horrocks, R. D., Grimes, D. W., and Zelinski, L. J. (1992). CALEX / Cotton: An integrated expert system application for irrigation scheduling. Journal of Agricultural Engineering Research, 35(6), 1833 –1838.

[12] Singh, R., & Singh, J. (1997). Irrigation planning in wheat (Triticum aestivum) under deep water table conditions through simulation modelling. Agricultural Water Management, 33(1), 19-29.

[13] Singh, A. (2010). Decision support for on-farm water management and long-term agricultural sustainability in a semi-arid region of India. Journal of Hydrology, 391, 63-76.

[14] Thysen, I., & Detlefsen, N. K. (2006). Online decision support for irrigation for farmers. Agricultural Water Management, 86, 269-276.

[15] Richards, Q. D., Bange, M. P., & Johnston, S. B. (2008). HydroLOGIC: An irrigation management system for Australian cotton. Agricultural Systems, 98(1), 40-49.

[16] Steduto, P., Hsiao, T. C., Raes, D., & Fereres, E. (2009). AquaCrop- the FAO crop model to simulate yield response to water: I. Concepts and underlying Principles. Agronomy Journal, 101, 426-437.

[17] Berhane, A., & Kefale, D. (2018). Applications of AquaCrop model for improved field management strategies and climate change impact assessment: A review. Modern Concepts and Development in Agronomy, 3(2), 1-11.

[18] Adeboye, O. B., Schultz, B., Adebayo, A. P., Adekalu, K. O., & Osunbitan, J. A. (2020). Application of the Aquacrop model in decision support for optimization of nitrogen fertilizer and water productivity of soybean. Information Processing in Agriculture, 8, 419-436.

[19] Zhai, Y., Huang, M., Zhu, C., Xu, H., & Zhang, Z. (2022). Evaluation and application of the AquaCrop model in simulating soil salinity and winter wheat yield under saline water irrigation. Agronomy, 12(10), 2313.

[20] Acutis, M., Perego, A., Bernardoni, E., & Rinaldi, M. (2010). AQUATER software as a DSS for irrigation management in semi-arid mediterranean area. Italian Journal of Agronomy, 5(2), 205-216.

[21] Zhang, Y., & Feng, L. (2009). CropIrri: A decision support system for crop irrigation management. In Proceedings of 3rd IFIP TC 12 International Conference on Computer and Computing Technologies in Agriculture (pp. 90-97). https://doi.org/10.1007/978-3-642-12220-0_14

[22] Mannini, P., Genovesi, R., & Letterrio, T. (2013). IRRINET: Large-scale DSS application for on farm irrigation scheduling. Procedia Environmental Sciences, 19, 823-829.

[23] Giusti, E., & Marsili- Libelli, S. (2015). A fuzzy decision support system for irrigation and water conservation in agriculture. Environmental Modelling & Software, 63, 73-86.

[24] Navarro-Hellin, H., Martinez-del-Rincon, J., Domingo-Miguel, R., F., Soto-Valles, F., & Torres-Sanchez, R. (2016). A decision support system for managing irrigation in agriculture. Computers and Electronics in Agriculture, 124, 121-131.

[25] Li, H., Li, J., Shen, Y., Zhang, X., & Lei, Y. (2018). Web-based irrigation decision support system with limited inputs for farmers. Agricultural Water Management, 210, 279-285.

[26] Todorovic, N., Ivkovic, V., Kordic, S., Dimitrieski, V., & Lukovic, I. (2018). IrrigDSS- Decision support system for irrigation scheduling. https://www.researchgate.net/publication/342053288

[27] Li, F. Y., Johnstone, P. R., Pearson, A., Fletcher, A., Jamieson, P. D., Brown, H. E., & Zyskowski, R. F. (2009). AmaizeN: A decision support system for optimizing

nitrogen management of maize. NJAS-Wageningen Journal of Life Sciences, 57, 93-100.

[28] Tilva, V., Bhatt, C., & Patel, J. (2013). Weather based plant diseases forecasting using fuzzy logic. In Proceedings of the *Nirma University International Conference on Engineering (NUiCONE)* (pp. 1-5). https://doi: 10.1109/NUiCONE.2013.6780173

[29] Lazaro, E., Makowski, D., & Vincent, A. (2021). Decision support systems halve fungicide use compared to calendar-based strategies without increasing disease risk. Communications Earth & Environment, 2(224), 1-10.

[30] Jakubowska, M., Tratwal, A., & Kachel, M. (2023). The weather as an indicator for decision making support systems regarding the control of cutworms in beets and cereal leaf beetles in cereals and their adoption in farming practice. Agronomy, 13(3), 786.

[31] Rydahl, P. (2003). A web-based decision support system for integrated management of weeds in cereals and sugarbeet. EPPO Bulletin, 33, 455–460. https://doi.org/10.1111/j.1365-2338.2003.00679.x

[32] Ayubu, J. C., Miozi, M. R. S., Mahoo, F., Siza, D. T., & Respickius, C. (2013). A decision support system for enhancing crop productivity of smallholder farmers in semi-arid agriculture. International Journal of ICT Research, 3(8), 238-248.

[33] Alugubelly, M., Reddy, P. K., Gade, S., & Ninomiya, S. (2019). Analysis of similar weather conditions to improve reuse in weather-based decision support systems. Computers and Electronics in Agriculture, 157, 54-165.

[34] Hayashi, K., Lorca, L. P., Bugayoung, I. D., Agustiani, N., & Capistrano, A. O. V. (2021). Evaluating the predictive accuracy of the weather rice nutrient integrated decision support system (WeRise) to improve rainfed rice productivity in Southeast Asia. Agriculture, 11(4), 346.

[35] Singh, K. K., Ghosh, K., Bhan, S. C., Priyanka, S., Latha, V., Balasubramanian, R., Attri, S. D., Goroshi, S., & Singh, R. (2023). Decision support system for digitally climate-informed services to farmers in India. Journal of Agrometeorology, 25(2), 205-214.

[36] Doorenbos, J. & Kassam, A. H. (1979). Yield Response to Water (FAO Irrigation and Drainage Paper No. 33). FAO.

[37] Damos, P., & Karabatakis, P. (2013). Real time pest modelling through the World Wide Web: Decision making from theory to praxis. IOBC-WPRS Bulletin, 91, 253-258.

[38] Lacoste, M., & Powles, S. (2015). RIM: Anatomy of a weed management decision support system for adaptation and wider application. Weed Science, 63, 676-689.

[39] Deogun, S. J. (1988). A conceptual approach to decision support system models. Information Processing & Management, 24(4), 429-448.

[40] Meshram, C. S., Gawade, D. A., & Ingole, R. K. (2017). Provising revolution with decision support systems in agriculture. International Journal of Advanced Research in Computer Science and Management Studies, 5, 50-55.

[41] Kaur, G., Sunesh, Sarita, & Balhara, A. K. (2022). Role of decision support system in agriculture. Vigyan Varta, 3(6), 86-88.

[42] Abebe, G. K., Bijman, J., Pascucci, S., & Omta, O. (2013). Adoption of improved potato varieties in Ethiopia: The role of agricultural knowledge and innovation system and smallholder farmers' quality assessment. Agricultural Systems, 122, 22–32.

[43] Khan, G. A., Muhammad, S., Chaudhry, K. M., & Khan, M. A. (2010). Present status and future preferences of electronic media as agricultural information sources by the farmers. Pakistan Journal of Agricultural Sciences, 47(2), 166-172.

[44] Jafri, M. N., Khan, G. A., Muhammad, S., Munir, H., Iftikhar, M., & Ashraf, S. (2014). TV as diversified agricultural information source perceived by farmers: Issues and concerns. International Journal of Agricultural Extension, 2(3), 235-241.

[45] Hasan, M., Ito, M., & Ahmed, A. (2016). Dissemination of personalized agricultural knowledge for farmers in Bangladesh. International Journal for Innovative Research and Development, 5(3), 65-69.

[46] Kolawole, O. D., Piotr, W., Barbara, N., & Gagoitseope, M. (2014). Ethno-Meteorology and scientific weather forecasting: Small farmers and scientists' perspectives on climate variability in the Okavango Delta, Botswana. Climate Risk Management, 4(5), 43-58.

[47] Guido, Z., Zimmer, A., Lopus, S., Hannah, C., Gower, D., Waldman, K., Krell, N., Sheffield, J., Caylor, K., & Evans, T. (2020). Farmer forecasts: Impacts of seasonal rainfall expectations on agricultural decision-making in Sub-Saharan Africa. Climate Risk Management, 30, 100247.

[48] Mahendrakumar, S., & Mamatha, M. S. (2012). Market information system of agriculture in Karnataka: An empirical study in APMC of Mysore District. Economics, 2(10), 1-3.

[49] Haile, M. G., Kalkuhl, M., & Usman, M. A. (2015). Market information and smallholder farmer price expectation. African Journal of Agricultural Resource and Economics, 10(4), 297-311.

[50] Sain, V., Kundu, K. K., & Mehta, V. P. (2017). Dissemination and utilization of market information system by farmers for gram crop in Bhiwani district of Haryana, India. International Journal of current Microbiology and Applied Sciences, 6(4), 58-65.

[51] Nakasone, E. (2013). The role of price information in agricultural markets: Experimental evidence from rural Peru. Paper presented at the Agricultural & Applied Economics Association 2013 Annual Meeting. https://hdl.handle.net/10568/152811