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DECISION SUPPORT SYSTEMS IN A GLOBAL AGRICULTURAL PERSPECTIVE - A COMPREHENSIVE REVIEW

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Abstract- In global agricultural, decision making at all levels are increasing rapidly due to unreliable and uneven distribution of combined experience of complex processes associated with the food production. Besides flaws in human initiative judgement have far-reaching consequences for the sustainable agriculture development. Therefore, aiding the reliability and deficiencies of human judgement and quality decision-making has been a major focus of research throughout the history particularly with the development of Decision Support Systems (DSSs). DSS is interactive computer-based system that help decision makers solve unstructured problems under complex and uncertain conditions by providing access to data through procedures and analytical reasoning. These systems have been designed to address complex tasks involving multiple disciplines of agriculture, enabling us to mimic the necessary requirements of crop with respect to the land characteristics so that the optimum objectives specified by the user is obtained. Experimental use of these systems has resulted in improved integrated crop production and management with restricted use of the natural resources together with improved farm income and reduced negative environmental impact. With the advent of powerful computation, efficient database management system, on-line analytical processing (OLAP), improved knowledge representation, efficient searching techniques, data warehousing and mining, Geographical Information System (GIS) and Remote Sensing (RS); DSS are being extensively used world-wide using state of art technologies, integrating multiple models for sustainable agriculture development from farm to fork, despite "Problem of Implementation". Once the barrier is crossed, it will give a leading role to DSS in global sustainable agriculture.

Keywords- Decision Support System, Sustainable Agriculture, Crop modelling, Management Information systems, Agricultural Systems Research, Integrated pollution control, Land use planning, knowledge representation and searching

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Introduction

Agriculture is considered as a complex process of air, water, weather, soil, plant, animal, micro-organism, which are again unreliable and uneven in distribution, covering many disciplines and interacting at various scales [1, 2]. In order to manage different crops one has to generate alternatives to make choice, supported by estimation, evaluation and/or comparison. There is a substantial amount of empirical evidence that human initiative judgment and decision making can be far from optimal and it deteriorates further with added complexity and stress [3]. Also decisions made by the farm managers are irreversible and have far-reaching consequences for the crop being managed [4]. Therefore, aiding the deficiencies of human judgement and quality decision making has been a major focus of research to develop less intensive and integrated farming systems with lower inputs of fertilizers and pesticides and with restricted use of the natural resources (water, soil, energy, etc.) with the broader objective to maintain crop production in both quantitative and qualitative terms, maintain or preferably improve farm income, and at the same time reduce negative environmental impacts as much as possible[5].

For making rational decisions, disciplines such as statistics, economics and operational research have developed various methods, which have recently been enhanced by various techniques originating from Information Science, Cognitive Science, Artificial Intelligence and Pattern recognition. These methods have been implemented in the form of computer programs either as stand-alone system or complex computing environments for complex decision making using common name of decision support systems (DSSs).

Regarded as response to complexity, Decision Support System (DSS) is an interactive computer-based system or subsystem intended to help decision makers to use information and communication technologies, data, knowledge and/or models to facilitate formal and informal communication, mining knowledge, and building knowledge repositories [6]. DSS improves personal efficiency; speed up the process of decision making; increases organizational setup and control; encourages exploration and discovery of unknown data; speeds up problem solving capabilities; facilitates interpersonal communication; promotes learning and training abilities, provides new evidences in support of a decision and reveals new approaches to think about the problem more specifically through automation of managerial process.

DSSs are used by an organization or group of users to support and enhance decision making [7] when faced with ill-structured situations [8,9] for instance in natural resource issues [10-13]. They can assist in making better decisions by integrating information into a more useable form. They alter production systems, enhances management skills and reduces cost of production by applying modelling, hypothesis and optimization techniques. The current DSS industry is one of the most buoyant areas of investment despite the IT downturn of the early to mid 2000s. Recently, many attempts have been made at building decision support systems by employing mathematical models and databases [14].

Global agriculture has seen an increasing interest in the potential use of DSSs in recent years. The application of these systems to agriculture seems natural considering widespread use of extension agents in and out of the field. Status of soil, selection and yield characteristics of a variety, likely interaction between the field and variety, disease presence in the area, yield, weather conditions, current market and prices and related information have become important. For crop production, DSSs provides hypothetical environment for researchers to integrate all possible information from different sources to recommend the most appropriate action or choices [15]. Expert knowledge, management models and timely data are key elements of DSS and are used to assist producers with both daily operational and long-range strategic farm decisions [16].

Use of DSS in agriculture for providing information and recommendation on efficient utilization of fertilizer [17], reducing herbicide use [18], plant protection [19], variety-specific information [20], management of environment risks [21], Integrated Nutrient Management [22], Forest Management [23], Crop disease control [24], Agricultural practices and extension [25], Farm mechanization [26], Seasonal Climate Prediction[27], Integrated Pollution Control [28], labour requirements and land use planning [29], profit maximization and risk minimization [30] etc., have been designed and implemented successfully mainly for improving economic returns, changing farming practices or minimizing environmental risks. Developments in climate downscaling have helped to bridge the spatial and temporal resolution gaps between what climate modellers are currently able to provide and what impact assessors require [31]. In addition, tools that integrate climate and plant growth modeling will continue to be developed to help assess future impacts and adaptation options [32,33]. Future climate-related DSS are therefore likely to provide information on the current farming season, and potential changes in climate and farming risks for future seasons

Advancement in hardware and mathematical modelling, artificial intelligence techniques, data warehousing and mining, OLAP (examines and manipulates large amounts of detailed and consolidated data interactively in real time with rapid response from many perspectives), enterprise resource planning (ERP) systems, intelligent agents are adding new capabilities to agricultural DSS research and development. Moreover, the space technologies such as Remote Sensing (RS), Geographical Information System (GIS) are also providing support to agricultural DSS. Furthermore, with the rapid development of internet/intranet technology, Web technology is growing up to a new branch in the development of Automated Decision Support System or ADSS opening new opportunities for DSS design and implementation [34].

This paper chronicles basic concept of DSSs, their characteristics, capabilities, architecture, classification and applications in global agricultural perspective. Further it provides knowledge representation, searching mechanism, issues and future projections.

What are Decision Support Systems?

Decision Support System (DSS) has been used and defined in various ways depending upon the author's point of view [9, 35, 36] defines it as "useful and inclusive term for many types of information systems that support decision making". For [37], it is "a computer-based system that aids the decision making process". [38] has defined it specifically as "an interactive, flexible, and adaptable computer based information system, especially developed for supporting the solution of a non-structured management problem for improved decision making". [39] define DSS as "model-based set of procedures for processing data and judgments to assist a manager in decision-making". [40] Define DSS as "Computer-based support for management decision making". [41] define it as "extensible systems capable of supporting adhoc data analysis and decision modelling, used in future planning". [8] described DSS as "interactive Computer-based systems that help decision makers to solve unstructured problems using data and/or models". [42] is not of the opinion to give DSS a precise definition. For him "there can be no definition of DSS". He further adds that DSSs have typically quantitative output and place emphasis on the end-user for final problem solution. Often ES is developed around very specific and highly detailed "Domains" and thus tends to be narrow in their range of knowledge [43]. In order to avoid exclusion of any of the existing types of DSSs, we define them roughly as interactive computer based systems that aid in making a quality decision.

Characteristics and Capabilities

- Decision Support System comprises of vast set of characteristics and capabilities of DSS. The key characteristics and capabilities of DSS as reported by [38] are as follows:
- Ability to support in semi-structured and unstructured problems, including human judgment and computerized information.
- Ability to support managers at all levels.
- Ability to support individuals and groups.
- Ability to present knowledge on ad hoc basic in customized way.
- Ability to select any desired subset of stored knowledge for presentation or derivation during problem solving.
- Ability to support for interdependent or sequential decisions.
- Ability to support intelligence, design, choice and implementation. viii. Ability to support variety of decision processes and styles.
- Ability to support modelling and analysis.
- Ability to support data access.
- Benefits must exceed cost.
- Allow modification to suit needs of user & changing environment.
- Support quick decision-making using standalone, integration or web-based fashion DSSs having maximum number of these key characteristics and capabilities can be more useful and adoptable.

Major Fields of DSS

- **Personal Decision Support Systems (PDSS):** usually small-scale systems that are developed for specified managers;
- **Group Support Systems (GSS):** they use combination of DSS technologies to facilitate the effective decision process;
- **Negotiation Support Systems (NSS):** Here primary focus remains on negotiation between opposite perceptions;
- **Intelligent Decision Support Systems (IDSS):** It uses artificial intelligence techniques to facilitate decision;
- **Knowledge Management-Based DSS (KMDSS):** They provide knowledge storage, retrieval, transfer using organizational memory and inter-group knowledge access;
- **Data Warehousing (DW):** systems that provides the large-scale data infrastructure in multiple formats for decision support;
- **Enterprise Reporting and Analysis Systems:** enterprise focused DSS including executive information systems (EIS), business intelligence (BI), and corporate performance management systems (CPM). BI tools access and analyze data warehouse information using business intelligence software, query and analysis tools [44].

Classification of Decision Support Systems

There is no universally accepted taxonomy of DSSs, as different authors propose different classifications [Table-1]. However, important types of Decision Support Systems are:

- **A Model-driven DSS:** Model-driven DSS provides access to and manipulation of various underlying models by using data and parameters provided by users to assist decision making process. Dicodess[45] is an example of an open source model-driven DSS generator.
- **A Communication-driven DSS** allows more than one person to work on a one task. Microsoft's NetMeeting or Groove [46] is an example of communication driven DSS.
- **A Data-driven DSS or data-oriented DSS** emphasizes access to and manipulation of internal or external data. Example of such DSS is OLAP [47].
- **A Document-driven DSS** utilizes unstructured information in a variety of electronic formats for manipulation, retrieval and management ; example includes Google Search Engine.
- **A Knowledge-driven DSS** stores facts, rules, procedures and structures for expertise problem solving purposes. Mycin [48] is an example of knowledge driven DSS.

Table 1- Classification of Decision Support Systems given by different authors

Author	Classification	Features	Example	Criterion
Bhargava & Power [62]	Model-driven DSS	Emphasizes on access to and manipulation of statistical, financial, optimization or simulations model.	Dicodess [45]; production planning management Decision Support[49].	Mode of assistance
	Communication- driven DSS	Emphasizes communications, collaboration, and shared decision making support.	Microsoft's Net Meeting or Groove [46]; Basic Group Decision Support System [50].	
	Data-driven DSS	Emphasizes on access to and manipulation of time series data.	Data Driven DSS with OLAP [47].	
	Document-driven DSS	Manages, retrieves and manipulates unstructured information in a variety of electronic formats	Search engine [9]; On-line Analytical Processing [47].	
	Knowledge-driven DSS	Specialized problem solving expertise stores as facts, rules, procedures etc.	MYCIN [48]; EXSYS [51]; DENDRAL.	
Power [58]	Enterprise-wide DSS	Linked with large data warehouse, which serves many managers	Web-based DSS [52].	Scope
	Desktop DSS	Single user, small system that runs on managers Personal Computer	Visible calculator	
Haettenschwiler [59]	Active DSS	It aids the process of decision without bringing out explicit suggestions or solutions	Walmart	User relationship
	Passive DSS	Brings out explicit suggestions as Well	Exsys[53]	
	Cooperative DSS	modifies, completes or refines the decision suggFestions	Co-op [41]	
Holsapple & Whinston [60]	Text-oriented DSS	Works on text as input	Management, planning and control[54]	Type of Inputs used for decision making
	Database oriented DSS	Has a database in the back end for Inputs	ONVAREF[2]	
	Spread sheet oriented DSS	Uses spread sheet as inputs e.g. Excel	Optimization solver add-in for Microsoft Excel	
	Solver Oriented DSS	Mainly designed for solving problems. e.g. Linear Equations	Brandaid [55]	
	Rule oriented DSS	Uses inputs in the form of rules based on reasoning	NuMaSS[56]	
	Component Oriented DSS	Hybrid System that includes two or more of basic five structures described by Holsapple & whinston, 1996	GRAM++[57]	
Hackathorn & Keen [61]	Personal Support	Supports only one user	ONVAREF[2]	Scope
	Group Support	Supports group of user	Mindsight; Group Systems ; SAMM; PLEXSYS	
	Organizational Support	Supports an organization as a Whole	EXPRESS	

Components of DSS

Like classification, different authors have identified different components in a DSS and have proposed different architecture [Table-2]. Every DSS does not fits neatly into one category, but a mix of two or more architectures. The most general architecture of DSS can be divided into four subsystems viz., Database Management Subsystem, Knowledge-based Management Subsystem, User Interface subsystem and the User. Now-a-days as most of the data comes from external sources such as weather, satellite etc., and separate subsystems are used for model representation and transaction processing so the typical architecture of the DSS can be divided in to six subsystems viz., data management subsystem, model management subsystem, knowledge engine, the user interface, DSS architecture and network and the user [Fig-1].

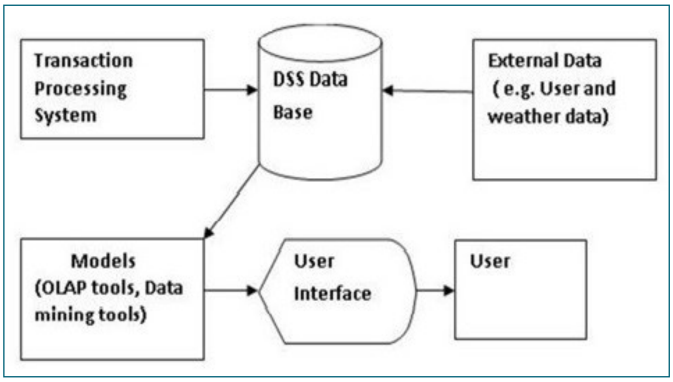

Fig. 1- Typical architecture of DSS

Table 2- Architectural components of DSS given by different authors

Author	Architectural Component	Description of component
Sprague & Carlson [63]	Database Management System (DBMS) Model Base Management system (MBMS) Dialog generation and management system	Stores information Integrates models Provides user interfaces to manage system
Haag et. al. [64]	Same as above but describes them in detail	Stores information (that can be further sub divided into organizations traditional data repository, form external source such as internet or from experience of individual user Using various kinds of models it, handles representation of events, facts, or situations. Integrates models and provides user interface. Participates different roles or functions in the data management process
Haettenschwiler [59]	User Decision context Target system Knowledge base	Specifically defined decision rules Describes majority of the preferences External data sources, knowledge databases, working databases, data warehouse, metadata bases, models, methods, integrates search engines to responding system
Marakas [65]	Database Management System Memory Management System Knowledge Engine User Interface User	Stores, manages and provides access to the data Organizes memory efficiently Inference procedure or control structure for utilizing the knowledge Allows user to interact with the system One who uses the system
Power [9]	The user interactive The database interactive The model and analytical tool The DSS architect and network	Interacts with the user over a command line Interacts with a single or a group of users using a database for heuristics Model designed for analysis Interacts with the other DSS or database server.

Knowledge Representation in DSS

Agricultural based DSS primarily represents knowledge in three broad categories viz., rules based, semantic networks and frames, depending on the type of DSS and domain for which it is designed.

Rule based knowledge representation are used for correlation of simple facts with a decision. The principle of rules is based on the correlation of one or more with one or more results that are activated or considered as true, when all treaties are true. Rules are constructed from a sequence of “if then” statements illustrated as follows:

Rule 1: *If* temperature is above 300 and relative humidity is between 50-70 and month is September

Then it is likely to spray Nuvan for stem borer

Rule 2: *If* temperature is above 300 and relative humidity is between 50-70 and month is August

Then it is likely to spray Kohiban for Leaf Hoper

The Semantic Networks

Often used as a form of knowledge representation, a semantic network represents semantics relations between concepts. It is a directed or undirected graph consisting of vertices, which represent concepts and edges. Representation of knowledge in Semantic Network [Fig-2].

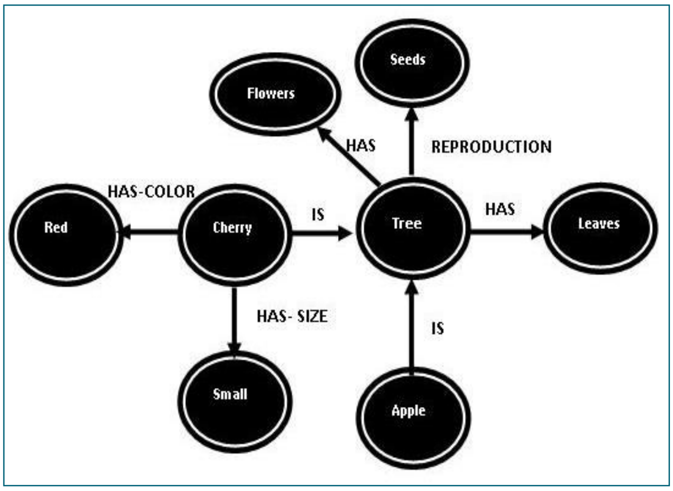

Fig. 2- Representation of a Semantic Network

Representation of Semantic Network in Lisp language

(defun *database* () ((apple (is-a tree)

(has flowers) (size big))

(cherry (is-a fruit) (color red))

(tree (is-a big plant) (has-part leaves) (reproduction by-seeds))))

The Frames

A frame contains information that accompanies an object. That information contains values or indicators to different frames or rules or processes, from where the values correspond to information and relevant with the object are drawn, is placed in slot. The frame contains information on how to use the information contained frame, next possibilities and course of action when desired expectations are not met. Some information in the frame is generally does not change in contrary within terminals. Different frames may share the same terminals. Simple structure of a frame is given in [Table-3].

Each piece of information about a particular frame is held in a slot. The information contains:

Facts or Data

Values (called facets)

Procedures (also called procedural attachments)

IF-NEEDED : deferred evaluation

IF-ADDED : updates linked information

Default Values

For Data

For Procedures

Other Frames or Subframes

Searching Strategies in DSS

Searching through huge networks, decision-trees and data bases is mostly used for document driven DSS in which unstructured information in a variety of electronic formats is retrieved, manipulated and managed. Some important search strategies used in agricultural DSS aids are explained as under:

Depth-first Search: The search backtracks and tries another path from B. A Depth-first strategy probes a knowledge-tree or a decision -tree by asking the detailed questions first in a limb of the tree (top downward) as the first path through the tree. In other words it explores a path all the way to a leaf before backtracking and exploring another path. For example, after searching parent node A it probes left siblings and goes deeper and deeper till the leaf node is encountered. Node are explored in the order A B D E H L M N I O P C F G J K Q. N will be found before J [Fig-3](a).

Breadth-first Search: A Breadth-first strategy, in contrast, searches all nodes at the same depth and then proceeds to the next lower level of nodes. In other words it explores nodes nearest the root before exploring nodes further away. For example, after searching parent node the search probes all the nodes at one level before shifting to another level. Nodes are explored in the order A B C D E F G H I J K L M N O [Fig-3](b).

The Best-first Search: It combines best features of the Depth-first and the Breadth-first strategy. A heuristic, or specific knowledge, guides the search to choose either a Depth-first or a Breadth-first strategy at any particular node, depending on the knowledge. In other words it explores a tree by expanding the most promising node chosen according to a specified rule [Fig-3](c).

Table 3- Structure of a frame

Slot	Value	Type
BOY	_	(This Frame)
ISA	Person	(parent frame)
SEX	Male	(instance value)
AGE	Under 12 yrs.	(procedural attachment - sets constraint)
HOME	A Place	(frame)
NUM_LEGS	Default = 2	(default, inherited from Person frame)

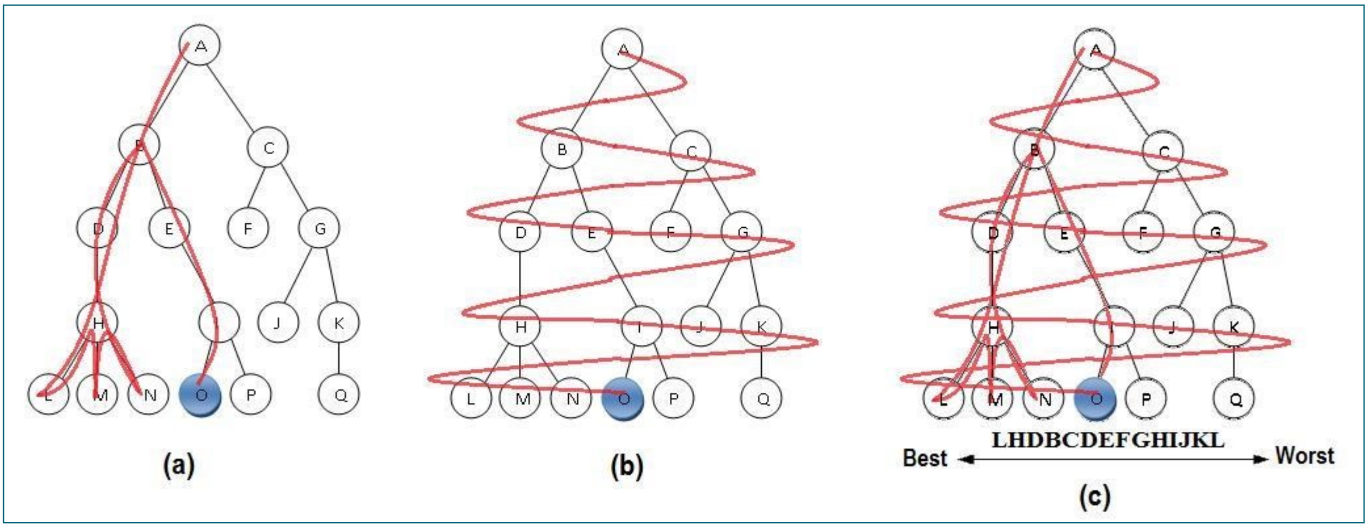

Fig. 3- Decision trees illustrating depth first, breadth first and best first searching

Decision Support Systems in Global Agricultural Perspective

Major DSS Projects

For global sustainable agriculture, pre-requisition is to maintain crop production in both quantitative and qualitative terms, maintain or preferably improve farm income, and at the same time reduce negative environmental impacts as much as possible [66,67]. DSS have proved to be an effective tool in this direction by development of Integrated Production [68] and Integrated Farming (IF) [69], which have been developed as holistic concepts that involve all crop and farming activities and shape these activities according to the individual site and farm. Globally large scale multipurpose projects on agricultural DSS have been successfully developed, covering diverse fields, incorporating different specialty to highest ever precision.

During 2002-10, Thailand and Cambodia have created a TRF-DSS research and development network, which consists of 59 research projects, involving 12 universities, two line agencies in Thailand, and one line agency in Cambodia. More than 20 DSS tools were developed and implemented for variety of users engaged in short and long-term planning and management. Most of these tools were designed to integrate biophysical and socioeconomic data as well as the decision support modules for alternatives evaluation and analysis; supporting dynamic simulation and multi-criteria analyses for model base software development to allow users evaluate various alternatives in agricultural and natural resource management [70].

The University of Tokyo in collaboration with National Agriculture and Food Research Organization, National Institute of Agro-Environmental Sciences Ishikawa, Prefectural University, Toyama Prefecture and Fukui Prefecture have developed decision support system for optimal agricultural production under global environment changes. It contains crop growth models for rice, wheat and barley; soil and water models for local water resource and whether models for locally useful high resolution data [4].

University of Stirling, UK has developed a user friendly PC-based expert system/decision support system CeserDSS for countermeasure implementation in agricultural food production systems in Scotland. It is regarded as a decision-aiding tool in the planning of long-term remediation at the level of a farm or small agricultural area [71].

In United States, the USDA-ARS Agricultural Systems Research Unit (ASRU), in collaborative effort with Colorado State University (CSU), developed the Great Plains Framework for Agricultural Resource Management (GPFARM) DSS. The general purpose of GPFARM is to serve as a whole-farm/ranch DSS for strategic agro-ecosystem sustainability evaluation across the U.S. Great Plains. The GPFARM DSS is primarily composed of six major components: 1) a Microsoft® Windows-based graphical user interface; 2) Microsoft® Access databases containing soil, crop, weed, climate, equipment, chemical, and economic parameters; 3) an object oriented modelling framework and science simulation model; 4) a stand-alone economic analysis tool; 5) a set of analysis tools, multi-criteria decision support system, an output visualization module and summary report tables and graphs; and 6) a web-based information system. Thus, GPFARM is unique in that it brings together the above suite of decision support tools integrated across a whole-farm/ranch system [72].

Also University of Nabaraska has developed GreenLeaf Project (Google-like Infrastructure for Climate Data), which is a revolutionary collection of decision-support tools and methodologies linked to provide dramatically new and unique views of the data critical to supporting producers, decision markers and researchers in analyzing climate -associated risk events and mitigating their effects. Recently The U.S. Department of Agriculture (USDA) and the National Aeronautics and Space Administration (NASA) signed a Memorandum of Understanding (MOU) to strengthen future collaboration to assimilate NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) data and products into an existing decision support system (DSS) operated by the International Production Assessment Division (IPAD). Integration of MODIS data and derived products into the IPAD, DSS provides better characterization of land surface conditions at the regional scale and enables monitoring of changes in the key agricultural areas in a more timely fashion and at a higher resolution.

In Kenya, the Regional Centre for Mapping of Resources for Development (RCMRD) in collaboration with European and African partners developed a decision support system (DSS) for sustainable development of dry lands in three countries of eastern Africa (Ethiopia, Kenya and Tanzania). In this endeavour, GIS modelling was used to support decision-making on agricultural product development and distribution, natural resource management, environmental rehabilitation, and institutionalization of indigenous environmental knowledge [73].

India under National Agricultural Innovative Projects (NAIP) is working on Precision Farming Technologies based on Microprocessor and Decision Support Systems for Enhancing Input Application Efficiency in Production Agriculture with the aim to develop sensor-based systems for assessing spatial and temporal variability of soil, moisture, crop and weed parameters and creating databases by adapting available components; precision applicators for seed, fertilizers, herbicides and water to address site-specific variability; and integrate variable rate input application technology with the available decision support systems (DSS) for higher use efficiency.

Australian agricultural has great experience with using DSS for Agriculture, which assist farmers with information and procedures to management decisions with regard to crop forecasting and management (*Whopper Cropper; Yield Prophet*), livestock production and management (*GrazFeed*), pasture growth and management(*GRASP, GrassGro*); weather and climate forecasting (*Rainfall Reliability Wizard; Water and the Land*), crop growth, irrigation and nutrient management[11,74,29]. CottonLOGIC DSS is considered to have influenced the adoption of sustainable farming systems in the cotton industry [75].

Recently Australian National University Fenner School of Environment and Society has developed EXCLAIM2 -A tool for assessing climate change impacts on natural resources at a regional scale. It contains underlying models that links climate, hydrology and ecology to predict the impacts to ecological health. It helps to explore plausible scenarios of climate change and helps to explore how plausible climates scenarios impact on: hydrology –river flow, water allocation; water quality –turbidity, nutrients, algal blooms; ecological health –habitat conditions for vegetation and water birds [76].

Area Specific DSS

Nutrient Management

Fertilizers and lime are increasingly expensive but are commonly needed to grow high-yielding and good-quality crops. However, unnecessary use is wasteful, reduces farm profits and increases the risk of diffuse nutrient pollution. To maximize profits and avoid waste, farmers need to plan their use of nutrients for each field crop in each year. Organic manures (farmyard manure, sewage sludge, slurries, etc.) contain large quantities of nutrients which can often mean that large reductions are possible in the need for inorganic fertilizers. Nutrient management can play an important role in many of the regulatory and non-regulatory duties of farm-related management, and can protect, restore and enhance the status and diversity of all surface water ecosystems and ensure the progressive reduction of groundwater pollution.

For Nutrient management, different DSSs have been designed to recommend site-specific and need-based parameters that result in an optimized fertilizer management strategy. One example of such system is CERES, which simulates the whole soil crop system [77]. Another example is rice fertility DSS, which provides recommendation on efficient utilization of fertilizer for the production of flooded rice in Arkansas [17]. A DSS for reduction in potential nitrogen (N) losses to the environment has been developed, which saves fertilizer expenditure [78]. There is an ongoing trend to develop Nutrition Management Decision support tools to make them available to the farmers through World Wide Web. These facilities are enabling farmers to use the service of these tools irrespective of computer owner-ship, which is being reported as one of the reason for low adaptation of DSS among farmers. Haifa Nutri-Net is an example of such system [79]. It is a comprehensive crop Nutrition DSS, operated over the web, assisting growers to formulate their crop nutrition programs and irrigation schemes by integrating virtually all relevant cultivation parameters. It is based on comprehensive databases of crop nutrition, irrigation, soil and climate, covering all most every growth environment. FarmN is another web based DSS providing INM recommendations [80].

Most of the existing DSSs are based on very specific aspects, for example, Nutrient management. One system that addresses all the major manure management systems has been identified [81]. DSS for Planning Land Applications of Nutrients for Efficiency and the Environment (PLANET)[82], provides best management practice tool for farmers and their advisors to adopt in the use of organic manure and fertilizers. Fertilizer recommendations for field are calculated based on the precious cropping fertilizer and organic manure application. To encourage maximum uptake of DSS by the farming community, the logic to generate fertilizer recommendations based on input data was developed and made available to commercial agriculture software developers for integration within their systems, which are being widely used by farmers. In India number of DSS have been designed mainly for nutrient and micronutrient management in field crops [83-86].

Insect and Pest Management

Plant protection is definable as the reasoned application of different methods, products as well as chemicals to allow optimal productive factors, with the objective to satisfy farm worker, consumer and safeguard environment. The concept of computerized DSSs for pest management is not new. DSS models have been developed for diseases that could expand very rapidly or those that should be controlled regularly. Development of weather-related DSS during 1990s resulted in a lower risk of crop damage by diseases and pests and minimal use of other input dosage [87]. [88] Reported 67 different DSSs for plant protection. Out of these, 30 deal with insect pest problems, 20 with plant disease and 17 with weeds. Most of the use systems have been developed in North America, particularly United States. [89] reported DSS for pesticide use management. For detection and tackling of air-borne herbicides, a DSS has been reported by [90]. Another model known as CLIMEX is used in 20 countries to examine the distribution of insect, plants, pathogens and vertebrates. It was developed by CSIRO Entomology in 1985 and has had numerous applications under practical conditions [91]. An insect pest forecasting tool, known as *SOPRA*, has been developed with the objective of optimizing timing of monitoring, management and control measures related to fruit orchards in Switzerland [92]. It uses local weather data, and simulates the age structure of the pest populations and crucial events for management activities are provided. Growers in alpine valleys and north of Alps can use it for decision support for the eight major insects and pests of fruit orchards.

In Europe, numerous DSSs exist to predict appropriate pesticide application times for various crops including potato. Of these, the most common are *Negfry, Prophy, Plant Plus* and *Simphyt,* which mainly focus on reducing fungicide inputs [93]. These four late-blight advice systems have the advantage of being in direct competition with each other, resulting to be useful for farmers. The Thematic Strategy on the Sustainable Use of Pesticides adopted in 2006 by the European Commission aims to establish minimum rules for the use of pesticides in the Community so as to reduce risks to human health and the environment from the use of pesticides. IPM creates synergies by integrating complementary methods drawing from a diverse approaches including biocontrol agents, plant genetics, biotechnologies, cultural and mechanical methods and information technologies, together with some pesticides that are still needed to control the most problematic pests and to manage critical situations [5].

Agricultural Land Use and Planning

With the rise in human population and their aspirations, land becomes an increasingly scarce resource – a scenario calling for land use planning. Land use planning is defined as a systematic assessment of land and water potential, alternative land use choices for better economic and social conditions. It has become essential to mitigate the negative effects of land use and to enhance the efficient use of resource with minimal impact on future generations. Land use planning is becoming complex and multidisciplinary as planners face multiple problems that need to be addressed within a single planning framework. These includes non-point-source deforestation, urbanization, pollution, ecosystem deterioration, water allocation, global warming, poverty and employment, deterioration of farmland and low economic growth. For land use planning it is increasingly necessary to recognize the complex tradeoffs between the multiple objectives of stakeholders. This is particularly apparent where outcomes of scales above the land management unit are considered important (e.g. water quality, biodiversity and land use planning). Many different DSS tools for land use related decision-making have been designed for agricultural planning [94], sustainable watershed management [95], forest planning [23], environmental planning [2], site selection [96], species protection plans [97] and conservation preserves planning [98]. A conceptual framework and a spatial DSS for rural land use planning have been developed for supporting decision making on selected area for different watershed management schemes for conservation planning [99]. The system provides suggestions and warnings for land use.

Linear programming approach based decision support have been employed variously covering wide range of including land use planning. The first linear programming models applied to land use planning were single objective problems [100,101]. However, because of the complexity of agricultural planning, multi-objective models are becoming increasingly more common. Within these models, goal programming is one of the techniques most frequently applied. [102] developed a goal programming addressing land use and the cropping system, maximization of gross margin and the minimization of risk. [29] reported continuous development of the DSS with multiobjective land use planning tools. Linear Programming model and Goal Programming-based DSS for farm regions in Greece have been designed, having development possibilities of agricultural sector in relation with the agricultural processing industries of the region [96,103-106]. It aims at the development of farm regions through a better utilization of available agricultural resources and agricultural industries.

Trends in modern land use planning increased with involvement of stakeholders in the planning process, which causes the need for interactive programming to exchange information between the decision-maker and the system. Interactive multiple objective learner programming has been successfully applied to agricultural development policy analysis [107], land use strategy evaluation [95] and land resource utilization [108]. DSS for sustainable land use planning to address conservation of land, improving soil quality and fertility, and local water balance with minimization of soil and nutrient translocation into surface water bodies and downstream fields have been designed keeping in view the optimized benefits for farmers as well as for the society [98].

Global Environment Change and Forecasting

Now-a-days global environment change is happening. Human activities related to the production, supply and consumption of food are responsible for changing global climate and giving rise to other globally and locally environment changes [109]. These include a change in fresh water supplies, carbon and nitrogen cycling, biodiversity and land cover and soils [110]. Ever increasing demand for food will further degrade the environment [111] the consequences of these changes must be estimated well in advance to minimize their impact for sustain ability of global agriculture [112]. DSSs for agricultural application of climate forecast can determine where, when and which sections of society are at most risk. They can construct future scenarios from food security point of view and reduce the vulnerability of food systems to Global Environment Change (GEC). Apparently, developed and deployed agricultural DSSs have the capacity to encapsulate scientific, practitioner and stakeholder knowledge and to present the consequences of alternative land use scenarios, to achieve an appropriate balance between economic, social and environmental outcomes [29].

An integrated pollution control DSS has been developed for rapid estimation of the extent and impact of pollution in a given situation [113]. Another model based on geographical information system (GIS), remote sensing and precision agriculture has been developed for Minland East Asia [114]. This model has a value in prioritizing and targeting of agriculture research in developed countries [115]. Decision Support System for Agro-technology Transfer (DSSAT) has been designed to answer "what if" questions frequently asked by policy-makers and farmers concerned with sustaining an economically sound and environmentally safe agriculture [116]. DSS for metrology has been designed by [117], which locates and analyzes historical situations of interest. It is used mostly by agronomists to forecast and provide recommendations to the growers. Climate forecasting based DSS are estimating the potential economic values for farm scale management decisions. They are helping in management and adjustment of different crops between specified regions having different climatic conditions [12]. They are also improving dissemination of grassland technology by predicting impact of climatic risks [118].

Water and Drought Management

Nearly one billion people worldwide are malnourished. The majority of these people live in developing countries, where increasing water scarcity complicates efforts towards food self-sufficiency. Huge amounts of water are needed to produce more food and eradicate hunger among increasing populations [119]. The current limited approaches to increasing demands of water will not be enough to eradicate hunger, especially in areas with growing populations and amidst dry climates in most developing countries. The central issue is how to manage water for all the different functions for which it is needed. With the advent of agronomic models that show how vegetation is likely to respond to climatic stress, with remote sensing to monitor vegetations conditions from airborne and space borne platforms, and with GIS to display spatial and temporal data in more comprehensible ways, it is now feasible to more accurately assess the impacts of drought [120]. Different DSSs have been developed to tackle with the problems related to water and drought management, [121], TEMPEST allows to model water flow both saline and fresh and predict the responses to each facet of the landscape to management [122]. Aussie GRASS, developed by the Queensland Department of Natural Resources, provides timely estimation of the extent of severity of drought [69]. A DSS developed in Vietnam formulates the plans for sustainable watershed management, using a combined approach of linear programming, goal programming and GIS for deriving the sustainable watershed management plan [95].

In Thailand, the collaborative project between the Department of Geography, Faculty of Liberal Arts, Thammasat University, and the Remote Sensing and Geographic Information System field of study at the School of Engineering and Technology, Asian Institute of Technology, aims to assess the effects of climate variability (especially droughts or dry spells) on rice production in rainfed environments and to develop a DSS tool that might help to properly anticipate and adapt farming to maximize agricultural production [70].

Other Applications

TropRice, an integrated rice management system being used by researchers, extension workers and some farmers has been used in Asia for irrigated rice areas [123]. It provides some generic and some site-specific information for rice cultivation. It is currently being used in many countries like China, India, Indonesia, the Philippines, Thailand and Vietnam. It is being translated or localized by national collaborators for local conditions in these countries. Other applications of DSS in agriculture range from conserving soil, local water balance, agronomical practices, canopy management cropping system analysis, and conservation of forest and computer multimedia instruction [98,124,125,126,127,128]. Web- based DSSs are assisting in forest management, resource management, and, agricultural emergency response [57, 129, 23]. DSS for farm mechanization using GIS based on linear programming provides machinery selection and planning to minimize farmer mechanization has been developed by [26]. The system includes the natural factors (climate and soil conditions), plot geographic site and the crop and machinery data. The GIS is part of the system to carry out a spatial analysis of the farm results to make machinery grouping.

Issues

Despite of vast applications of DSS in different areas of agriculture, their acceptability and adoptability has been constantly questioned throughout design, development to implementation, which has limited their application [2,10,11,19,63,91,129]. In other words they are facing problems of 'implementation' issues in comparison with the other DSS e.g., Medical DSS, which have revolutionised healthcare. Most of the researchers have pinpointed DSS issues viz., crisis for professional relevance, failure to support more than the exceptional circumstance, system complexity, user participation, ease of use, low adaptation, failure to show cost-benefits, complexity with user inputs, relationship between developer and user, regret avoidance, distrust for output, lack of field testing, lack of integration among heterogeneous components, success measurements, non-involvement of end user before and after development stages and under-definition of end users [10,130-132]. Evaluation of every DSS at post-implementation stage based on usability, portability, extendability, usefulness, operateability and adoptability investigates beyond user involvement and tends to monitor developed tool besides user [133]. Moreover, design, development and implementation of DSS through participatory approach in recent years has enhanced uptake of DSS in agricultural [134,135].

Future Trends

Researchers are optimistic about the future of DSS. This optimism continues to produce products and contributions to literature. A host of new tools and technologies are adding new capabilities to DSS. They include hardware and mathematical software development, artificial intelligence techniques, data warehousing and mining, OLAP enterprise resource planning, ERP, intelligent agents and World Wide Web (WWW) [136]. Separated from operational databases and optimized for decision support, data warehousing is an integrated, time-variant and non-volatile collection of a relational or multidimensional database (MDDB). It organizes data as an n-dimensional cube so that users deal with multidimensional data views such as crop, region, yield and area, with speedy query response time. Also known as knowledge Data Discovery, Data Mining refers to discovering hidden pattern from data, not known before. It attempts automatic extraction of knowledge from the large databases like data warehouse, spreadsheets, weather observatories, text documents etc.

Intelligent agents research is an emerging interdisciplinary research area involving researches from such fields as ESs, DSS, cognitive science, psychology and databases. Intelligent agent's research has contributed to the emergence of a new generation of active and intelligent DSS. This approach will enable us to integrate simulation models, GIS and multimedia with ESs, giving DSS a dominant role to play in modern agriculture. Development of domain-specific tasks will help in knowledge sharing and reuse. Sophisticated user interfaces for different media types are expected to be designed based on the users expertise and need.

World Wide Web (WWW) is becoming an infrastructure for the next generation of DSSs and groupware applications. There is also a trend to develop tools and techniques that could facilitate the dissemination of ESs through WWW. High bandwidth, reliable internet connectivity and carefully prepared underlying data will be keys to the future success of web-based decision tools. ERP, a new generation of information system, is integrating information and information-based processes within and across functional areas in an organization. The extensive databases created by the ERP system provide the platform for decision support using data warehouse, data mining and executive support systems. Global DSSs are emerging as the new frontiers in MIS area. Over the next decade, DSS will focus on large scale decision making involving groups, teams within distributed and decentralized structures [137]. In future, DSS will be a small tool for aiding farmer's tactical decisions, a versatile simulator as a consultant's tool, a core of a facilitated learning & training and a formal frame work that supports regulatory objectives in constraining and documenting farming practice [131]. DSS integrated with precision agricultural equipments, GIS and site-specific farming are changing the realm of modern agricultural practices. Future developments may include the possibility of implementing a number of DSS models into a GIS, which will support precision agriculture by providing adjusted spraying advice based on plot-specific characteristics [87].

In future, design and development of DSS is expected to get advantage from promising technologies like data warehousing and mining, agent-based approach, intelligent agents and enterprise resource planning besides advancement in hardware and software technologies. These technologies shall facilitate easier design of more complex DSSs. Agricultural is expected to get maximum benefits out of these as well as new milestones laid by the technologies like modelling, hypothesis, simulations and projections. Continued progress in system modelling combined with increasing growth in computer power, improvements in Remote Sensing, Geographical Information Systems, Precision Agriculture, new developments in the data extraction like data warehousing and date mining with new concepts of data exchange over the Internet should all contribute to expanded use of DSS for cropping systems in the future. Also there has been renewed interest in search strategies that can exploit the rapidly expanding information base on the Internet. These strategies may make qualitative information much more accessible to computer based reasoning systems to give new spin in DSS research and development.

Conclusion

DSS practice, research and technology continues to evolve though its history covers only a relatively brief span of years. There is no general account of classification and architecture of DSS. But it is possible to reconstruct the history from retrospective accounts considering published and unpublished material and redefine classification and architecture of DSS through in-depth research and literature contribution. Agriculture is in the midst of powerful changes influenced by industrialization and modernization, farm consolidations, environmental limitations, land use conflicts and overall increased risk; the availability, accessibility and application of contemporary expert agricultural information in the form of portable DSS is of high priority for farmers, technicians and researchers. With these changes and demands, different useful, scientifically valid and user-specific models have been implemented successfully. Many scientific and academic institutions have turned to computerized DSSs as a means of packaging biological and technical information to make the information more easily accessible and useful for various intending users in a short span of time.

In the last one decade researchers have reviewed the use of computer models in land use planning, forecasting, agronomical practices, water resources and emphasized the need for DSSs to make these models more useful. Incorporation of simulation and optimization models with interactive graphical capabilities is encouraging the acceptance of techniques related to literature development in practice. Now we have interactive, user-friendly computer systems which are becoming the rule, rather than the exception. Perhaps the greatest challenge to DSS development is how they are delivered to and used by industry and policy-makers. In order to achieve these goals we must not only learn from experience but be ready to accommodate new technologies and research areas. In addition, adoption to long-term climatic change, integrating process planning, natural hazards mitigation, matching new scientific information with local and indigenous knowledge are being addressed for sustainability of vulnerable areas.

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