# Smart Agriculture: An Approach Towards Better Agriculture Management

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# Preface

This edited book, Smart Agriculture: An Approach towards Better Agriculture Management aims to present utilization of advanced technologies towards the better management of Agriculture requirements. The book is triggered by ubiquitous applications of sensors and actuators, and the real world challenges and complexities to the Wireless Sensors and Actuator Networks (WSAN) application. The materials presented in this book include, Introduction to Smart Agriculture, Sensor based irrigation management, Smart water management, GIS utilization towards smart agriculture and the Semantic representation of Agricultural concepts.

The intended audience of this book will mainly consist of researchers, research students and practitioners in Ubiquitous applications for Agriculture. The book is also of interest to researchers and practitioners in areas such as knowledge engineering, Wireless Sensor Networks, artificial intelligence, Agriculture, decision support systems, knowledge management and Semantic representation. We would like to convey our appreciation to all contributors including the accepted chapter's authors and many other participants who submitted their chapters that cannot be included in the book due to space limits. Our special thanks are to Ms. Gracia S Oliver and Mr. Martin Weickert from OMICS group International of US for their kind support and great efforts in bringing the book to fruition. In addition, we also appreciate all reviewers and OMICS eBook assistance in formatting the book.

**Prof. Dr. Aqeel-ur-Rehman**

# About Editor

Dr. Aqeel-ur-Rehman is a Professor, Deputy Director (Admin) and Chairman of Department of Computing for Faculty of Engineering Sciences and Technology, Hamdard University located in Karachi, Pakistan. Besides Teaching, he is an active researcher and has over 30 publications in conferences and Journals of International repute. His PhD dissertation was on Developing Context-aware Framework for Agriculture Management that he completed with dedication and published multiple International conference and Journal Publications having good impact factor. Dr. Aqeel is supervising 3 PhD and several BS students. His Area of specialization is Computer Science, Wireless Sensor Networks, Internet of Things and Computer Application in Agriculture. He has over 17 years' experience in Teaching and managing University related procedures.

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I thank Allah (SWT), who gave me patience, strength, health and many other uncountable blessings that helped me completing this task.

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# Introduction

This edited book, Smart Agriculture: An Approach towards Better Agriculture Management aims to present utilization of advanced technologies towards the better management of Agriculture requirements. The book is triggered by ubiquitous applications of sensors and actuators, and the real-world challenges and complexities to the Wireless Sensors and Actuator Networks' (WSAN) application. Agriculture is a very vast domain. This book is providing coverage of some of the aspects of the agriculture like Introduction to the concept of Smart Agriculture, Automatic Irrigation Management, Water Management, use of advanced technology like GIS towards Agriculture and Agricultural Ontologies to provide semantic understanding for computing devices.

Ubiquitous computing is considered to be the core concept behind all advance concepts of today and future. The terms, Ubiquitous Computing was first coined by Mark Weiser in 1988. The core concept was Computing everywhere for everyone. It is also known as the Calm Technology and the other name that is given to it is Pervasive Computing. According to Mark Weiser, in future every object will become smart object and it will be having capability to compute, store and communicate. The computing will be available to everyone just like the utility. There will be no fancy interfaces and no specialized requirements to use computing facility. The concept that was given a way back in 1988 is now becoming the reality and the core concept behind the future networks. The offshoots of this concept are WSN, IoT, Cloud Computing, Smart Agriculture etc. We are becoming the part of the connected world and the Mark Weiser vision is becoming the reality.

Smart Agriculture is one of the good examples of Ubiquitous Computing. Use of technology in different areas to get numerous benefits is itself a valuable research. Use of Sensor network in the area of agriculture is not new. But due to the different weather, soil, water and land conditions, diverse models, methods of analysis and solutions are needed on which different communities of researchers are working and proposing several solutions. That instigates need of some different ways specifically for agriculture that can be helpful in developing solution for different conditions. Smart Agriculture concept is the combination of context-aware computing and WSAN. Smart agriculture proved its viability for the better management of Agricultural requirements.

The book consists of five chapters. Chapter 1 comprises over the basic concept of smart agriculture, needs and the impact of technological innovations in agriculture, possibilities for achieving this goal, socio-economic challenges and advantages of being smart. Chapter 2 is presenting Sensor Network based Automatic Irrigation Management System (SNAIMS) that consists of agriculture sensor boards, gateway and a computer. In SNAIMS, the irrigation activity is need based and decisions are based on soil moisture content, temperature, air humidity and leaf wetness data obtained through sensor nodes deployed at different locations. SNAIMS investigates collected data and identifies water deficient locations. In case of vulnerable situations, SNAIMS activates alarming unit and sends a message over LAN. In Chapter 3, various practical options for inducing water use efficiency in agricultural sector has been presented and reviewed. The concepts of deficit irrigation, drip and sprinkler irrigation systems and use of automatic sensors for water and labor management, other resource saving techniques like water course lining, direct seeding for rice, precision laser leveling and rainwater harvesting farming system have also been discussed through this chapter. Chapter 4 is about GIS and its use for smart agriculture. GIS is presented as a tool that will help farmers who are interested to get advantages of smart agriculture. In this chapter, Geographical Agriculture Information System (GAIS) is introduced as a future tool of smart agriculture. The last chapter that is Chapter 5 introducing Ontology that provides a shared conceptualization of a domain such that different domain entities can interoperate. This chapter provides an overview of agricultural ontologies. It starts with a brief discussion about various aspects and issues related to ontology. Then the role of ontologies in agriculture is discussed. Finally, the chapter concludes with discussion on ONTAgri, Ontology for solving agriculture problems.

| Contents | Page # |
|---|---|
|  | |

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# Towards Smart Agriculture: An Introduction

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## Introduction

Agriculture, farming or husbandry is a vital occupation since the history of mankind is maintained. The name agriculture represents all entities that came under the linear sequence of links of food chain for human beings. As humans are the smartest living species on this planet, so their smartness always provokes them to change and to innovate. This provoking has led to invention of wheel, advancements in living standards and styles, languages, life spending methodologies and countless more achievements.

The restless attitude of mankind towards innovations has given birth to major inventions, which have not only provided the ease to human beings, but also improvements in efficiency which further lead to better productivity on the cost of less skills. The advancements in agriculture are necessary to balance the demand and supply as population is increasing day by day. As compare to the last fifty years and earlier, the demand of food has accelerated. To overcome the requirements, the deployment of modern technology over this vital source for humans is intolerable. With the use of modern and advanced technologies, efficiency of the agricultural industry can be improved, where it not only includes better productivity, but also lessens intra-field and inter-field losses present in conventional methods.

From the beginning, agriculture is crucial part of human society due to the reality that man and agriculture are directly related to each other. This fact leads towards the advancement and enhancement of the typical, inappropriate and time consuming methodologies, used for agriculture. The fast moving world, new trends and technological advancement has changed the life style of people. Emerging new technologies are becoming an important part of routine. Smart homes and grid, smart cities [1] smart campus, and smart farming are some of the whole advanced and upgraded, information and communication technologies that are helping humans to save time and get faster and aureate outcomes.

Multiple technologies like ubiquitous computing, wireless networks, RFID tags, after having advanced in other fields of life, due to their tremendous efficiency, are now also imposing the agriculture industry [2]. Moreover, the coming era of IT equipped world will replace traditional methodology with smart, efficient and sustainable agriculture regime [3].

The advanced highly efficient, cost effective, sustainable, fast and aureate results have been the main factors which have invoked researchers' to contribute towards smart agriculture. E-farming, smart mobilized fertilization, RFID tags for cattle monitoring, GPS field monitoring, sensor networks in farming, moisture and humidity detection, context aware computing, precious farming, web of things and livestock and ware house management applications, etc.; are some of the technological projects related to the smart farming regime.

In this chapter, the author presents their observation towards smart agriculture.

## Trends and Conventions

Trends and research conventions are mainly focused on precise agriculture, database integration system and network information, virtual agriculture, expert systems, the connotation and extension, development stage and the impact of agricultural modernization [4] for economic growth and improved life style of rural areas.

Due to the direct impact on human life, agriculture is stepping towards modernization steadily. New trends are being introduced often, in order to meet the technological advancements. Comparing the past and continuing technological implementations it can be understood easily how most of the communication and information technologies are playing an effective role in modern agriculture. An increase in the demand for agriculture as a consequence of an abruptly growing population will enhance the need of efficient and actuate infrastructure support, in-order to fulfill the agricultural requirements of the modern society, without any interruption in its production.

Wireless sensor networks and RFID tags are the most standardized technologies playing an active role in the smart agriculture. Many countries like china, India, Korea, Brazil, Australia, several European countries and different American estates, are introducing agricultural technologies in order to strengthen their economy by using information and communication technologies for the improvement in agricultural and rural development.

Hybrid architecture for localized agricultural information dissemination is the client server architecture, in conjunction with the mobile applications on smart-phones, which can be used to deliver the precise agricultural information to the farmers. Geographical data of mobile phones can further localize the required information needs of the farmers [5]. The cattle and farm management, by using RFID tags and the recognition of cattle with the help of image processing, can lead to a decrease in the probability of viral spread [6].

Considering these facts, the green houses are increasing in their popularity, every day. According to recent trends and technological development in Wireless Sensor Networks, it has been made possible to use WSN in the monitoring and control of the greenhouse parameter, in precision agriculture. Actuated sensor networks are being deployed for the management of green houses. Using wireless sensor networks will reduce the chances of human errors that can occur while investigating the facts, about the ideal method of irrigation suitable for all weather conditions, types of soils and different crop cultures [7]. The usage of advanced technologies and automated machines, which is making the world soar to greater heights, experiences a lag when it comes to the farming either due to the lack of awareness or because of the unavailability of advanced facilities in the market, leading towards poverty in farming. In order to make the market more accessible to the farmers, the concept of e-farming is introduced. E-farming is the web application that will help the farmers to perform the agro-marketing leading to achieve success and increase in their standard of living [8].

Smart agriculture is composed of many different technological implementations. These applications are replacing the tough, unreliable and time consuming traditional farming techniques with efficient, reliable and sustainable smart agriculture [9]. Water irrigation context aware farming, pesticide control, remote monitoring, security control, environmental monitoring, precious agriculture, machine and process control, vehicle guidance, animal feeding facilities, traceability system, food packaging and inspection etc are a few examples [5].

In compliance with smart technologies, robotics is also being introduced so as to make more room for technological advancements in agriculture. Internet of Things (IoT), the hottest topic of today's research era is also contributing in smart agriculture [10]. Basically the agricultural reforms are the sum of three main domains: Figure 1

- Bio technology
- Nanotechnology
- Information And Communication Technology (ICT)

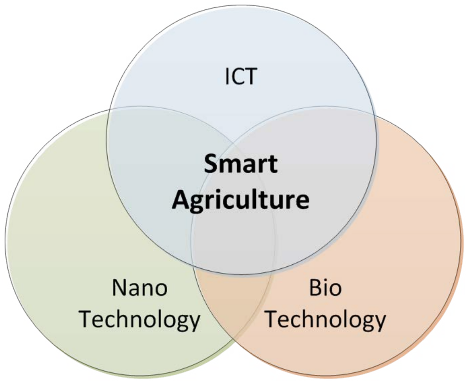


**Figure 1:** Standing of Smart Agriculture.

The summation of these three distinct technological aspects leads the ideology of smart agriculture. Bio, Nano and informatics are counter parts of this technological reform, and are somewhere inter-related. Agricultural biotechnology, biosensors directly related to Bio technology as impact of enhanced innovations to communicate the development and desired attributes to meet the changing demands of consumers closer innovations for on-farm and post-harvest operations due to increased demands of product lines, material testing and Bio-control. Agricultural biotechnology is used for implanting RFID tags inside plants and animals for enhancing productivity, available resource utilization and product monitoring. 'Smart' machines are used as a helpful tool for achieving higher quality and accuracy, capacity and can save time. Use of smart micro-machines has partial impacts on agriculture, environment and ecosystems [11]. Table 1

| Trends | Reforms | Impact |
|---|---|---|
| Agriculture e -marketing | • Web portals<br>• Direct consumer and retailer interaction<br>• Online availability<br>• Improved social approach<br>• E-store | Improved economic condition, direct interaction between two parties, discarded communication gap, & marketing of surplus products |
| Farmers | • Controlled and automated farm fields.<br>• Hot line support<br>• On time pesticide and other fault detection by using different sensors.<br>• Always connected to the farm by smart phones.<br>• Alarm support and monitoring | Reduced labor,<br>Reduced human errors, accurse, time saving, and resource availability. |

| | | |
|---|---|---|
| Farming | • Smart irrigation system<br>• Weather and humidity detection<br>• Tracking system<br>• GPS and satellite enabled monitoring<br>• Smart application for pesticide and fertilizer applications<br>• Smart security for field<br>• Smart automated machinery<br>• Actuated nodes for farms<br>• Smart harvesting<br>• Soil monitoring | Improved hand tools, advanced irrigation practices, improved storage , better productivity, development in machines mechanically e.g. power, tractors, and equipment, mechanical harvesters, Irrigation system, reclamation, development in the tools and equipment for different Product testing. Improved quality. |
| Food safety and food security | • Climate-smart farming<br>• Eco friendly farming | Larger growth , economic stability |
| Food labeling | • Bar code<br>• 2D visual tags<br>• Ware house management<br>• Tag base identification technology | Well organized fields,<br>Time saving |

**Table 1:** The trend in smart agriculture paradigm

## The Concept of Smart

Generally speaking, if a machine/artifact or any system does something that we think an intelligent person can do, we consider the machine to be smart. Any system, process and domain is said to be smart if follows 6 different levels of intelligence.

- Adapting: The term adapting refers to the change to meet any particular requirements in terms of smart agriculture the changes would be referred to as environmental.
- Sensing: The ability to sense the changes in surrounding or to observe any change.
- Inferring: It basically refers to conclusion which is based on results and observations.
- Learning: After getting conclusions and observed results the learning can be used to improve the methodologies used previously. It involves different type of information.
- Anticipating: It relates to thinking of something new and innovative which going to be happened or we can say it as the next level of anything.

Self-Organizing: The processes referred to any intelligent system which has ability to sense and monitor and then change its parameters according to the need.

Jotting all the 6 initials, smart agriculture can be composed of these main paradigms;

1. Smart Consumer
2. Smart Farmer
3. Smart farms

Smart consumer tends to the online access, for any end user to get information related to the productivity, particularly the consumer electronics [12] in which one can be able to buy and sell the productions directly from the farm. This involves internet applications, web application, data base and online stores etc. The other end of smart consumer is the smart farmer side. It is the main node from where the farmer can directly interact with open market, without any extra expenses and involvement of third party. Any farm management system can be used to manage these outside activities. This node is then connected with the smart farm, which implies sensor nodes for humidity, moisture, weather, irrigation system, ware house management, cattle, pesticide detection and monitoring [2]. Figure 2

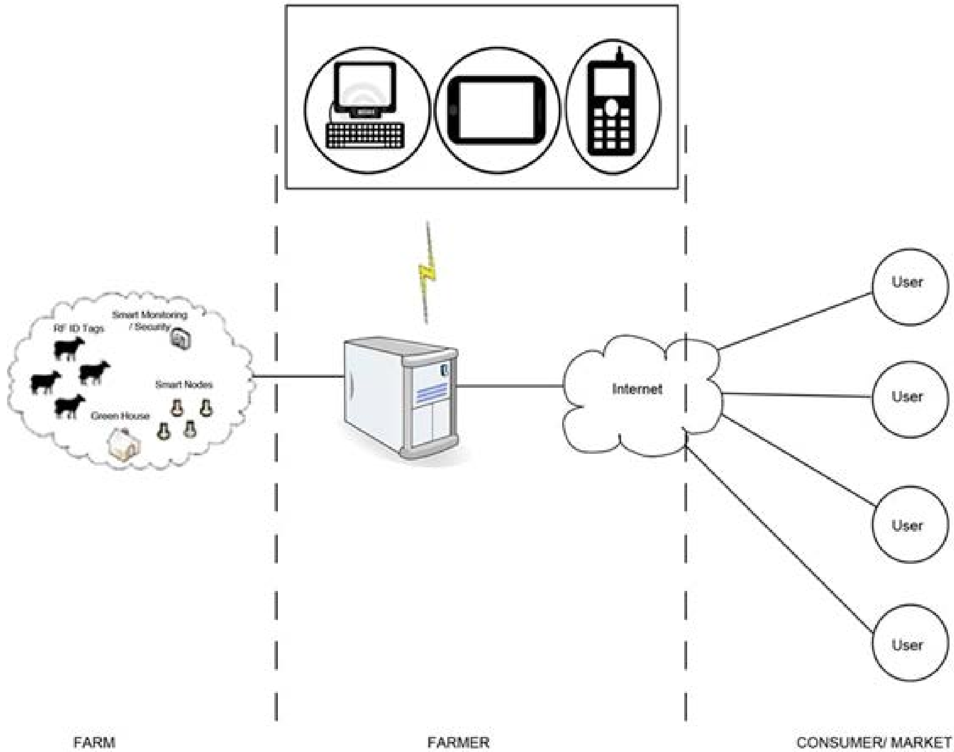


**Figure 2:** The three tier Smart Agriculture distribution.

## Relevant Technologies

In the present era, there are various and constantly evolving technologies available. Many of them are suitable, in various locations and scenarios. These technologies are fairly equal to use and fine in their output regardless of their deployment in either rural or urban areas. While we are discussing agriculture and relevant technologies, there are two major groups to discuss; the sensors available and the communication platforms.

### Sensors

The Sensors available for remote deployments are not for a single measurement or coordinate collections. They are especially designed for gathering a bunch of information from concerned entity. The main composite sensors are available for climate, soil and plants. For better understanding a chart is given below in which the sensors and their sensing abilities have been mentioned.

| S.No | Sensors | Sensitivity |
|---|---|---|
| 1. | Weather | • Temperature<br>• Humidity<br>• Atmospheric Pressure<br>• Wind<br>• Speed<br>• Direction |

| | | |
|---|---|---|
| 2. | Soil | • Temperature<br>• Moisture<br>• Conductivity<br>• Salinity |
| 3. | Plants | • Temperature<br>• Moisture<br>• Carbon die Oxide<br>• Hydrogen<br>• Photosynthesis |

**Table 2:** Sensors Available

### Communication Technologies

Deployments of sensors are in remote areas so as to collect their gathered information or data and wireless is the best fit medium. Moving towards wireless three constrains other than cost must be considered before selection of node or sensors communication technique, Range of Communication, battery life and data Integrity/Security. Till date there are four standards available and suitable for wireless nodes in agriculture based areas.

- ZigBee
- Bluetooth
- Wibree
- Wi-Fi

All above are for ISM band. The considerable specifications will be their transmission range, power consumption, cost and data security. As we can extract easily from the Table 2 [13] that ZigBee is undeniably the winner for maximum applications, since 250Kbps is an acceptable data rate for frequent transmission of data, and no transmission in agriculture field will be in stream or in real time. It has low power consumption, high transmission range, as along with 128 bit security key processing power. The reason behind 250Kbps is the 128bit encryption key and due to its low power consumption, its processing is also slow but still there is no better option than ZigBee.

## Issues and Proposed Solutions

According to the International Assessment of Agricultural Science and Technology for Development (IAASTD) [14].

The widespread realization is that despite significant scientific and technological achievements in our ability to increase agricultural productivity, we have been less attentive to some of the unintended social and environmental consequences of our achievements. We are now in a good position to reflect on these consequences and to outline various policy options to meet the challenges ahead, perhaps best characterized as the need for food and livelihood security under increasingly constrained environmental conditions from within and outside the realm of agriculture and globalized economic systems.

The synthesis proposed some of the factors like equitable environment and sustainability which can be used to improve the rural livelihoods and can be useful in reducing hunger and poverty. In compliance with these factors, biological diversity and services for ecosystem rapid changes in climate and availability of water are some of the major concerns which are addressed. To fulfill the diverse needs of human life, there is a need for sustainability which requires the concern of the international collaboration.

Apart from the technological advancement making its way towards smart agriculture, in order to benefit this industry which the humans directly associated with, along with its long lasting benefits also has some issues related to the agricultural advancement.

### Human behavior

The main barrier in the development of agriculture is the human behavior towards adapting new technology. It has always been hard for a common man to adopt something different from the traditional method.

Most people from the ruler areas are associated with the farming and are not much educated and independent in technological advancement. This factor has widened the gap between the modern and ruler areas. It is evident that the electronic media can be a great means of reducing the hesitation of adapting new technologies by commercials and on-air campaigns.

### Agriculture

There are many issues directly associated with agriculture like grid, croup and soil monitoring, irrigation, pesticide and fertilization applications, and cattle farming [15]. Information and communication technology can be a practical tool for overcoming these technical issues.

### Climate Changes

The climatic change is biggest issue in agricultural paradigm, which directly affects each and every factor associated with farming. This natural conflict directly influences productivity and quality, leaving lasting and long-term impacts on food security.

Quick solutions are needed for this issue. Pre-weather detection, temperature monitoring, climate changes, moisture levels, air flow and pressure, rain and extreme weather prediction are few of the many solutions.

### Market/Vendors

Due to the long geographical distances between the open market and the actual farm the field cost of the production is increased and will directly benefit the brokers or the third person involved, leaving the farmers inadequately paid for their efforts.

When it comes to venders of agriculture equipment's equal opportunities should be given to the manufacturing industries. Monopoly should be discouraged. This will improve the quality and cost reduction. Online services and applications can be used to provide direct interaction between farmers and consumers; e-store can be a better option. Standardization in equipment manufacturing can improve the productivity and compatibility between different vendors.

### Regulations

Reforms are needed on national and international level. Government policies and regulations are needed. The formation of regulating authority and its up gradation for technologically advanced agriculture is needed in order to provide an accessible and open market [14].

## Socio Economic Challenges

Whenever there is a new invention or anything out of the regular practice it is hard to implement and to convince the society and users to adapt the change. Most of the people related to the occupation of farming are under privileged and are not much familiar with the rapidly changing technologies due to which they lay emphasis on continuing practice with the traditional methods which are not only time consuming but also require greater man power resulting in limited outcomes. Distance learning call center for customer care and guidance and awareness campaigns in this regard are needed.

Another major challenge is the dramatic increase in the world population. According to Food and Agriculture Organization (FAO).

The future is daunting too: food needs are projected to increase by 70% by 2050 when the global population reaches 9 billion, while climate change is projected to reduce global average yields [16]. The use of advanced production techniques and new researches can contribute to overcome this problem.

Decline in economy is one of the biggest problems, which agriculture industry is facing presently. The unstable inflation in the rates is of major concern. A remarkable investment is becoming the need in modern agriculture and the poor image of farming should be changed among the new farmers [11] [16].

## Advantages

Technology is improving the efficiency of agriculture, in terms of production and economic growth. This directly creates an impact on employment and labor opportunities, environmental sustainability, small holder income, good security and the price of food.

The spread of smart technologies in the field of farming has been impressive and is particularly contributing towards improved varieties in the production of grains. Advances in farm management technology have also become popular, in terms of providing accuracy and ease of management and security. Development of supporting infrastructure, high-tech irrigation, increased employment opportunities, increased production and decreased food price, nutrition and food utilization, access to land and other resources and the utilization of all available resources are some of the plus points of technology in agriculture [17]. These all result in the transformed reformed economic growth for common man. Following is the table summarizing benefits provided by CSIRO documentation Smart Farming: leveraging the impact of broadband and the digital economy. Table 3

| In terms of: | Advantages |
|---|---|
| On-farm benefits | • soil fertility monitoring<br>• Improved pasture production<br>• Monitoring<br>• Animal weight and body condition<br>• Animal disease monitoring<br>• Early detection of pesticides |
| Broader economic opportunities | • New financial opportunities and development<br>• Provide ways to add values for farming produce.<br>• Use of smart sensor systems which help to improved quality.<br>• Helping enable such claims for premium products and prices.<br>• Pro-poor reduction |
| Agribusiness Service Sector | • Development of an agribusiness services sector.<br>• Supporting the agricultural and food industries<br>• Use of digital services<br>• Enabled broadband connectivity. |
| Environmental Management | • Sensor data for weather<br>• Sensors for water quality and flow<br>• Use of Satellite for data collection.<br>• Greater capacity.<br>• Enhanced environmental management. |
| Broader Social Benefits | • Improvements to the quality of life.<br>• Provide access to health<br>• Improve education<br>• Income sources for government<br>• business services and<br>• Improved life style for rural communities.<br>• Fill the gap between rural and urban. |

**Table 3:** Benefits of Smart Agriculture

### Required Advancements

In the agriculture Industry especially in under-developed countries the technological advancements are necessary. Although, it may not be very economic and may have financial constraints at the time of planning and deployment but if we talk about broader scope or of the fore vision of these advancements it will not only increase the net income of agriculture but also improve the quality of the production. As we know that the precise and time to time collection is not an easy task done by humans. Therefore technology will keep the farmers aware of each and every instance and the drift of the coordinates in some underneath areas which humans might miss to check and are able to take prompt action to relevant issues. These issues may be related to rain, parasites, condition of soil or humidity/dryness factors.

## Summary

In this chapter we have discussed the importance of agriculture, it's conventional as well as adopted methods and trends in the light of productivity and requirement of market. As all us can understand that production in every field must equal the demand and supply ends, which is certainly not possible without integration of technology in the field. Moving further we have disused the available technologies and platforms in wireless communication field, according to their data rates and most useful areas. Continuing with the wireless technologies we have also elaborated the concept of SMART and its relevance in the future for overcoming the necessity human engagement or appointment. As the chapter goes on the discussion continues on the available sensors for agriculture field as well as the wireless communication technologies those can be utilized in the field of agriculture. Moving on we have disused the issues and some of the proposed solutions in the light of Human behavior, agriculture, climate changes, market and the proper regulation.

Keeping in the vision that deployment is not as easy, as it is not accepted very easily by the consumer due to its pre-benefit cost, we have also a convincing discussion under the Socio economic challenges. At the end of it we have not only disused the advantages but also listed them in tabular form. The chapter is concluded on a short discussion on areas where advancements are required.

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# Sensor Network based Automatic Irrigation Management System for Agricultural Crops

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During the last decade, in Asian countries including Pakistan, water resources were depleted due to severe environmental conditions. Agriculture sector is the major source to fulfill the food requirements of continuously growing population. The vital requirement of sufficient and on time availability of water is vital through a an advanced irrigation system for good yield of agricultural crops.. Throughout the world, irrigation schedules are based on farmers experience and changes according to weather fluctuation. With the passage of time, the importance of an optimized, environment friendly and intelligent irrigation management system are increasing where irrigation schedules are based on soil water contents and environmental parameters. In this chapter, Sensor Network based Automatic Irrigation Management System (SNAIMS) is presented that consists of agriculture sensor boards, gateway and a computer. In SNAIMS, the irrigation activity is need based and decisions are based on soil moisture content, temperature, air humidity and leaf wetness data obtained through sensor nodes deployed at different locations. SNAIMS investigates collected data and identifies water deficient locations. In case of vulnerable situations, SNAIMS activates alarming unit and sends a message over LAN. It is capable of detecting noisy data using a simplified procedure and avoids it while taking irrigation related decisions. Likewise, detected noisy data is prohibited from storing in database. SNAIMS provides GUI based solution for showing data and enables farmers to monitor and control irrigation operation of their crops remotely. The proposed system is deployed over an area of 6050 square meters inside GIK Institute orange orchard.

## Introduction

Throughout the world, water is considered as an important resource as far as living creatures are concerned because without water life on this earth is almost impossible. As we know that every living creature uses water according to its needs. Due to its importance in our lives, it is necessary that water resource should be used in an efficient manner and a single drop of water should not be wasted. Almost every sector uses water but the main consumer of water is the agriculture sector. This sector consumes approximately 70% of the world water resources for irrigating farmlands and is liable to fulfill about 40 percent of the world's food requirement [1]. As the world population is increasing day by day and so is the Foods demand. In order to fulfill foods requirement of the growing population, farmers needs to grow more crops and orchards and hence uses more water. The problem of water scarcity is controlled by utilizing modern technology in irrigation procedures namely DNA based breeding, sprinkling of gardens, drip irrigation, and other advanced irrigation

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technologies. However, these procedures are in experimental stages and farmers, scientists, research funding organizations and investor cooperation are required to commercialize them [1]. In addition, farmers are needed to be convinced on using modern technologies in irrigation and to avoid the traditional irrigation procedures especially flooding. Modern technology is extremely useful in controlling over irrigation as well as under irrigation and determines when and where irrigation is desperately needed. Thus an efficient and intelligent irrigation management system based on modern technology is needed that caters to produce maximum crop yields even for low supply of water and utilizes available water resources in an efficient manner [2].

The efficiency of an irrigation management system is highly dependent on irrigation methods and schedules utilized such as surface irrigation or drip irrigation. Each method has its own merits and demerits and its usefulness is totally dependent on suitable circumstances. Likewise, irrigation procedures of various crops are completely different from one another such as the irrigation procedures and schedule applies for orchards are different from that of wheat crops or other crops. As we know that proper irrigation schedule is necessary for maximizing crops yields and quality because both under irrigation and over irrigation are extremely harmful and proper mechanism is needed to avoid them. Both have severe effects over crops yield, quality, increase vulnerability to diseases, and most importantly wastage of water resources [3]. In order to manage under and over irrigation, different methods are proposed in literature for automating, optimizing and organizing irrigation activities [4]. But most of the farmers especially in under developed countries including Pakistan are still sticking to the traditional manual irrigation procedures which causes wastage of water.

During the last decade, reduction in the cost of technology especially sensors and actuators attracted researchers organizations, scientists and investors to focus on WSNs technology and its usage in different applications from experimental phase to commercial levels [5,6]. Although, WSN technology has some limitations associated with it but most were addressed by adopting new routing protocols, preprocessing of data, sensors sleeping modes etc. [7-9]. In agriculture sector, initial experiments of WSN technology were carried out in controlled environment namely green houses and most of these experiments were successful. Similarly, a number of experimental studies were carried out in open fields as well but still requires more work to be done in this area [10]. As far as irrigation operation is concerned, irrigation schedules depend upon weather conditions, soil properties, crops varieties. For example, irrigation schedules of wheat crops in hot areas are completely different from that of cold areas that is irrigation schedules adopted in Lahore area is different from the irrigation schedules of district Bunir. Taking into account the complexities and problems associated with traditional irrigation procedures automatic irrigation controlling mechanism was introduced, which would not only result in time saving but also utilizes different resources (water) efficiently. Among other automation mechanism WSN is one of them which is used to collect environmental parameters and soil properties continuously and take necessary action or assist the farmer in this regard [11].

In order to overcome the problems associated with traditional irrigation procedures, WSNs based irrigation controlling mechanisms were presented in literature. Although, these methods were useful and solved most of the problems but each of these methods carries some limitations as well. Most of these methods were developed to work efficiently in special but for the changing circumstances the results are not convincing. For example, WSNs developed functions of tested and implemented in vineyard monitoring system which may work fine for vineyard but the same network cannot work for Maize crop field, because of different crop and circumstances. Although, these methods are useful in a sense that it reduces labors overhead, save time, reduce load on farmer, and regulate irrigation but these systems do not solve over irrigation, under irrigation, need based irrigation and water wastage. Similarly, noisy data is rarely considered in these projects. In order to solve these problems, an efficient irrigation management system is needed that not only automates crops irrigation mechanism but also considers environmental parameters, soil properties and noisy data removal while taking various decisions. Over irrigation and under irrigation is solved if the system is able to collect soil properties regularly and utilize it before making irrigation decisions.

In response to the problem stated, this chapter presents a Sensor Network Based Automated Irrigation Management System (SNAIMS) for oranges orchards. SNAIMS is capable of collecting soil properties and environmental parameters continuously through various sensors integrated with agriculture pro boards deployed at different locations in oranges orchard. Irrigation schedules of different plots are automatically controlled and are based on soil moisture contents, air temperature, air humidity and leaf wetness. These parameters are sensed after a defined time interval and investigated by decision support system installed at central location. WSNs nodes have to rely on it are on board batteries. In SNAIMS, we consider efficient utilization of batteries and data is preprocessed by the processing unit before it is handed over to the transceiver. A season dependent threshold value is defined for soil moisture contents along with temperature, air humidity and leaf wetness threshold values. During analysis of data if the soil moisture value is less than the defined threshold values then irrigation activity are crucial. Once the vulnerable condition is detected, SNAIMS delays its decision until upcoming reading from similar sensor node. After collecting next reading, three readings are compared and if the vulnerable value is found correct then it activates alarming unit and send a message over LAN. However, if the vulnerable data value is identified as noise, malfunctioning of sensor nodes then it is discarded and thus increasing system accuracy in terms of decisions. It enables farmers to identify locations where irrigation is needed by viewing different graphs plotted by SNAIMS automatically. In order to inform farmers about vulnerable conditions, it activates the alarming unit and sends an alarm activation message over LAN. In subsequent section of this chapter, a brief overview of WSNs technology in the context of agriculture sector is presented.

## Wireless Sensor Networks in Agriculture

The reduced size of a sensor node makes it one of the prominent and contested among other electronic devices to automate various agriculture related activities. Apart from the limitation associated with sensor nodes, this technology is extremely useful for different application areas including agriculture sector. In agriculture, sensor nodes are used for collecting environmental parameters and soil properties which have drastic effects on crops yields, quality, cost and irrigation schedules. Irrigation schedules, pesticides sprays and fungicides sprays are completely dependent over environmental parameters and sensor nodes are proficient to provide this information regularly. Soil parameters are extremely useful to determine various crops suitability and also depicts whether crops need water or not [12]. Additionally, WSNs are used in different agricultural projects ranging from greenhouses automation to open field's deployment as shown in Figure 1 [13]. Some of experimental studies are presented here briefly.

In greenhouses environments, dew condensation problem requires major attention because most of the diseases occur due to this. WSNs are used to automatically control or prevent dew condensation problem inside greenhouses [14]. Three different types of sensor nodes were used namely sensing nodes for gather data, computation over gather data is performed by base nodes and relay nodes are used to adjust environment inside greenhouse. Additionally, a server is used for applying Bahrenburg formula to calculate dew condensation, processing saving gathered data. Bangladesh University of engineering and technology, MIT and CENS (a small unit of University of California log Angles) has started a joint project to comprehend the ratio of arsenic compound presence in groundwater

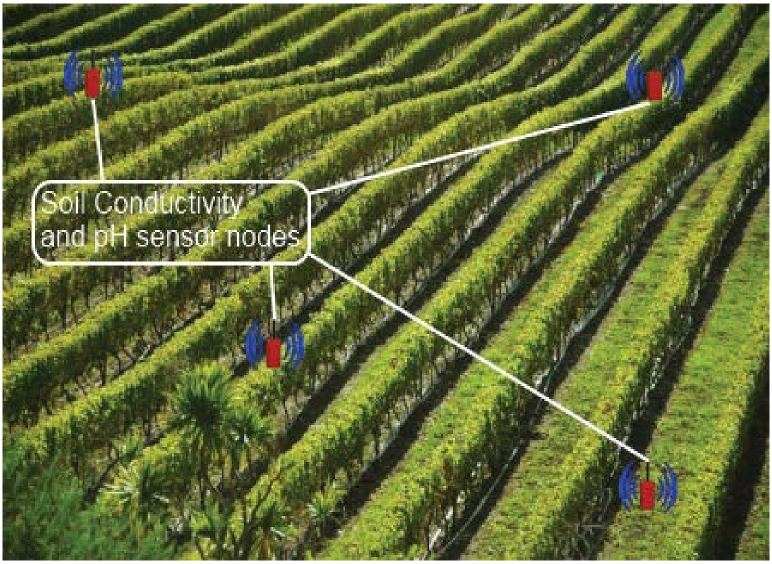


Figure1: Soil Conductivity and pH sensor nodes

In order to achieve their goal, WSN comprised of 48 sensor nodes were deployed in rice fields for short period of time (ten days). Sensor nodes were used to measure arsenic, soil moisture, temperature, calcium, carbonate, chloride, nitrate, and $P^H$ etc. [14]. WSN was used for collecting data which is analyzed at laboratory. In Malawi, a WSN based project was carried out by Zennaro et al., [15] to understand water quality. WSN was comprised of four nodes relay on single hop communication and each node was measuring $p^H$, turbidity and redox (reduction/oxidation). Initial focus of the project was on automatic fault recovery mechanism because the system has to be deployed in remote area.

In Spain, WSNs comprising of three different types of nodes were successfully deployed and tested for monitoring salt, soil water contents, and temperature [16]. Looking to the importance of water in life of living creatures, a WSN was applied to identify different means of saving water. By thoroughly investigating the relationship between the capacity of shower nozzle and sensor node radius, an expression is identified that describe how area under consideration will be covered by least number of sensor nodes [17]. A conceptual model of WSN based automated irrigation management system was proposed by Feliciano et al., [18] but only realized a prototype model of their presented system by utilizing soil moisture sensor, temperature sensor, electro mechanical sensor and capacitance sensors along with computer controlled decision support system. In 2011, a WSN based architecture for precision agriculture is presented by Anurage et al., [19]. Their proposed architecture comprised of three distinct components. First component of their architecture is intelligent nodes capable of sensing different parameters necessary for an automatic agricultural system. Second component is a mesh network of wireless nodes used for communication with other nodes with energy efficient routing protocols. Third activation part is used for activating various units automatically. In rural areas, currently farmer's experiences are used for determining and managing seedling periods of water melons. Likewise, environmental temperature has a dominant role in its seedling periods as well but presently thermometers are used to measures temperature values. Zuol et al., [20] presented a WSN based monitoring system deployed in plastic greenhouse of watermelon. Three different parameters namely temperature, air humidity and light are sensed periodically using different sensors and then a thorough investigation is performed at centralized location. Due to the valuable role of water in growth and yields of different crops, water level monitoring is considered seriously by research community. In this regard, a design of water level monitoring system based on wireless sensor network in presented in [21]. In addition, an algorithm is presented for delivering maximum packets to destination.

A process control strategy based management system for the production of an efficient water melon seedling process is realized by S. Ke et al., [22]. WSNs along with decision support system, RFID based method, and queuing theory based algorithm for seedling in nurseries is presented. In Lofar project, a pilot study was carried out to understand and describe the potentials of WSNs in detecting various diseases. Phythophthora is a fungal disease and was used as a case study. Environmental parameters along with soil properties are sensed after a predefined time interval and investigated to identity this disease. The results of this pilot study were convening but the complete projects results are not reported yet [23]. Vineyard monitoring system [24] utilized wireless sensor network for disease prediction, pest controls, identifying disease locations and helps managers in handling different activities smoothly. Kotamaki et al., [25] deployed sensor nodes at different location for perceiving river basin water quality and investigated soil parameters effects over crops yield. In order to prevent the occurrence of tomato disease favorable conditions inside greenhouses, sensor nodes are deployed for periodically sending information to disease prevention system which analyzes received data by comparing it with previously stored data for taking necessary actions [24]. Various studies on automatic controlling of greenhouses ranging from automatic control of a single parameter to overall management are reported in [13-16]. In Common-sense net project, sensor network based decision support tool was designed for marginal agriculture in Indian state of Karnataka. This system helps in conserving rainy water for long term usage and sensor nodes were deployed to collect environmental data for controlling different crop diseases [26]. Flow AID presented a controlled irrigation mechanism useful in situation where water quality and quantity is limited [27]. Automatic drip irrigation management system for cherry trees was proposed by Dursun et al., [28]. Soil moisture sensors were deployed at different locations for report to base station after certain time interval. A. Pardosi et al., [29] investigated the possible integration of rote zone sensors into wireless sensor network and its utilization in water resource limited conditions. X. Ding et al., presented underground sensor pivot system for managing irrigation activities automatically [30].Different site specific automatic irrigation management systems based on wireless sensor networks were investigated for enhancing crop yield and efficient utilization of water resources [31,32,33].

## Sensor Network Based Automated Irrigation Management System (SNAIMS)

Considering the potentials of WSNs in different application areas especially agriculture sector, Sensor Network Based Automated Irrigation Management System (SNAIMS) is presented and realized to automate the irrigation activity of oranges orchard. SNAIMS irrigation related decisions are based on temperature, air humidity, leaf wetness and soil moisture values collected from agricultural sensor boards positioned at different locations in oranges orchard of GIK Institute. Water deficient locations are identified by comprehensively investigating collected environmental and soil data. The proposed system is comprised of two different parts namely hardware unit and software unit. Hardware unit is utilized for collecting and storing information whereas software unit examines the collected information to decide whether irrigation is necessary or not. Both of these units are briefly explained in subsequent section.

## Hardware Unit

The hardware unit of SNAIMS comprised of agriculture boards and pro-board, soil moisture sensors, temperature sensors, humidity sensors, leaf wetness sensors, Wasp-Mote gateway, and a computer used as a sever. Wasp-mote agriculture boards are used in this experimental setup due to distinguished feature (long range capabilities, easy programming, and designed especially for agriculture sector). Likewise, fourteen different sensors are integrated with it at the same time and to prolong batteries lifetime, its switches to different operational modes. The schematic diagram of wasp-mote agriculture sensor board is shown in Figure 2. It has two types: simple and pro boards. A pro board has the capacity of connecting four extra sensors compared to a simple board. Each board is equipped with 3.7 volts lithium-ion battery having lifetime between 6-12 months depending heavily on sampling rate of different sensor and wireless communication range. In order to recharge batteries, it has a 12 volts solar penal unit as well [33]. The board has AT mega 1281 microprocessor and 2 GB micro-SD card port. In Figure 3 [33] depicts soil moisture sensors that are integrated with wasp-mote board in group of three. For precise and accurate analysis of soil moisture, three soil moisture sensors are connected to one board at the same time and are placed at different depth levels. XBee-802.15.4 is used for wireless communication as pointed out by dotted arrow in Figure 2 [33]. It communicates with microcontroller at baud rate of 38400bps speed through UART_0. Its transmission range is about 500meters. Figure 4a shows SHT75 modules (sensirion) used for sensing temperature and air humidity [33]. Figure 4b shows leaf wetness sensor integrated with wasp-mote agriculture board during this experimental study.

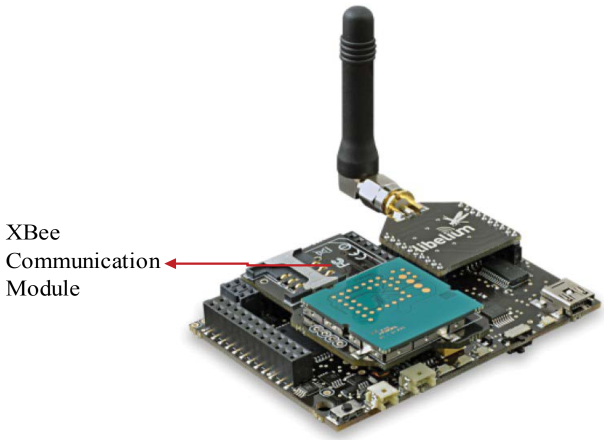


Figure 2: Wasp-mote Agriculture Board with Integrated Communication Module.

Figure 3: Soil Moisture Sensor Unit.


Figure 4: a. Sensirion temperature and humidity sensor b. Leaf Wetness Sensor

Figure 5: Wasp-mote Gateway

Gateway is an important part of wireless sensor networks and acts as a bridge between sensor nodes and server. Figure 5 [25] shows wasp mote gateway. It communicates wirelessly with sensor nodes and serially communicates with computer must set to on before deploying it in experimental fields. In order to perform processing over sensed data, the data needs to be stored in allotted memory location. Xbee802 is the communication module name followed by different functions such send () mean broadcasting data depending over embedded mac address of destination module.

## Software Unit

Prior to the actual deployment of SMAINS in open field, agriculture boards are programmed using wasp-mote integrated development environment. Keeping in view the importance of batteries lifetime in wireless sensor networks scenario, boards programming was done in a manner to efficiently utilize available power. In this regards, every sensor unit was switched off after performing its intended task of probing environment. A sample of wasp-mote working code is presented below. The status of an agriculture board [Starting Wasp-Mote Module]

### Sample of working code of Wasp-Mote Agriculture Board

Wasp-Mote.Status : ON

1. Communication.Module.initi()
2. [Setting Frequency Range]

Communication_Module.Frequency (Status)
3. [Setting API of Communication Module]
Comm.Module.API(Status)
4. [Setting Communication Module Status]
Comm.Status : ON
5. [Setting Destination Address in Communication Module]
Mac address of Receiver
6. [Repeat Step to ]
Start Loop
7. [Setting Temperature Sensor Status to ON]
SensorAgr.TempSensorMode : ON
8. [Storing Value of Temperature Sensor]
Store.Temp (Value)
9. [Conversion of Temperature Sensor Reading in Compatible Format]
Convert.FloattoString(Temp)
10. [Setting Air Humidity Sensor Status to ON]
SensorAgr.AHumidSensorMode : ON
11. [Storing Value of Air Humidity Sensor]
Store.AHumid (Value)
12. [Conversion of Air Humidity Sensor Reading in Compatible Format]
Convert.FloattoString(AHumid)
13. [Setting Soil Moisture Sensor Status to ON]
SensorAgr.SMoistureSensorMode : ON
14. [Storing Value of Soil Moisture Sensor]
Store.SMoisture (Value)
15. [Conversion of Soil Moisture Sensor Reading in Compatible Format]
Convert.FloattoString(SMoiture)
16. [Setting Leaf Wetness Sensor Status to ON]
SensorAgr.LWetnessSensorMode : ON
17. [Storing Value of LWetness Sensor]
Store.LWetness (Value)
18. [Conversion of Leaf Wetness Sensor Reading in Compatible Format]
Convert.FloattoString(LWetness)
19. [Packet Formation]
Msg : (“Destination Add”, Sender ID ,String Data)
20. [Sending Sensors Data]
Comm_Module.Send(Msg)
21. [Setting Communication Module Status OFF]
22. Comm_Module.Status : OFF
23. [Free Temporary Memory Assigned to hold Data]
Temp.Memory: Free
AHumid.Memory : Free
SMoisture.Memory : Free

LWetness.Memory : Free

24. [Setting Temperature Sensor Status to OFF]

SensorAgr.TemperatureSensorMode : OFF

25. [Setting Air Humidity Sensor Status to OFF]

SensorAgr.AHumidSensorMode : OFF

26. [Setting Soil Moisture Sensor Status to OFF]

SensorAgr.SMoistureSensorMode : OFF

27. [Setting Leaf Wetness Sensor Status to OFF]

SensorAgr.LWetnessSensorMode : OFF

28. [Time Interval between Next Reading]

AgrB.Dely(Time)

29. [Exit]

Stop

Graphical User Interface (GUI) design of system is an important measure for naïve users i.e. farmers to understand and efficiently use it. Bearing in mind GUI's importance, special attention is given to an easily understandable GUI design in SNAIMS. It is designed in Lab View which is a system design software tool by national instruments [34]. Lab view is used due to its integration of graphical, text based, and other programming paradigm within a single programming environment. A schematic diagram of SNAIMS programming carried out in Lab view is presented in Figure 6.

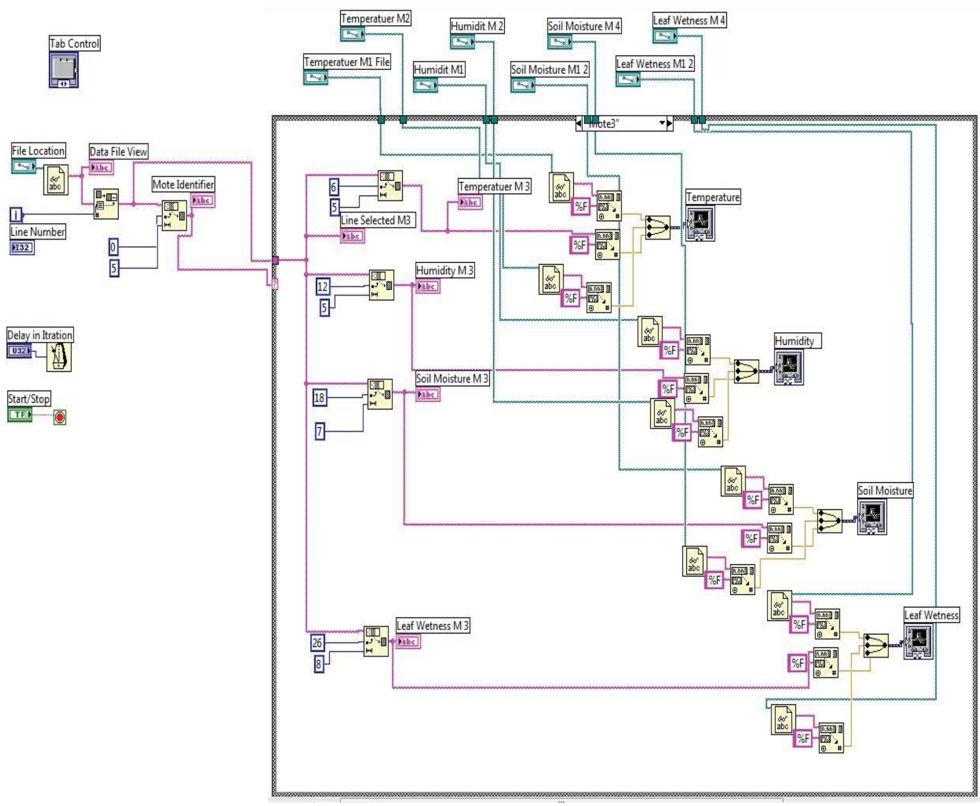


**Figure 6:** SNAIMS programming in Lab view [120].

SNAIMS GUI is shown in Figure 7 representing different tabs for navigation among different parts. It allows user to fine-tune SNAIMS file reading according to the sampling rate of sensor nodes because sampling rate of sensor nodes is adjusted during experimental setup.

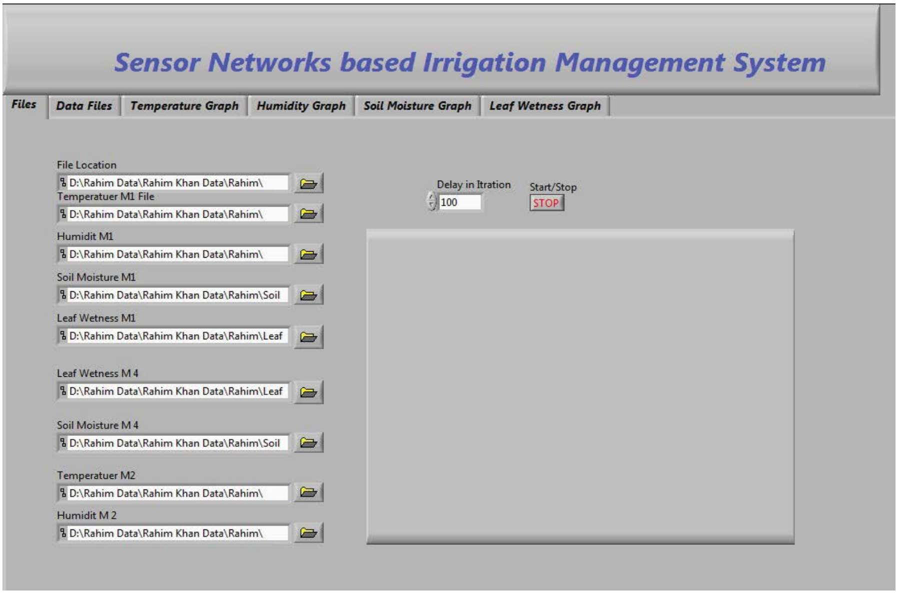


Figure 7: SNAIMS GUI with adjustable delay iteration mode.

This software presents received data in more user friendly way that is textual data representation as well as graphical data representation. An example of textual data representation is shown in Figure 8. Textual data from sensor nodes is represented separately with selected line number and wasp-mote identifiers. Similarly, data is represented collectively as shown in data file view of Figure 8 where data is represented as starting with name of agriculture board, temperature, air humidity, soil moisture and lastly leaf wetness senor's data.

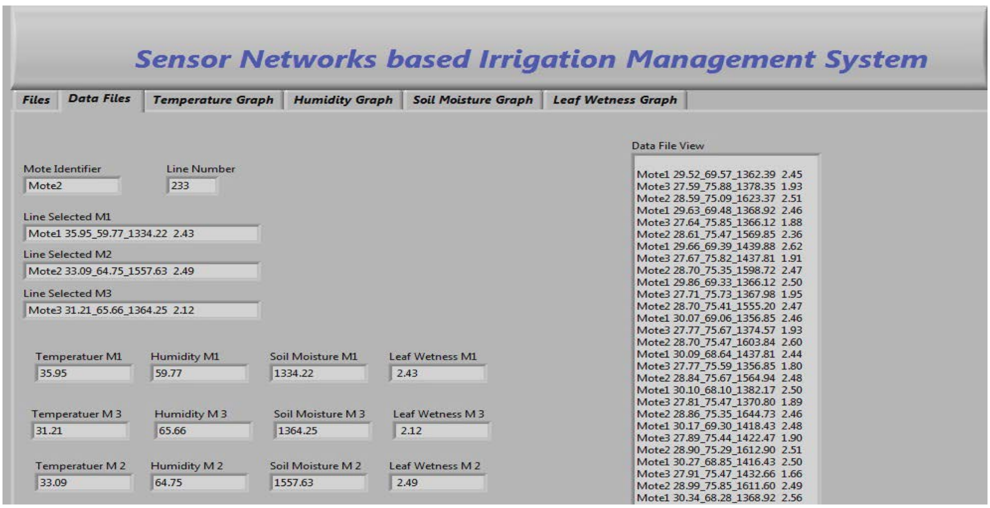


Figure 8: SNAIMS GUI's textual data representation.

Graphical representation is easier to understand than textual data representation. Therefore, SNAIMS provides a consistent graphical data representation as well. As received data is in packets format and needed to be separated before its plotting. Hence, the data is divided into its constituent parts and forwarded to concerned module to plot it separately. Data is plotted continuously by appending newly arrived data with existing graph as shown in Figure 9 and Figure 10 for 10 and 15 consecutive

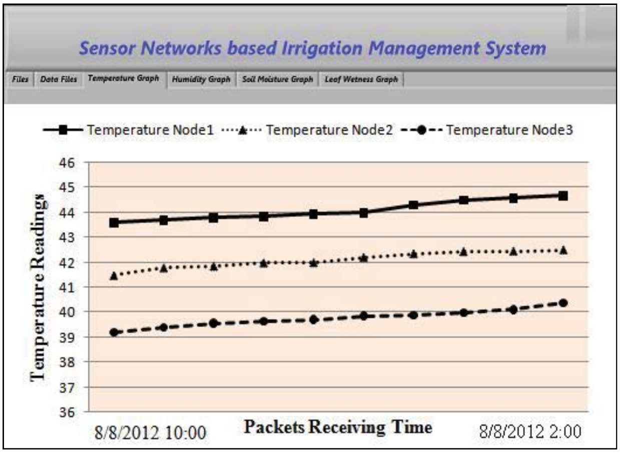


Figure 9: SNAIMS temperature values plotted graph.

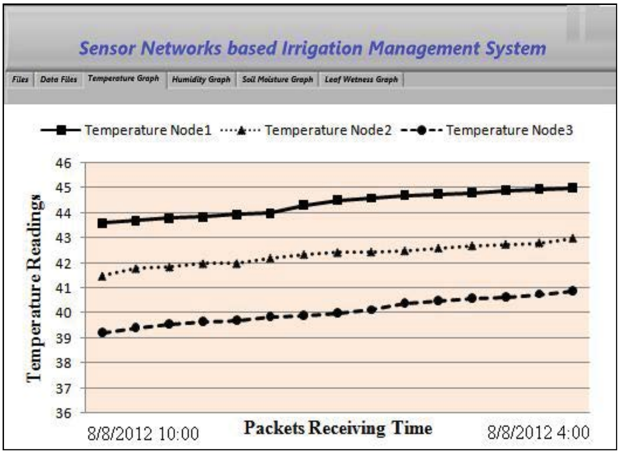


Figure10: SNAIMS fifteen temperature values plotted graph.

Temperature readings from different sensor nodes. Separate data plotting of each individual sensor's reading is valuable and beneficial in identifying water deficient locations.

Wasp-mote agriculture board's sensed data is viewed in serial monitor provided with wasp-mote programming environment. Before realizing SNAIMS, these boards were programmed using wasp-mote programming environment, an open source software platform, which supports java based programming. In WSNs scenario, energy is a significant resource and its efficient utilization is desperately needed. Hence, the boards programming was carried out by considering energy efficiency. In this regard, sensors and boards work in operational modes for shorter time interval and then switched to hibernate mode. Likewise, before transmission data is preprocessed and merge into a single packet. Serial monitor of wasp-mote Integrated Development Environment (IDE) allows user to view data as received from boards but does not let it to store or copy to another location. However, data storage is a major requirement in any decision support system, therefore, Cool Term software [35-37] was utilized that is capable of storing data automatically in form of a text file.

The decision support system of SNAIMS is programmed in java by using java socket programming in two different variants. Its server version is running over server PC where client version run on other PC's connected with server PC through local area network. The former version takes Cool Term auto saved text file as input and examine it for vulnerable condition where vulnerable condition means desperate need of water. If water scarcity locations are identified then alarming unit is activated an alert message is sent via LAN to other PC's connected to t Server.

**DSS Client Side pseudo Code**

1. [Open or Start Server Socket]
- Ss: Server Socket
2. [Check Server Status]
- Check.Sever (Status)
3. [Read Input File in Text Format]
- Read. File (file_name.txt)
4. [Repeat Step 5 to 16 ]
- Continue until End of File
5. [Start File Reading Line by Line]
- String.Read.Line (File_name.txt)
6. [Split Packets into Its Constituent Parts]
- Split.Line.(Parts)
7. [Store Temperature value at Temporary Location]
- Store.Temperature.Value("Storage Path")
8. [Store Air Humidity value at Temporary Location]
- Store.Humidity.Value("Storage Path")
9. [Store Soil Moisture value at Temporary Location]
- Store.SoilMoisture.Value("Storage Path")
10. [Store Leaf Wetness value at Temporary Location]
- Store.LeafWetness.Value("Storage Path")
11. [Setting of Threshold Values]
- Temp.ThresholdValue(Value)
- Humid.ThresholdValue(Value)
- SMoisture.ThresholdValue(Value)
- LWetness.ThresholdValue(Value)
12. [Compare Most Recent Packet Values with Threshold Values]

- CurrentValue.Temp≤Temp.ThresholdValues
- CurrentValue.Humid≤Humid.ThresholdValues
- CurrentValue.SMoisture≤SMoisture.ThresholdValues
- CurrentValue.LWetness ≤LWetness.ThresholdValues

13. [If Result of Previous Step is False Then Store Values]

- Step-12.Result: False Then
- Store.Values("Storage Path")
- Display.GUI(Temp.Value)
- Display.GUI(Humid.Value)
- Display.GUI(SMoisture.Value)
- Display.GUI(LWetness.Value)

14. [If Result of Step 12 is True Then Postpone Decision Until Next Packet]

- Wait. NextInputStream
- Store.Temp(Temporary location)
- Store.Humid(Temporary location)
- Store.SMoisture(Temporary location)
- Store.LWetness(Temporary location)

15. [Match Postponed Packet with Coming Packet and Previously Stored Packet ]

- $Diff_1$ (Postponed and Coming Packet) and $Diff_2$ (Postponed and Previous)

16. [if $Diff_1$ Greater than $Diff_2$ then Vulnerable Condition]

- $Diff_1 > Diff_2$

17. [True Result of Previous Step is indication of Vulnerable Condition]

- Activate Alarming Unit

18. [Send Message Over LAN]

- Msg.Send(LAN)

19. [Store Values]

- Store.Temp("Location")
- Store.Humid("Location")
- Store.SMoisture("Location")
- Store.LWetness("Location")

20. [Display Via Continuous Graph]

- Display.Temp : True
- Display.Humid : True
- Display.SMoisture : True
- Display.LWetness : True

21. [False Result of Step 12is indication of Noisy Data]
- Evade.Posponed.Packet()
- Remove.Posponed.Packet()
- Display.Posponed.Packet : False

22. [if not end of File ]
- Go to Step 4

23. [Otherwise]
- Exit

**Server Side Pseudo code**

1. [Open or Start Client Socket]
- cc: Client Socket

2. [Check Client Status]
- Print Client Status Info

3. [Set IP Address of Server in Client]
- C : Socket(192.168.155.86)

4. [Set Port of Server in Client]
- C: Socket(8080)

5. [Check Connection Setting]
- Connection.Status (Checked)

6. [Store Received Message from Server Module]
- Store.Msg("Location")

7. [Display Message Regarding Vulnerable Condition with Location Info]
- Msg.show("Vulnerable Condition")

8. [Activation of Alarming Unit if Attached]
- Activate.Alarm (Unit)

9. [Stop]
- Exit

**SNAIMS Design**

SNAIMS monitors various environmental parameters and soil properties hourly and on daily basis during a week. These parameters play a vital role in the design of an efficient irrigation management system. In order to investigate their effects on irrigation schedule of oranges orchards, Wasp-mote agriculture boards are deployed at three different locations. In first phase of our experimental setup, nodes were placed in close vicinity such that every node was able to communicate directly with gateway. But later on nodes were placed such that one of them is able to communicate directly with gateway while remaining two nodes were out of wireless communication range of Xbee module. These nodes communicate with gateway using multi hop communication. For this purpose, sensor boards placed in closed proximity of gateway is programmed in a manner to work as a relay node, Node3 in our experimental setup functions as a relay node. Node1 and Node2 broadcast their packets by appending node3 Mac address to its header and destination address as gateway. When Node3 receives a packet from one of these nodes it examines it and finds destination address gateway. Then it resends it to destination without modification. The design of our experimental setup is shown in Figure 11 where dotted arrows represent wireless communication and solid arrows represent wired communication through a defined USB port. The wasp-mote gateway communicates serially with computer through a defined USB port, port-6 in our experimental study. Every node senses temperature, air humidity, leaf wetness and soil moisture after a defined interval of time that is 30 minutes. The wireless communication of Xbee module is in a range of about 500 meters. Node3 is placed at about 350 meters from gateway and is able to communicate directly with it. Other nodes are placed at a distance of about 300 meters from Node3. as shown in Figure 13.

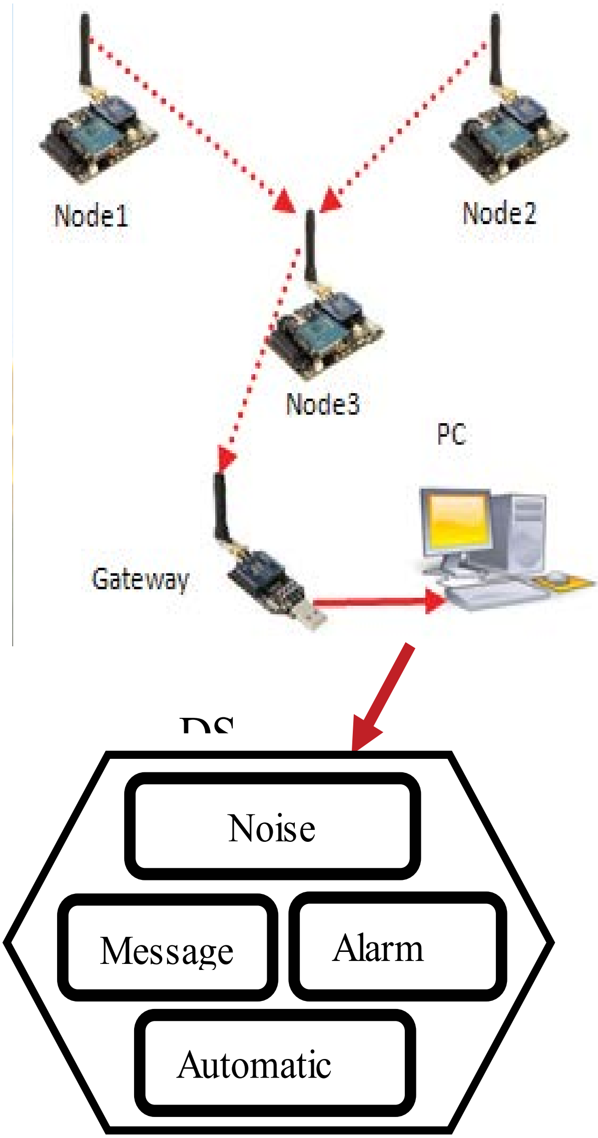


**Figure 11:** WSN for irrigation management system.

The distance between nodes and gateway is kept low so that packet lose intensity is minimized. The gateway module acts as a bridge between sensor nodes and PC. The collected data is received in a PC via a defined serial port that is COM6 in our case. SNAIMS checks the received data for any vulnerable condition and informs farmers if the soil moisture, temperature, air humidity values are below their defined frequency threshold values i.e. 500HZ for soil moisture in our case.

## SNAIMS Experimental Setup and Working Mechanism

In order to check and validate SNAIMS performance and efficiency, wasp-mote agriculture boards are deployed at three different locations in oranges orchard as shown in Figure 11. The distance between boards and gateway is adjusted according to their wireless communication ranges. Four sensors are integrated with each board that is temperature, air humidity, leaf wetness and soil moisture sensing. Figure 12 presents the internal structure and working mechanism of SNAIMS. Initially, desired data is collected by sensors and pass it to agriculture board. Agriculture board creates a packet from it by appending the destination Mac address and passes it to its Xbee802.15.4 module. The packets are forwarded to Xbee802.15.4 module of gateway that is connected serially to a computer or laptop. SNAIMS investigates every packet and compare it against the defined threshold values. It activates alarming unit, if parameters values are below the threshold values. However, before taking decision of activation alarming unit, it investigates whether the vulnerable condition is correct or not. For this purpose, the decisions are delayed until next data packet is received. This mechanism is carried out to detect noisy data that is likely to occur in WSNs scenario. Noisy data must be prohibited from storing in data and DSS should be smart to ignore noisy data because decisions made over noisy data are critical. In this regards, SNAIMS compares most recent data packet with previously stored packets but in vulnerable situations this packet is stored in temporary location and waits for the next packet from similar sensor node. Upon receiving new packet, comparison is made among three different packets (that is packet received at time $T_1$, $T_2$, and $T_3$). Now if the data is found noisy, the difference between these three packets are greater than defined threshold, then packets received at time $T_2$ is discarded while other two data packed are stored permanently. On the other hand, if the vulnerable packet is found correct then it is stored and alarming unit is activated. Similarly, a message is send via LAN to client PC's so that necessary measures are taken. It enables farmers to check the orchard conditions remotely and fulfill plant's water needs according to their requirements. This scenario is depicted in Figure 12 and Figure 13. The dotted circle in Figure 12 represents noisy data which is detected and removed by SNAIMS as shown in Figure 13.

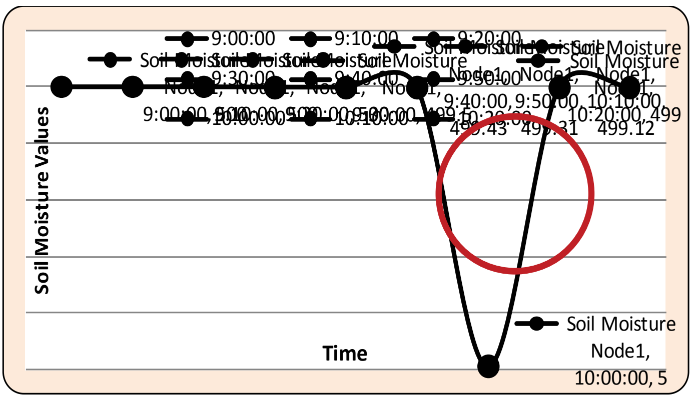


Figure 12: Example scenario of noisy data depicted by dotted circle.

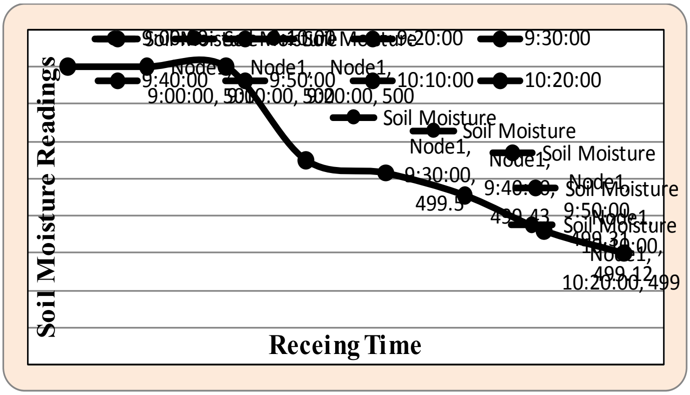


Figure 13: Example scenario after noise removal.

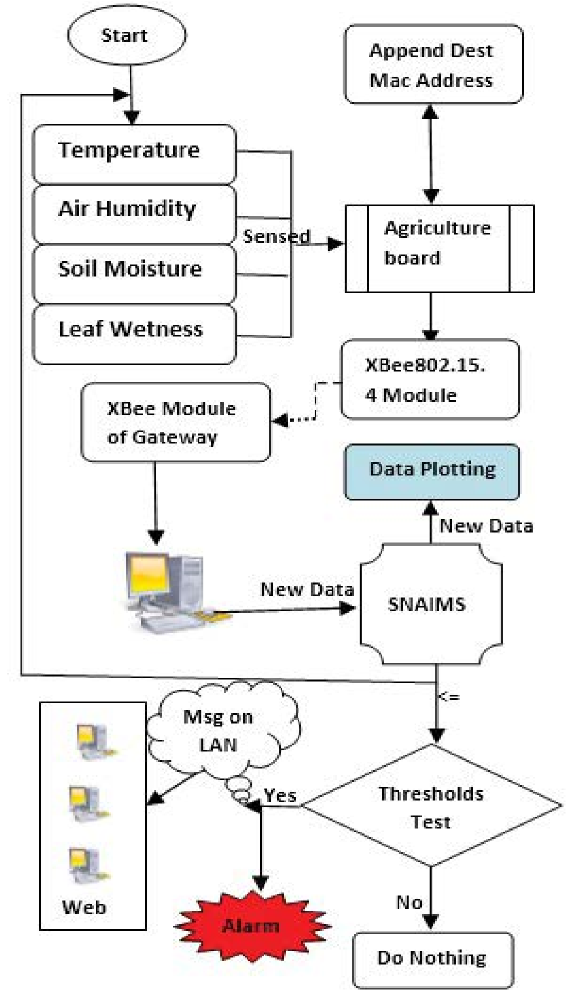


Figure 14: SNAIMS processing block diagram.

Environmental parameters are important measures to design and implement an efficient irrigation management system such as SNAIMS. SNAIMS investigates the effects of temperature and humidity on irrigation schedule of oranges orchard during four different seasons in Pakistan. Figure 15 shows deployment of wasp-mote agriculture pro-board. The Sensiron temperature and air humidity sensor is integrated with it as pointed out by red circle in Figure 13. These sensors are capable of acquiring data after a defined interval of time and transfer it to board for necessary processing. The processing unit combines it into one packet and forwards it to its XBee module for wireless transmission. In order to prolong agriculture boards batteries lifetime, before transmission sensed data is transferred to the processing unit. It accommodates different sensor's data (temperature, humidity, soil moisture, and leaf wetness in our case) into a single packet which is then transmitted.

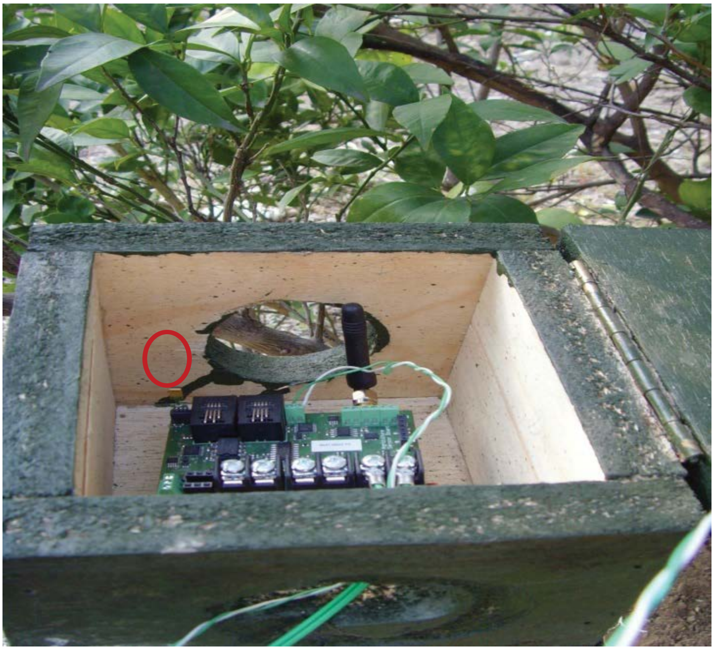

Figure 15: Wasp-mote agriculture board deployment in orange orchard

Leaf wetness sensors are utilized in this study and are placed over the oranges plant leaf as shown in Figure.-16. It measures the humidity condensed on leaf surface that is inversely proportional to its output voltage. It is connected with board through a wire as shown in Figure.-14. Its higher values than the corresponding thresh-hold value means that the weather is dry and the irrigation schedule must be adjusted accordingly. In SNAIMS, leaf wetness sensor values are combined with sensiron and soil moisture sensors data and passed to XBee module for transmitting it to the base station. In order to save energy, we have programmed these sensors to be ON for small duration of time to sense and pass their data to processing unit.

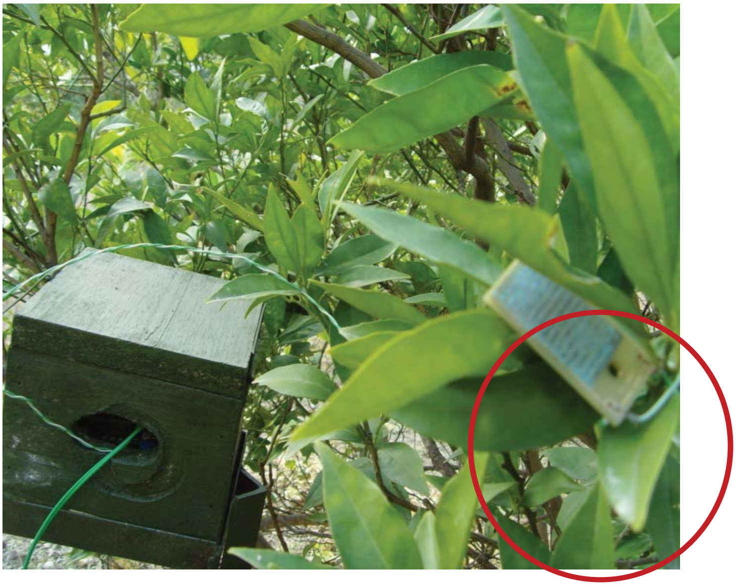

Figure16: Leaf wetness sensor deployment in orange orchard.

In SNAIMS, irrigation schedule is primarily based on soil moisture sensor's data but temperature, air humidity and leaf wetness sensors data are used to make it more precise and accurate. The soil moisture sensors are deployed at depth level of 30, 40 and 50 cm underground and 12cm away from the stem of oranges plant as shown in Figure 4-15 and Figure 4-16. Different levels deployment is performed to make the irrigation schedule more accurate and precise. In order to save energy, soil moisture sensor is switched off after passing data to agriculture board. The plants are in desperate need of water if the $S_3$ (Soil Moisture Sensor deployed at the deepest level) value is less than a defined threshold.

Figure17: Soil moisture sensor deployment near orange plant.

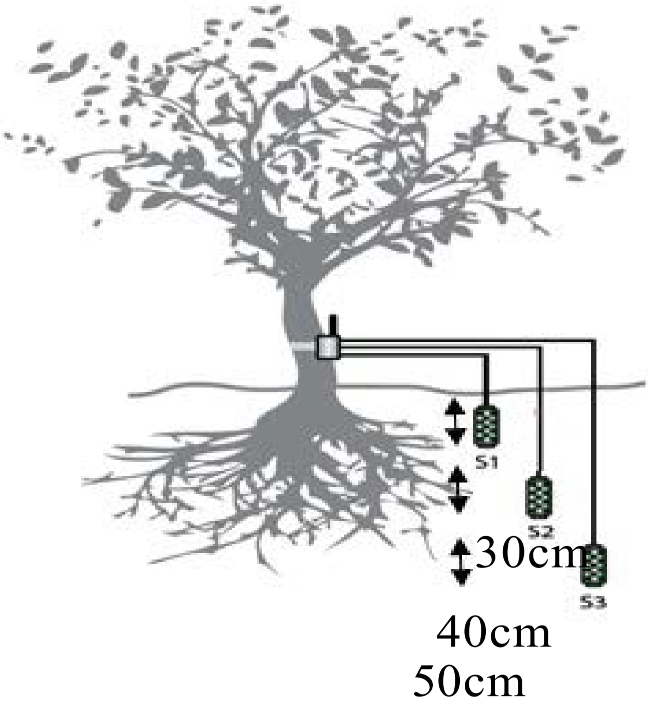


**Figure18:** Soil Moisture sensor deployment at different levels.

Interference among nodes is one of the major issues associated with WSNs and needed to be handled carefully. Interference at a particular node may be due to an edge that is going to transmit its data or the node is within the communication range of another node [26]. Interference of a node is directly proportional to the number of nodes in its transmission range. In proposed experimental setup, interference was avoided by introducing a simplest mechanism. Sensor nodes were deployed at oranges orchard as shown in Figure 4-11 where only $node_3$ is capable of directly communicating with base station and no interference at base station side. The distance between $node_1$ and $node_2$ is greater than 500m and hence no interference because of their limited transmission rages i.e. 500m. Interference was occurring at $node_3$ when it was receiving packets from $node_1$ and $node_2$ simultaneously. In order to reduce interference various algorithms were considered but were not realized in proposed experiment setup due to their associated complexities. Considering the limited number of sensor nodes in this study, a simplest interference reduction strategy was implemented. Interference may occur if the packets from $node_1$ and $node_2$ received at the same time. To avoid this situation, $node_1$ were scheduled to sends its packets at least five minutes before $node_2$. In order to make it more accurate and precise, different delay timers were introduced at $node_1$ and $node_2$ thus reducing the chances of simultaneous packets receiving at $node_3$. In proposed system, nodes sense their defined parameters after 30 minutes and send it. So if $node_1$ sends packet at time 10:00:00 then $node_2$ must send packet at 10:05:00 and thus avoiding interference creating situation. However, this mechanism is applicable in situations where small numbers of nodes were deployed at experimental fields. Similarly, different delay timers may also reduce interference up to some extent but not completely avoids it. An example scenario is $node_1$ sending packets after 30 minutes whereas $node_2$ sends packets after 29minutes and 30seconds, an applicable situation in the proposed experimental setup.

Another issue associated with WSNs is the crops canopy effects over the sensor nodes communication range. In start of this experiment study the effects of plant's canopy were not considered and nodes were deployed at random locations without considering line of sight importance. But we were surprised by the receiving packets at the terminal that was from sensor $node_3$ that was directly communicating with base station. The distance was same but the only reason of not getting data packets from other nodes were the unavailability of direct line of sight communication. This experiment inspires us to check the wasp mote board's communication range in two different phenomenon i.e. direct line-of-sights and in the presence of plants canopy. These experiments were fruitful because the communication ranges of these nodes were confirmed. According to our experiments, wasp mote boards have transmission range of 480m in case where there is possibility of direct line of sight communication but in presence of obstacles, oranges plants canopy, their transmission range is about 290m. In light of these two experiments, wasp mote boards were placed at locations in oranges orchard where direct line of sight is possible. Therefore, $node_1$ and $node_2$ were redeployed at most suitable locations.

## Results and Evaluation

Wasp-mote agriculture boards transmit data to a central location via gateway which is serially connected to a computer or laptop as shown in Figure.4-11. For perceiving data, wasp-mote's serial monitor is used but it did not allow data storage or copying. Therefore, hypo terminal, cool term or other software's is needed to be used for perceiving its data. These are simple and useful for researcher or experts but very difficult for a naïve user, farmer or orchard owner, to understand data and use it. In order to make SNAIMS user friendly, we have proposed and developed software solution that is not only shows data to its user in more easily understandable format but automatically plots it as well. Initially, SNAIMS divided packets into its constituent parts and plots every parameter in a separate chart. Figure 4-17 represents the soil moisture sensor data received from different sensors. The abrupt changes in data are due to the mal functioning of soil moisture sensor or packet loss. SNAIMS sampling rate is adjusted according to the sensor nodes sampling rate and is provided on main page.

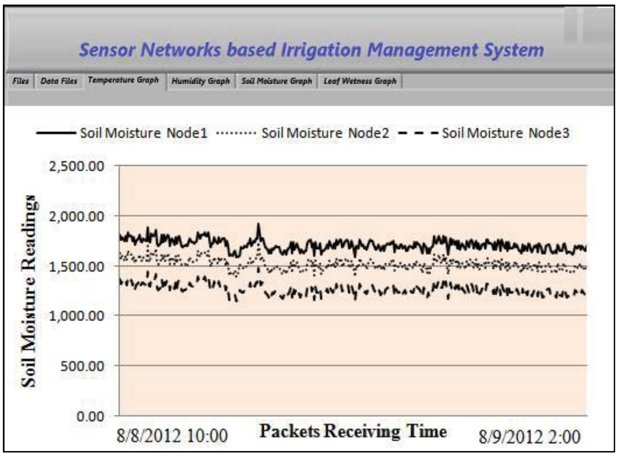


Figure19: Soil Moisture sensor data plotting by SNAIMS

Figure 18-20 show the plotting of temperature, air humidity and leaf wetness sensors reading successively. In our experimental setup, Wasp-mote boards send data to a personal computer via gateway. The data is stored automatically using Cool term software [28] in a file that acts as a data source for SNAIMS decision support system. It reads every data entry and start plotting it. It also analyzes each and every entry against the parameters under consideration threshold values. Normally, it plots data and saves data but if water deficient condition is detected then it activates the alarming unit connected to it and sends a message over LAN. In addition to handling irrigation intelligently, manual procedure is also supported in SNAIMS. Users view and monitor data regularly and if values in graph are below the defined threshold value, then it is an indication of water deficiency and irrigation activity is needed to be started immediately. This timely information is not only useful for plants growth but also saves valuable resources.

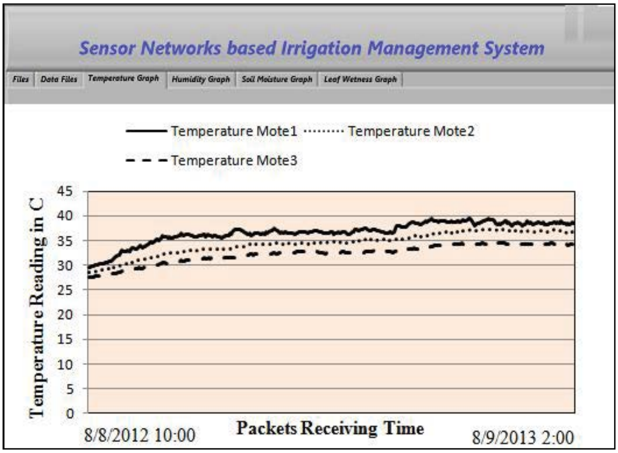


Figure 20: Temperature sensor data plotting by SNAIMS.

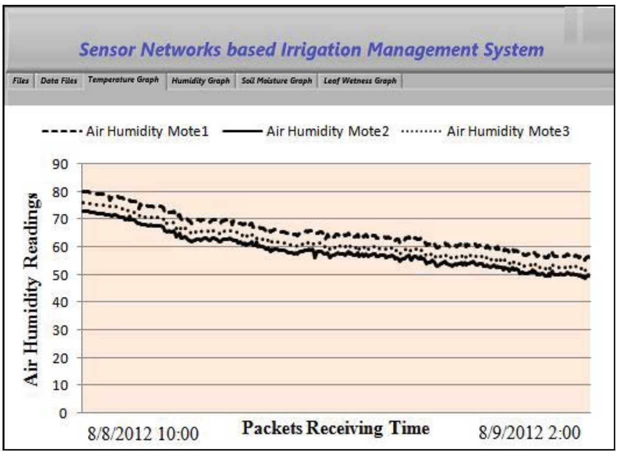


Figure 21: Air humidity sensor data plotting by SNAIMS.

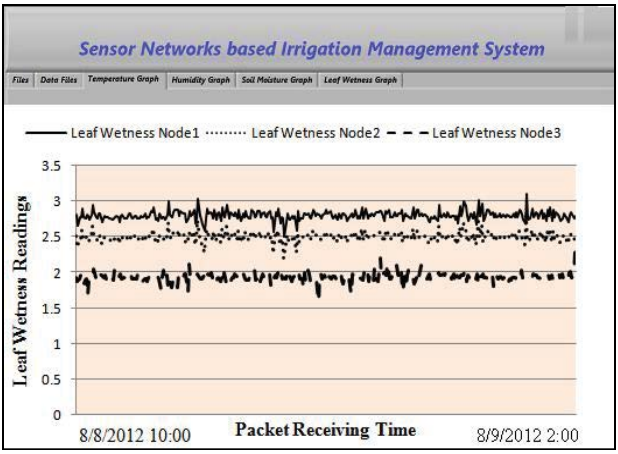


Figure 22: Leaf wetness sensor data plotting by SNAIMS.

The irrigation schedules of oranges orchards and other crops are affected by heavy rains. It may delays the irrigation activity from three to thirty days depending on crops water requirements. Hence the irrigation schedules,whether technology based or tradition mechanisms, must consider this fact. The proposed irrigation management system is a need based irrigation mechanism and suggests irrigation activity accordig to oranges plants needs. Therefore, separate case study to be carried out in rainy season is not neede. Similarly, seasons depending case studies were not investigated due to the fact that SNAIMS suggest irrigation activity according to p[1] and DropsMaking the Best use of Water for Agriculture.

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# Smart Water Management

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## Introduction

Fresh water is a limited resource and under tremendous pressure due to increased competition among various sector like agriculture, domestic, industrial and environment. In addition, the challenges posed by rapidly increasing global population and changing climate have put additional stress on availability and distribution of fresh water. Since, agriculture is one of the largest water-consuming sectors of available fresh water resource at global scale. therefore, logically water has to be reduced in future to feed other sectors. On the other hand to sustain food security of rapidly growing global population on sustainable basis, more agricultural activities are required. Thus a tradeoff is required to resolve this competing water allocation situation and one way could be improving water use efficiency in agriculture sector. The improved water use efficiency in agriculture sector can help in reducing water allocations for agricultural sector.

In this chapter, various practical options for inducing water use efficiency in agricultural sector has been presented and reviewed. The concepts of deficit irrigation drip and sprinkler irrigation systems and use of automatic sensors for water and labor management have been presented in this chapter. Moreover, other resource saving techniques like water course lining, direct seeding for rice, precision laser leveling and rainwater harvesting farming system have also been discussed through this chapter.

## Water and Agriculture

Water is the most crucial and important input for agricultural production. It is an indispensable input when it is combined with other inputs of production such as improved seeds and fertilizer [1]. Thus it has a tremendous role to play in agriculture in increasing both production and productivity. The total volume of water on earth is about 1.4 billion $km^3$ of which only 2.5 percent or about 35 million $km^3$, is freshwater [2]. Freshwater is a highly valuable resource as there are large number of competing demands, including drinking water, irrigation, hydroelectricity, waste disposal, industrial processes, transport and recreation, as well as ecosystem functions and services. Agriculture currently uses 11% of the world's land surface, and irrigated agriculture uses 70% of all water withdrawals on a global scale. In developing regions like Africa and Asia, agriculture uses 86% and 81% of their total water, respectively [3]. Irrigated agriculture, which accounts for 72% of global and 90% of developing countries water withdrawal, will have to increase its productivity to mitigate the growing water crisis [4].

As most of food production systems depend on groundwater for sustaining productivity, therefore, consistently declining aquifer levels due to over exploitation has emerged another risk for local and global food production at risk [5]. Globally, the rate of groundwater abstraction is increasing by 1% to 2% per year [6]. If the world continues to use water at current rates it is estimated that demand could outstrip supply by as much as 40% by 2030, putting both water and food security at risk. Demands on agricultural water are likely to increase in future as domestic, industry and environment uses of water continue to grow. World population is projected to reach 9.3 billion in 2050 [7]. This population needs more water for drinking, health and sanitation, as well as for energy, food and other goods for their production and delivery.

## Deficit or Supplemental Irrigation

Deficit (supplemental) irrigation, defined as the application of water below full crop-water requirements (Evapotranspiration-ET), is an important tool to achieve the goal of reducing irrigation water use. Deficit Irrigation (DI) is an irrigation management strategy that can be applied by different types of irrigation application methods. The correct application of DI requires thorough understanding of the yield response to water (crop sensitivity to drought stress) and of the economic impact of reductions in harvest [8]. In areas/regions where water resources are limited and scarce it can be more profitable for a farmer to maximize crop water productivity instead of maximizing the harvest per unit land [9]. Deficit irrigation is one way of maximizing Water Use Efficiency (WUE) for higher yields per unit of irrigation water applied. The main objective of deficit irrigation is to increase the WUE of a crop by eliminating irrigations that have little impact on yield.

Research results of a study conducted by United Nations through ESCWA (Economic and Social Commission for Western Asia) and ICARDA indicate that wheat yield under supplemental irrigation of 2.93 tons/hectare is higher than that under rainfed conditions of 1.28 tons/hectare. In other words, the total input of supplemental irrigation is an increase of wheat yield by 128 percent as compared to rain fed [10]. In Pakistan, Ahmad et al., [11] evaluated the benefits of supplemental irrigation for wheat crop under rainfed farming systems opting three different irrigation strategies (Rainfed, 10 mm Rauni, 10 mm at 50% depletion and 25 mm at 75% depletion).Irrigation was scheduled using CROPWAT model and fertilizer was applied in single dose. The highest increased in grain yield was obtained with irrigation strategy of 25 mm application at 75% MAD, which was 1.92 and 1.70 ton/ha for both location at Islamabad and Fatehjang respectively.

Ahmad [12] evaluated effect of 20 and 40% deficit irrigation on wheat and canola grain yield in Islamabad area. The irrigation management strategies were $I_1$ (100% of crop water requirement; CWR); $I_2$ (80% of CWR); $I_3$ (60% of CWR) and $I_4$ (Rainfed). The grain yield of wheat under various irrigation strategies was 6673 kg/ha under $I_1$, 6030 kg/ha under $I_2$, 3805 kg/ha under $I_3$ and 2492 kg/ha under $I_4$.The water productivity of wheat was 20.5 under $I_1$, 19.2 under $I_2$, 12.6 under $I_3$ and 14.7 kg/ha/mm under $I_4$.The grain yield of canola was 1344 kg/ha under $I_1$, 1151 kg/ha under $I_2$, 1151 kg/ha under $I_3$ and 757 kg/ha under $I_4$.The water productivity of canola was 5.5, 5.1, 5.5, and 4.4 under $I_1$, $I_2$, $I_3$ and $I_4$ respectively. Result show that wheat grain yields can be increased up to 150% more than the rain fed with irrigating 20% less water than the requirement. Under limited water areas, optimum canola yield can also be achieved with 40% less irrigation than the full water requirement.

Hussain et al., [13] conducted supplemental irrigation experiment in Potowar region (Islamabad), Pakistan for wheat crop. Three irrigation treatments employed under the experiment were:

i) Rain fed without irrigation and fertilizer application ($I_0$).

ii) Supplemental irrigation; SI of 25 mm was applied to non-fertilizer field at 75% management allowed deficit; MAD ($I_1$).

iii) Rain fed with fertilizer application at sowing time ($I_2$) and

iv) SI of 25mm was applied at 75% MAD and at the time of fertilizer application as top dressing ($I_3$).

Increased in grain yield under non-fertilizer conditions ($I_1$) ranges between 770-980 kg/ha, which is 27 to 48% higher than the rainfed yield ($I_0$). Supplemental irrigation and split application of fertilizer ($I_3$) increased the grain yield within the range of 1000-1350 kg/ha, which is 27-49% higher than yield under treatment $I_2$. Whereas, due to synergetic effect of supplemental irrigation and fertilizer application, increased in grain yield ranges between 1550-2030 kg/ha, which is 49% to 100% higher than the rainfed and non-fertilizer field (Table 1). Thus synergetic effect of supplemental irrigation and fertilizer is dominant than other inputs. Water use efficiency (WUE) for wheat under non fertilizer ranges between 6.2-7.1, 7.9-8.5 and 19.6-30.8 kg/ha/mm under $I_0$, $I_1$, and $I_2$ respectively and it varied 7.0-8.7 kg/ha/mm under $I_0$, 8.5-11.1 kg/ha/mm under $I_{1,}$ 26.8-40 kg/ha/mm under $I_2$, and 40.2-62 kg/ha/mm under $I_3$ (Table 2). Results indicate that the optimum grain yield as well as water use efficiency can be achieved with combined effect of supplemental and fertilizer.

| **Irrigation strategy** | **Wheat grain yield (kg /ha)** | | |
|---|---|---|---|
| | 2003-04 | 2004-05 | 2005-06 |
| $I_0$; Rainfed | 2840 | 3150 | 2030 |
| $I_1$; 25 mm at 75% MAD; | 3610 | 3190 | 3010 |
| non fertilizer | | | |
| $I_2$; Rainfed with fertilizer | 3500 | 3700 | 2720 |
| $I_3$; 25 mm at 75% MAD | 4850 | 4700 | 4060 |
| with fertilizer | | | |

**Table 1:** Wheat grain yield under supplemental irrigation in Islamabad area.

| Irrigation strategy | Water use efficiency of | |
|---|---|---|
| | wheat (kg /ha/mm) | |
| | Non-fertilizer | Fertilizer |
| $I_0$; Rainfed | 6.2-7.1 | 7.0-8.7 |
| $I_1$; 25 mm at 75% MAD; | 7.9-8.5 | 8.5-11.1 |
| non fertilizer | | |
| $I_2$; Rainfed with fertilizer | 19.6 - 30.8 | 26.8-40.0 |
| $I_3$; 25 mm at 75% MAD | - | 40.2-62.0 |
| with fertilizer | | |

**Table 2:** Water use efficiency of wheat under irrigation strategies in Islamabad area.

Oshaughnessy et al., [14] investigated the use of the Crop Water Stress Index (CWSI) over a 24 hrs period of time as an irrigation trigger for an early variety grain sorghum hybrid and investigated the impact of deficit irrigation on crop yield. The field was divided into six pie-shaped zones of which three were irrigated automatically using the CWSI and three were irrigated based on information from weekly neutron probe readings. Each zone had four irrigation treatments and two replications. The yields from the automatically irrigated treatment plots receiving the highest level of irrigation compared well to those manually irrigated at the same treatment level. Irrigation water use efficiency was similar between irrigation methods in the 55% and 30% treatments but significantly greater in the 80% automatically controlled treatments. This shows that the water can be saved by using automatic controlled irrigation. Levidow et al., [15] reviewed prospects and difficulties of innovative practices for improving water efficient irrigation. It was concluded that innovative irrigation practices can enhance water efficiency, economic benefits along reducing environmental burdens.

As water supplies decrease and the cost of water increases, it is evident that farmers are being driven toward deficit irrigation management. Deficit irrigation management requires optimizing the timing and degree of plant stress. Irrigation managers and farmers can adopt the approach of deficit irrigation to sustain regional crop production in water scarcity areas.

## Furrow Bed (Raised Bed) Irrigation System

Furrow bed (raised bed) irrigation permits growing of crops on beds with less water. This technique has been tested for various crops and has proved quite successful for cotton, wheat and maize (Figures 1 and 2). Among the gravity irrigation methods, raised bed technology permits more efficient use of irrigation water as compared to basin or border irrigation [16].

Raised beds technology could help in reducing deep percolation losses and increase crop production. This technology is appropriate for soils having low permeability, seasonal water logging, salinity and shortage of water supply [17]. Mehmood et al., [18] observed about 30% water saving for maize and cotton crops under raised beds. Under raised beds technology, the plants are grown on raised beds which not only use irrigation water more efficiently but also ensure better crop growth under heavy rains [19]. Yasin et al., [20] conducted experiments on water productivity improvement through furrow-bed irrigation system. Their results indicate that water productivity of wheat and maize improved 10-20% and 20-40% under large furrow bed system respectively. Moreover, it is presented that water saving 30 -50% can be achieved through adopting large furrow bed irrigation system.

**Figure 1:** Wheat sown at furrow beds.

**Figure 2:** Maize germination at furrow beds.

The impact of raised bed technology was evaluated for water productivity and lodging of Wheat. It was reported that 15% less lodging of wheat in raised bed planting as compared to flat method [21]. Farmers are adopting raised bed technology in many irrigated area of Pakistan. Ashraf et al., [22] evaluated alternate and regular furrow under skimmed groundwater application in saline environment. Their results showed that application efficiency of alternate furrow was 17% higher than regular furrow. The water use efficiency of alternate furrow was more than 30% higher than regular furrow. Shafiq et al., [23] evaluated maize and wheat production under basin and furrow-beds irrigation methods. The mean maize grain yield was 39% higher under furrow-bed than basin irrigation system. The mean water use efficiency for maize and wheat was 63% and 17% higher under furrow-bed than basin irrigation system. These studies indicate that in water scarce areas this technique is helpful to save irrigation water and get higher water use efficiency than conventional surface irrigation systems.

An automated real-time optimization system for furrow irrigation was developed and tested [24]. The system estimated the soil infiltration characteristics in real time and utilized the data to control the same irrigation event to give optimum performance for the current soil conditions. A modem was attached to a microcomputer enabling it to receive signals from the flow meter and advance sensor via a radio telemetry system. Sample data from a furrow-irrigated commercial cotton property were used to demonstrate how the system works. The results demonstrate that improvements in on-farm water use efficiency and labor savings are potentially achievable through the use of the system. Automatic timers and controller were compared in a bahiagrass plot study by measuring irrigation applied, water volumes drained and $NO_3$-N and $NH_4$-N leached. Three different depths were evaluated with automatic timer: 15, 19 and 32 mm. Results show that the rain sensor, soil water sensor and ET controller treatments applied significantly less water ($p<0.05$) than the automatic timer treatment. Water reduced 17-49% by rain sensors, 64-75% by soil water sensors, and 66-70% by ET controllers [25]. These findings suggest that water can be saved using the sensors and controllers (smart irrigation technologies).

## Low Head Trickle Irrigation System

It is recognized that trickle (drip) irrigation system can deliver water and fertilizer to root zone of plants more efficiently than other forms of irrigation. Trickle irrigation is a mean of increasing the efficiency of irrigation water by reducing deep percolation. These are important goals for irrigated agriculture, which faces pressure to reduce environmental impacts. Drip irrigation delivers water and fertilizer directly to the roots of plants, thereby improving soil moisture conditions in some studies; this has resulted in yield gains of up to

100%, water savings of up to 40–80% and associated fertilizer, pesticide and labor savings over conventional irrigation systems [26]. Low head drip irrigation system is presented in Figure 4 for fruit and vegetables production.

Trickle irrigation systems are generally permanent and have low labor requirements. The low rate of water application reduces deep percolation losses. The systems have lower energy requirements than sprinkler systems because of lower operating pressure requirement [27]. The water application uniformity of locally developed trickle irrigation system was above 85% [28]. This shows that trickle irrigation systems has potential to use scarce water resource more efficiently if designed properly. Mangrio et al., [29] reported hydraulic characterization of locally manufactured drip emitters where it was reported that coefficient of variation of locally developed micro tube emitters was the lowest. Moshabbir et al., [30] presented a basic development of trickle irrigation systems in Pakistan. Bashir et al., [31] reported performance of low head trickle irrigation systems on hand pump. Moreover, Ahmad et al., [32] measured the discharge and water application uniformity of locally developed micro tube emitter of different diameters of 1.1, 1.3 and 1.9 mm at various pressure heads and lengths in the laboratory as well as at farm level. The detail is presented in the 5.1 and 5.2 sections.

**Discharge Variation under Pressure Heads and Lengths**

The average discharge of microtube emitter with 1.1, 1.3 and 1.9 mm diameter and 0.30, 0.45, 0.60, and 0.90 m lengths is presented in Figure 3 (A), (B) and (C) respectively. The average discharge of micro tube emitter with 1.1 mm diameter was 9.72 $Lh^{-1}$ at 3.5 m head, 14.2 $Lh^{-1}$ at head of 7.0 m, 20.8 $Lh^{-1}$ at head of 14 m and 25.8 $Lh^{-1}$ at 21 m head when the length of the emitter was 0.30 m. This indicates that the discharge increased by increasing pressure head. The average discharge of microtube emitter with diameter of 1.1 m was 9.7 $Lh^{-1}$ with a length of 0.30 m, 6.50 $Lh^{-1}$ with a length of 0.60 m and 4.9 $Lh^{-1}$ with a length of 0.90 m at a pressure head of 3.5 m.

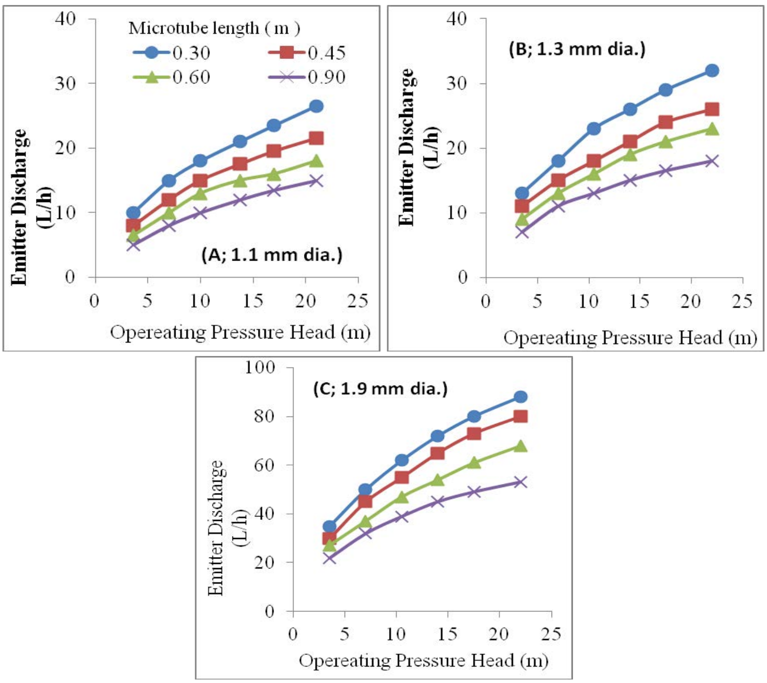


**Figure 3:** Micro tube emitter discharge under various pressure heads, lengths and diameters.

The similar trend was observed at high pressure heads. This shows that the discharge decreased with increasing length of a microtube emitter of the same diameter. These results are helpful in designing of the trickle irrigation system.

## Water application uniformity and discharge

The discharge and water application uniformity of 1.1 mm diameter microtube emitter with a length of 0.30 m was studied. The discharge was 5.0 $Lh^{-1}$ at the start point and decreased to 4.0 $Lh^{-1}$ at a distance of 23 m at 3.5 m operating pressure head. At 7.0 meter head, the discharge was 10 $Lh^{-1}$ at the start point and it decreased to 9.0 $Lh^{-1}$ at a distance of 23 m and the discharge was 12.3 $Lh^{-1}$ at the start point and it decreased to 11.3 $Lh^{-1}$ at a distance of 23 m from the beginning (Table 3). These results indicate that discharge decreased at rate of about 4% when operating pressure head was 3.50, 7.0 and 10.5 m in a distance of 23 m. These results suggest that the system can be operated at low pressure head instead high pressure head to save the energy if the length of the lateral is within 23 m.

**Figure 4:** Low head drip irrigation system for vegetables and fruit plants.

| Distance | Pressure Head (m) | | | | | |
|---|---|---|---|---|---|---|
| | 3.5 m | | 7.0 m | | 10.5 m | |
| | Discharge | Uniformity | Discharge | Uniformity | Discharge | Uniformity |
| (m) | (L $h^{-1}$) | ( % ) | (L $h^{-1}$) | ( % ) | (L $h^{-1}$) | ( % ) |
| 0.7 | 5.0 | 93.1 | 10.0 | 96.5 | 12.3 | 97.5 |
| 3 | 4.9 | 92.9 | 10.0 | 96.0 | 12.1 | 95.0 |
| 6 | 4.9 | 94.8 | 9.9 | 95.8 | 12.0 | 96.7 |
| 9 | 4.8 | 95.2 | 9.8 | 97.4 | 12.1 | 98.1 |
| 11 | 4.8 | 95.7 | 9.9 | 96.9 | 12.0 | 97.2 |
| 14 | 4.4 | 92.1 | 9.5 | 94.7 | 11.6 | 97.5 |
| 17 | 4.4 | 95.7 | 9.5 | 96.8 | 11.5 | 95.6 |
| 20 | 4.3 | 95.4 | 9.3 | 96.8 | 11.5 | 95.6 |
| 23 | 4.0 | 95.0 | 9.0 | 94.1 | 11.3 | 95.3 |

**Table 3:** Microtube emitter discharge and water application uniformity at various pressure heads and distances.

The water application uniformity varied from 95 to 98% at 10.5 m operational pressure head. It varied 94-97% at 7.0 m pressure head and 92-95% at 3.5 m pressure head was. These results indicate that the satisfactory performance of water application uniformity even at low pressure head. This type of system is being used for vegetable production at small scale.

Automated drip irrigation was carried out to demonstrate the utility of multi-sensors capacitance probes for watermelons production. Irrigation water treatments of 15% Available Water Depletion (AWD), 50% AWD and no water application were tested in sandy Coastal Plain soils in South Carolina [33]. Multi-Sensor Capacitance Probes (MCPs) monitored soil water status in the top 50 cm profile and automatically triggered short (30-60 min) duration irrigation water cycles whenever the average 0–30 cm profile soil water content reached the irrigation set points. The tactical irrigation scheduling capability offered via MCPs in an automated mode was highly advantageous. The 15% Available Water Depletion (AWD) showed a significant yield increase of 44% and 18.4% as compared to No water application and 50% AWD irrigation water treatments respectively.

Miranda et al., [34] used the distributed irrigation controller for Soil Water Potential (SWP) measurements and controlling the amount of water applied to each specific management area of a field. Each controller is autonomously powered by a solar panel and battery, eliminating hard-wire connections among control units. The results indicate that the controller was effective in maintaining the SWP in the root zone close to a predetermined management allowed deficit.

Romero et al., [35] introduced the main concepts of control theory and presented that how can it be applied to irrigation. They presented some promising preliminary experimental results to show the potential of the application of control techniques to irrigation. A Programmable Logic Controller (PLC) was used to adapt the daily irrigation amount to actual ETc, using a Hargreaves-Samani type equation. The irrigation was managed through the PLC according to the characteristics of the field, the irrigation method and the growth stage of the crop. One year results of this study indicated 12% saving in irrigation water [36]. These studies show that saving of water and cost is possible through the use of automatic controllers. However, detail evaluation is required specific to existing environment and local skill of farmers.

## Direct Seeding of Rice

The Rice-Wheat cropping pattern is one of the largest agricultural production systems in the world. There are about 1.3 billion or about 20% of the world population is dependent on the system. Rice-Wheat systems cover about 32% of total rice area and 42% of the total Wheat area in four countries; Bangladesh, India, Pakistan and Nepal [37]. The irrigated Rice-Wheat systems consume a large proportion of water resources in the region. There is concern about the productivity of water use in agriculture as the increasing competition of water from industrial, domestic and environmental sectors.

The field study in Punjab, India in 2008 investigated component of water balance and water productivity in Direct Seeded Rice (DSR), Puddled Transplanted Rice (PTR) and with different irrigation schedules [38]. Irrigation scheduling was based on different thresholds of soil water tension (SWT). The input water productivity of rice was significantly higher in DSR irrigated at 20 kPa (0.71 g/kg) than in all other treatments followed by PTR at 20 kPa (0.50 g/kg). The differences water productivity between PTR and DSR at 20 kPa was largely due to reduced seepage. Yet, deep drainage beyond 0.6 m soil depth was higher in DSR, most probably due to the absence of hard pan in the non-puddled system. There was no significant difference in evapotranspiration (600 mm) between DSR and PTR when irrigation was scheduled on the basis of SWT.

The Direct Seeding of Rice (DSR) technology in Pakistan was introduced a couple of years back, with the idea to increase the crop yields and to save the use of inputs like water, fertilizer and labor. For estimating the impact detailed comprehensive survey was carried out in three main Rice-Wheat districts i.e. Gujranwala, Sheikhpura and Hafizabad. The empirical analysis indicates that adopters of direct seeding of rice sowing technology are getting higher net returns in the range of 8-9 maunds per acre. The comparative profitability analysis indicates that in case of direct seeding of rice sowing technology the cost of production is high than the conventional transplanting of rice. However the gross profit is more in case of direct seeding of rice as compared to traditional transplanting of rice. The farmers are getting higher net returns in the range of rupees 3500-4000 per acre [39]. Moreover, results for the number of irrigation employed are negative and significant at 1% level of significance implying that the adopters of the DRS technology have to apply less number of irrigations as compared to non adopters. The numbers of irrigations are less in the range of 4.86-5.37. The labor demand of DSR technology are also less is in the range of 3.15-3.55 persons. The results for labor demand are also significant at 1% level of significance indicating that adopters of DSR technology require less labor.

## Sprinkler Irrigation System

Sprinkler irrigation systems use sprinklers operating at pressure ranging from 70 to 700 kPa (10 to over 100 psi) to form and distribute rain like droplets over the land surface. Sprinkle irrigation uses a spray or jet created by expelling water from a nozzle. The spray is broken up into droplets and acts like a simulated rainfall of controlled frequency, intensity, duration, and droplet size. Sprinkle systems are designed to apply water at rates that do not exceed the soil's rate of infiltration to prevent surface runoff. Sprinkle systems are often a practical alternative for sloped or shallow soils. The uniformity of application generally depends much more on sprinkler position and placement than the soil type.

**Figure 5:** Various portable rain gun sprinkler irrigation systems.

These systems are affected by wind and uniform distribution may be limited. Sprinkle systems have high initial cost and maintenance requirements. They also use high operating pressures, which is a large energy requirement. The cost of portable and semi portable system is less but difficult to operate due to movement of laterals.

The Pakistan Agricultural Research Council in collaboration with local industries developed a complete range of raingun sprinkler irrigation systems, including diesel, electric and PTO-driven pumping systems, couplers, other fittings and joints. To keep the systems portable, the pumping unit along with power unit (diesel engine or electric motor) was mounted on a trolley (Figure 5). The pre-sowing irrigation (Rouni) is also being applied with this system for timely planting of crops [40]. In the Khanpur Dam area, the raingun sprinkler irrigation system is being used for establishment of orchards, efficient irrigation of fruits and vegetables, washing of Lychi and citrus and for cooling and frost control in orchards. Initial investment requirements and un-reliable electricity are restricting wider adoption of this technology.

The application efficiency of these systems varied 60-75% depending upon the pressure heads [41]. These raingun sprinkler irrigation systems have been installed in various parts of Pakistan for demonstration and introduction of the technology. In rainfed areas, these systems are being used for supplemental and life-saving irrigations to fruits, vegetables and field crops (Figure 6 and 7).

**Figure 6:** Solid set sprinkler (rain gun) system.

**Figure 7:** Semi-portable rain gun sprinkler.

Timely application of irrigation water a few mm of water through these raingun sprinkler systems only at critical growth stage has doubled the crop yields [11]. The pre-sowing irrigation (rouni) is also being applied with this system to sow various crops. The fodders, wheat, sunflower, groundnut, chickpeas have been successfully irrigated with raingun sprinkler irrigation system.

Water-efficient methods and better irrigation scheduling could also integrate water and nutrient management,thus minimising agrochemical runoff and leaching problems. To fulfil this potential, experts have developed various models of water efficiency and environmental benefits [42]. Yet these models are little used for irrigation scheduling and mostly evaluate seasonal approaches. Environmental protection agency USA [43] recommended using Watersense labels as irrigation controllers, a type of smart irrigation control technology that uses local weather data to determine when and how much to water. It is reported that these controllers can save an average home nearly 8,800 gallons of water annually. If every home in the United States with an automatic sprinkler system installed and properly operated a Watersense labeled controller. It is shown that the nation could save $435 million in water costs and 120 billion gallons of water across the country annually from not overwatering lawns and landscapes. That's equal to the annual household water needs of nearly 1.3 million average American homes. These results indicate that irrigation controller may help in saving water, energy and cost.

## Watercourse Lining

Tertiary irrigation conveyance network in Pakistan is called watercourses. These are community channels off-taking from government/farmers controlled irrigation canals. Averagely a watercourse commands 150-250 ha of land and serves about 40-50 farm families. Systematic work on watercourse loss measurement was initiated jointly by the Colorado State University and Water and Power Development Authority (WAPDA). The seepage losses from unlined irrigating channels varied from 25 to 50% of transported irrigation water [44] whereas, WAPDA determined that irrigating water course conveyance loss arranged from 31 to 59% [45]. Lining of water courses reduced seepage losses and prevents water losses from the system, but due to heavy cost the subsidy by the government provided on 15-30% running length [46].

The water conveyance efficiency and annual water savings was studied [47]. It is reported that conveyance efficiency of lined water course sections ranged from 83 to 90% where as it varied 36 to 69% of unlined water course. This shows that the conveyance efficiency can be improved up to 47%. Moreover, it was reported that the average water loss varied 0.3-0.6 lps in lined portion and 1.0-2.0 lps in unlined water course in 100 m length. Results indicate that there is significant water saving in lined section. Moreover, it is reported that the cropping intensity in the lined water course commands area increased 40% in rabi and 55% in kharif season. Lined and earthen water course improvement is presented in Figure 8 and 9. Water course lining is expensive but important conveyance efficiency of irrigation water. Therefore, brick lining and Precast Parabolic (PCP) lining was compared [48]. It is reported that 22% more cost of PCP lined irrigation water course than the brick lined. However average conveyance efficiency of the PCP line irrigation water course is 27% more than the conventional brick lined.

**Figure 8:** Earthen watercourse improvement.

**Figure 9:** Earthen watercourse improvement.

Lozano et al., [49] used automatic control for the main canals for increasing the efficiency and flexibility of irrigation systems in Southern Spain. This canal was divided into four pools and supplies an area of 5154 ha. Ultrasonic sensors and pressure transducers were used to record the gate opening and water levels at the upstream and downstream ends of each canal pool. Using the recorded data and the SIC (Simulation of Irrigation Canals) hydraulic model, two canal control options (local upstream control and distant downstream control) were evaluated using a PI (Proportional-Integral) control algorithm. The controllers were tested using theoretical demand changes and real demand changes generated. The results obtained show that only the distant downstream controller was able to adjust quickly and automatically the canal dynamics to the varying water demands; it achieved this efficiently and with few spills at the canal tail, even when there were sudden and significant flow variations.

## Precision Land Leveling

Uneven soil surface has a major effect on crop germination, stand and yield and it impact water and soil moisture distribution in plant's root system. Therefore, precision land leveling is a prerequisite for better agronomic, soil, crop and water management practices. Land leveling may minimize erosion and sediment. Leveled fields help reduce the amount of irrigation water and labor. High efficiency surface irrigation is more probable when earth moving elevations are laser leveled. Precision land leveling was introduced in Pakistan during 1976-80 and about 850,000 acres were precisely leveled in the country so far but the major area is in Punjab. Initially, bucket type scrapers were used, which have been replaced by laser beam guided automatic scrapers (Figure 10 and 11).

It is reported that this technology reduce 25% irrigation application losses, enhanced cultivated area by 20% and increased crop productivity by 20% in Punjab [50]. Reymond [51] reported that an increase in rice yield of 24% due to well field leveling. Impact of laser leveling on the changes in output level and water saving was determined by Ahmad et al., [52]. It is reported that there is water saving of 17-33% for various crops with laser leveling. Kaur et al., [53] conducted experiments for enhancing water productivity through on farm resource conservation technology in Punjab agriculture, India. Their results show that there is 24% water and energy saving and 4.25% higher crop yield with laser leveling. Moreover, irrigation cost can be reduced by 44% over the conventional practice. This shows that water and energy can be saved along higher crops yield by adopting the technology at farm level.

**Figure 10:** Laser land leveling unit.

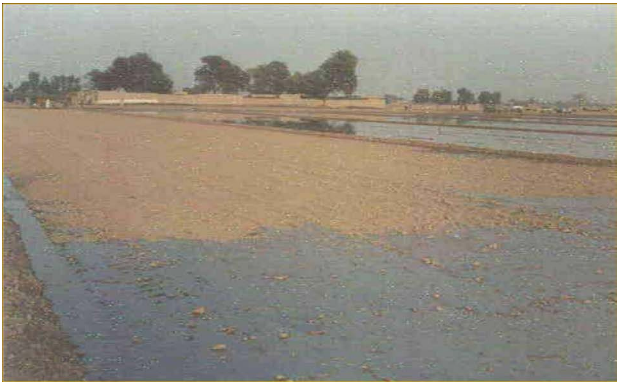

**Figure 11:** Irrigation on leveled borders.

## Water Harvesting Farming System

In areas where natural rainfall is only marginally sufficient for rainfed farming, uncultivated areas may be used for water harvesting to support an economically high value crops. Such systems were also used by ancient communities [54]. The technique of water harvesting is simple. Rainfall runoff water from uncultivated contributing area is collected and diverted to infiltrate in adjacent cropped recipient areas.

Rainwater harvesting from sloping land must flow to lower lands in a manner that no soil erosion should be there. Vegetative type and slope are important factors for rainwater harvesting and storage. Vegetated water ways should be used to carry discharge for farm pond or other structures. Slope gradient should be is another important factor to be considered. Shafiq and Ahmad [55] evaluated natural rainwater runoff under 3 land gradient and 2 types of vegetative cover. It was observed that surface runoff increased with the increase in land surface gradient. During 1998 monsoon season rainwater runoff increased 76 and 235% under 5 and 10% land slope over 1% land slope. In 1999, the rainwater runoff was more 56% under 5% land slope and 93% under 10% land slope. Two types of vegetative cover, Mott and Cenchrus grass were studied. Rainwater runoff generated less under Cenchrus than the Mott vegetation under all slopes. These results indicate that land slope and vegetative cover type are important for water harvesting and runoff farming.

**Figure 12:** Rainwater storage farm pond.

**Figure 13:** Wheat crop on level terraces.

Harvested water may be stored in farm reservoirs and the distribution may be through various efficient irrigation systems or by direct delivery to level basins. The practical use of terracing and storing of harvested water are being used in Potowar region, Punjab, Pakistan. The level basins should be with spillways controlling overflow from higher basins to the adjacent lower ones (Figure 12 and 13). Microcatchement is another technique of water harvesting farming system where concentrating local runoff towards the low point of small basin where a tree is planted (Figure 14). These microcatchments are being adopted in various districts of Potowar region of Punjab, Pakistan for growing fruit plants and these can be used in the similar regions.

**Figure 14:** Micro-catchments for fruit plants, Potowar region, Punjab.

## Conclusions

Decreasing water availability, higher input costs, and growing environmental concerns are issues that water resources manager will not be able to ignore in the future. Solutions will not be easy and likely will be multifaceted. Managing water properly is certainly one of the major challenges of the 21$^{st}$ century. Water use in agriculture sector has to reformed to conserve water and other resources so that non-agricultural demand for water can be sustained. Efficient use of agricultural water can be ensured through different water smart technologies to optimize productivity. The future agriculture has to be carried out smartly so that not only water but other key input resources like labor, chemicals etc can be sustainably minimized. Along with technological innovations, increased farmer's awareness and necessary policy support (e.g. water pricing and changes in water entitlements etc.) will be essentially required to achieve the objective.

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# GIS Enabling Smart Agriculture

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## Abstract

Geographical Information System (GIS) is a database tool, to create, disseminate, store, update, analyze and predict space related information in a smart manner. This chapter will first introduce GIS. Next section will cover GIS tools used for smart agriculture, this section will help farmers who are interested to get advantages of smart agriculture using GIS. Next role of GIS in agriculture will be explored. Next Geographical Agriculture Information System (GAIS) will be introduced as a future tool of smart agriculture. Finally summary section will conclude the chapter.

**Keywords:** Geographical Information System, Smart Agriculture, Geographical Agriculture Information System

## Introduction to GIS

The common concept about Geographical Information System (GIS) is vague, several people think of it as map making tool. In reality GIS is a complex environment, starting at one end with digital representation of landscapes captured by field research (GPS), and Remote Sensing (orthophotograph and satellite images) transmitted and on the other hand is database environment, which is capable of storing, checking, manipulating, enhancing, analyzing and displaying spatial data of the earth [1]. GIS is no longer restricted to the fields of computer science, geography, cartography or environmental science, but nowadays GIS tools and techniques are successfully used and implemented in many other fields of life, such as advertising, agriculture, agribusiness, banking, entertainment, estate management, finance, forest, food services, government organizations, health services, insurance, libraries, manufacturing, non-traditional security measures, pharmaceutical services, queries to the maps, retail, security traditional and non-traditional, social services, travel services, utilities, and many more [2].GIS allows us to manipulate and display geographical knowledge in new and exciting ways. A GIS uses geographically referenced data as well as non-spatial data and includes operations, which support spatial analysis. The common purpose of GIS is decision-making, of location, of proximity, of spatial distribution etc. GIS allows access to administrative records - property ownership, tax files, utility cables and pipes - via their geographical positions [3].

Currently making decisions based on space related data is basic for human need. Where shall we go? What will it be homogeneous to? What shall we do? When we get there? they are applied to the simple event of going to somewhere. By understanding relationship among geography, location and people's, we may make decisions about the way we live on our planet. A GIS is a tool for understanding geography and making smart decisions. GIS tools are enabling users to organize geographic data so that a smart decision can be made for a specific project or task. GIS tools are useful for every walk of life from archaeology to zoology. The GIS is processing geographic data from different sources and integrating into a visual map format. Using GIS tools, user can scan a map in any direction and use GIS features on the map to zoom in or zoom out, and alter the nature of the information contained in the map. Some GIS programs are designed to carry out sophisticated calculations for prediction erosion patterns and/or tracking storms etc. GIS gives users the geographic advantages to become more aware, responsive and productive, citizens of planet Earth [4].

In summary GIS is an environment, consists of hardware, software, procedures and users to facilitate analysis, dissemination, display, manage, manipulate, model and represent spatial and non-spatial data to solve complex problem related to planning and management of resources related to earth, as shown in Figure 1 bellow [5].

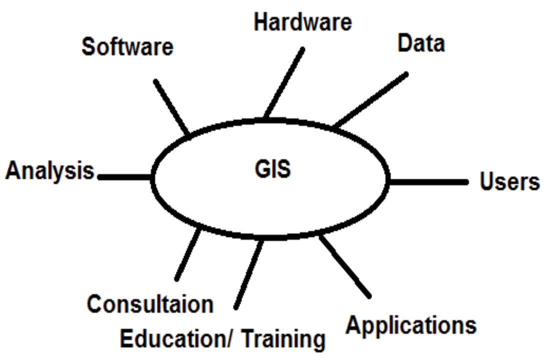


**Figure 1:** GIS environment.

## GIS Tools for Smart Agriculture

Environmental System Research Institute (ESRI) is the largest research and development organization, which mainly support GIS tools. ESRI provides several GIS products in various categories, for example, desktop GIS, server GIS, mobile GIS, Developer GIS and online GIS. ArcGIS is ESRI suite of GIS products [6]. The main tools in desktop GIS of ESRI's suits are Arc Map, Arc Catalog and Arc Toolbox - allowing users to create, analyze, map, manage, share and published GIS information. ArcGIS Explorer, Arc Reader and Arc Explorer are freeware products of ESRI. The main tool for Web GIS is ArcGIS for Server – an internal application service, e, extending the functionality of ArcGIS for desktop. The main tools of mobile GIS are ArcPad, ArcGIS for Mobile, and ArcGIS for Server and Arc Web Services. The main tools of developer GIS tools are Arc engine, ArcGIS for Server and Arc Web services. The main tool for online GIS is ArcGIS online [7].Other prominent tools are Google Earth Pro, Rhino Terrain [8], GlobalMapper, Microdem [9], Microsoft Virtual Earth, Map Window, Manifold GIS [10] and others.

According to ESRI ArcGIS (available in two flavor desktop and server) is working with geographic data. It is used for creating and using maps; analyzing mapped information; compiling geographic data discovering and distributing geographic data; managing geographic information in a database and using maps and geographic data in variety of applications, such as helping farmers getting greater profits in harvest; identifying priority areas for Crops and improving Pest Inspection and Suppression etc. Arc Map is the main component of Esri's Arc GIS suite of geospatial processing programs, and is used primarily to analyze, create, edit and view geospatial data. Arc Map allows the user to explore data within a data set, symbolize features accordingly, and create maps. Arc Catalog is a module of ArcGIS Desktop that allows user to manage GIS and related data sets. Using Arc Catalog, user can view available GIS data sets in a catalog tree similar to Windows Explorer, see what the data looks like (Preview tab), and read any available documentation that comes with the data (Metadata tab). Arc Toolbox is an integrated application developed by Esri. It provides a reference to the toolboxes to facilitate user interface in ArcGIS for accessing and organizing a collection of geo-processing tools, models and scripts. ArcGIS Explorer is GIS software. It can be used to draw digital maps and store geographic data and analyze the content of the maps based on attribution data associated with the objects which make up the map. Arc Reader is a basic data viewer for maps and spatially oriented data published in the proprietary Esri data format using ArcGIS Publisher. This software also provides some basic tools for map viewing, printing and querying of spatial data. Arc Explorer is a lightweight data viewer from ESRI for maps and GIS data only in the ESRI Shapefile (shp) file format of data. Arc Pad is mobile field mapping and data collection software designed for GIS professionals. It includes advanced GIS and GPS capabilities for capturing, displaying and editing geographic information efficiently and quickly. ArcGIS for Mobile helps organizations deliver GIS capabilities and data from centralized servers to a range of mobile devices. User can use ArcGIS for Windows Mobile to deploy intuitive and productive mobile GIS applications to increase the accuracy and improve the currency of GIS data across user's organization. Arc Web Services is one of the ESRI's GIS product to provide Web-oriented spatial data services. Arc Web Services is a Hosted GIS that provides geographic web services (W3C/SOAP and others) to web browsers and other Internet-enabled technology. ArcGIS Engine is a complete library of embeddable GIS components for developers to build custom applications. Using ArcGIS Engine, developers can embed ArcGIS functions into other information tools and build custom applications that deliver advanced GIS solutions. ArcGIS Online is a collaborative, cloud-based platform that allows members of an organization to creat, share and use maps, apps, and data, including authoritative base-maps published only by Esri [7]. In general ESRI's GIS tools are helping farmers to improve business practices, increase yields, manage resources, predict outcomes, reduce input costs and more. Users of agricultural field are getting help from these tools to visualize agricultural-environments and workflow; also helping the farmers to examine their farm conditions and measure and monitor the effects of their farm. Some other areas of agriculture where these tools play an important role are analyses of soil amendment; estimation of crop yield; identification and remediation of erosion and reduction of farm input cost etc.

According to [8] Google Earth Pro is a 3D interactive globe that can be used to aid planning, analysis and decision making. Businesses, governments and professional users from around the world use Google Earth Pro data visualization, site planning and information sharing tools. Rhino Terrain (plugin) is a powerful tool used to easily create digital terrain models. It is based on a robust and reliable constrained triangulation algorithm, able to handle huge data volumes. It uses all the geometric and graphical computing capabilities of this free-form modeler and is suitable to anyone who may have an interest for realistic 3D visualization of Digital Elevation Models (DEM) or engineering works, i.e. architects, surveyors, offices study, local authorities, designers, etc.

According to [9] Global Mapper is an affordable and easy-to-use GIS Data processing application that offers access to an unparalleled variety of spatial datasets and provides just the right level of GIS functionality to satisfy both experienced GIS professionals and mapping novices. Microdem is a freeware microcomputer mapping program written by Professor Peter Guth of the Oceanography Department, U.S. Naval Academy. User may freely use it with no restrictions. It displays and merges digital elevation models; satellite imagery; scanned maps; vector map data and GIS databases.

According to [10] Microsoft Virtual Earth (currently known as Bing Maps Platform) is a geospatial mapping platform produced by Microsoft. It allows developers to create applications that layer location-relevant data on top of licensed map imagery. The imagery includes samples taken by satellite sensors, aerial cameras, Street-side imagery, 3D city models and terrain. Map Window is an Open Source Users and Developers Group GIS tool. This group includes developers and users of the Map Window GIS open source mapping and geospatial data analysis software. Manifold GIS is a combination of mapping, CAD, DBMS and image processing. The hallmark of GIS is the power of using a visual interface to view, grab, analyze, manipulate and transform data that would not be comprehensible in classic row and column DBMS text presentations.

## Role of GIS in Agriculture

Researchers believe that GIS plays an important role in forming global agricultural policy as discuss in [11] GIS and related technologies monitoring crop yield and from these yield monitors farmers could yield maps of every 10 meters for example. The researchers also discuss Agronomic, logistic and marketing applications of GIS in agriculture. GIS plays an important role in agriculture along with other walk of life. In agriculture GIS plays role in policy making, soil erosion mapping applications, decision making applications, prediction applications, simulate climate change applications, cropping pattern analysis, pest management, nitrogen management, using historical management to reduce soil sampling errors, yield data and its monitoring, weed management, fertility management and soil Salinity mapping etc. [11-16].

GIS tools are enabling agricultural users to handle their agricultural spatial data from collection through mobile devices or tablets to analyses of remote-sensing data at their office and helping farmers expand production, reduce overall farming costs, and manage their land more efficiently along with analytical support, better handling of risk factors and resource management, generating higher revenue, greater saving and timely decision making etc.

## Geographical Agriculture Information System (GAIS): Future of Agriculture

Smart Agriculture doesn't mean use of Nanotechnology in agriculture [17], but smart agriculture means spatial geographical Agriculture Information Systems (GAIS) using computers and GIS applications, for information, together to increase the efficiency of agriculture in all aspects. GAIS here means existing GIS tools, plus set of agricultural applications, enabling agricultural users to get full benefit in the form of reducing and saving the input farming cost, managing the resources in smart way and getting higher profit and productivity with the help of analyses and predictive capabilities of GAIS. GAIS is nothing but the combination of GIS tool or tools and dedicated bundle of apps for agriculture as one package as shown in Figure 2 bellow. It is the responsibility of the developers to choose existing GIS tool or tools and develop dedicated agricultural applications to enable GAIS.

The future of GAIS is smart and intelligent agriculture, where capturing of spatial agriculture data is done in smart way, by using smart devices, such as, mobile phone, tablets, and PDAs; processing of agriculture spatial data through smart GAIS tools; and producing results and outcomes in smart forms and formats, such as graphical formats along with traditional tabular formats. In future agricultural machines will also be communicating through GPS devices and controlled by Smartphone's and tablets using GAIS. In this regards the researcher will also focus on developing GAIS mobile apps for Smartphone platforms.

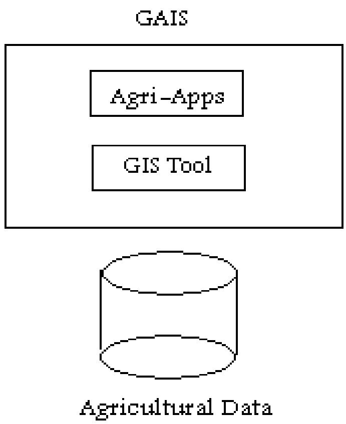


**Figure 2:** Typical Geographic Agriculture Information System (GAIS).


## Summary

All agricultural data can have spatial components from the field research or by Remote Sensing and GIS is the only tool, which allow agriculturist to visualize information that might be difficult to interpret otherwise. The GIS role in agriculture is increasing as technology is advancing for the acquisition, analysis and management of space related data on the agricultural forms. GIS as a technology, is greatly advanced today thus, its users, by sharing their innovations and applications formally and informally, were very consequential to the development of the GIS implements available today. GIS in agriculture recognizes that GIS applications are playing a vital role in this field and making it smart in all aspects. That's why Geographical Agriculture Information System (GAIS) is proposed. GAIS means dedicated GIS tools along with bundle of agricultural applications all together. In this regards more and more focus on dedicated applications for GAIS is also proposed along with Smartphone's apps for all platforms.



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# Agricultural Ontologies

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## Introduction

During the past few years, ontology has been used as the primary mechanisms to describe knowledge in different domains. A number of ontology based applications have emerged in the domain of cloud computing, internet of things, grid computing, software agents, smart agriculture and ubiquitous computing [1-4]. Ontology provides a shared conceptualization of a domain such that different domain entities can interoperate. It is defined as a collection of:

- **Classes:** these are entities or concepts of the domain
- **Attributes:** describe the properties of classes
- **Relationships:** denote the relation among classes
- **Individuals:** instances of objects
- **Axioms:** denotes the assertions
- **Rules:** if then statements to help in drawing inferences

This book chapter provides an overview of agricultural ontologies. It starts with a brief discussion about various aspects and issues related to ontology. Then the role of ontologies in agriculture is discussed. Finally, the chapter concludes with discussion on ONTAgri, ontology for solving agriculture problems.

### Ontology Languages

Ontology languages are used to represent ontology formally for consumption by machines. Different types of ontology languages such as Simple HTML Ontology Extension

(SHOE), Ontology Markup Language (OML), Ontology Extension Language (XOL), Resource Description Format (RDF), DARPA Agent Markup Language (DAML) and Web Ontology Language (OWL) have been proposed in literature [5]. SHOE enables annotation of web pages with semantic data. In this way, search engines can semantically find contents over the web. OML, extension of SHOE, is the first effort towards describing the semantic using Extensible Markup Language (XML). XOL was developed as a language to exchange ontology among different systems.

RDF is a W3C recommendation for describing the ontology. The information is represented as a triple of form (subject, predicate and object). Here subject is the entity being described; predicate is the property of subject and object is the value of property. RDF Schema (RDFS) is an extension of RDF that enables defining schema i.e. classes, domain and range, sub-classes and sub-properties.

DAML, a successor of RDF, is an agent markup language for describing web contents. DAML was then followed with DAML+OIL and eventually to OWL, the W3C recommendation. OWL addresses various limitations of RDF (and its successor languages) and provides advanced constructs for specifying domain knowledge such as local properties, disjointness of classes and cardinality restrictions. There are three flavors of OWL i.e. OWL Lite, OWL DL and OWL Full, that can be used depending upon the requirements.

A number of non-XML based languages have also been proposed in literature [6]. This includes Common Algebraic Specification Language, CycL, Rule Interchange Format (RIF) and Knowledge Interchange Formation (KIF).

## Ontology Engineering

Development of ontology is a complex task and several ontology development methodologies such as Toronto Virtual Enterprise (TOVE), Methontology and On-To-Knowledge (OTK) methodology have been proposed in literature [6]. To help ontology developers in creation of ontologies, different ontology editors have also been proposed. This includes Protégé, Tool for Ontology Development and Editing (TODE),OBO-Edit, NeOn Toolkit and WebODE etc. [6]. One of the important features of an ontology editor is visualization of ontology from different perspectives. An ontology can be viewed as indented tree or node-link diagram [7]. In the former approach, the class and sub class relationships are illustrated via indentations. In the later approach, the classes are shown as nodes of a graph with links showing relationships among them. Different two dimensional ontology visualizers such as OntoViz, IsaViz, Space Tree, OntoTrack, GoSurfer and GOBar and three dimensional ontology visualizers such as ConeTree, Tree Viewer and OntoSphere have been proposed in literature [8].

## Ontology Querying

In order to extract data from ontology, querying languages have been proposed. These are similar to Structure Query Language (SQL) and are posed to an ontology document (similar to RDBMS) and the results are consumed by the user. SPARQL Protocol and RDF Query Language (SPARQL) is a query language for RDF comprising SELECT, WHERE, ORDER BY, JOIN, SORT and AGGREGATE statements to query against key-value RDF data [9]. Similarly, RDF Data Query Language (RDQL) provides statements for extracting data from RDF graphs [10].

## Ontology Learning

The development of ontology is a labor-intensive task. Hence, automatic or semiautomatic approaches to ontology development from natural language text have been employed in some research. Representative works can be seen in [11-13]. The process generally involves extraction of domain terminologies, discovery of concepts, hierarchy derivation, learning of relationships, rule discovery, populating ontology, concept hierarchy extraction and frame/event detection [14].

## Role of Ontology

Ontology has been used in different domains for providing metadata of concepts and their relationships. This metadata can be used for ensuring interoperability among different systems, modeling contextual information, inferencing, reasoning and efficient searching of contents and resources. Till date, ontology has been used in almost every domain such as e-governance, medical science, chemistry, social sciences and agriculture. Several published ontologies are available such as [6]:

- **Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE):** captures concepts relating natural language and human cognition
- **Cyc:** captures every day knowledge such that machines can perform reasoning
- **Disease ontology:** captures disease knowledge and maps to medical code
- **Dublin Core:** describe resources (over the web), documents and their publishing details
- **Friend of a Friend (FOAF) ontology:** describes persons, their activities and relationships with other persons
- **Plant ontology**: describes plants, their structure and stages of development
- **Standard Ontology for Ubiquitous and Pervasive Applications (SOUPA):** describes resources in pervasive environments such as Person, Time, Space and Location [3]
- **Software Ontology for Ad hoc and Vehicular Environments (SLAVE):** provides an extensible approach to describe concepts for ad hoc networks and vehicular environments [1]
- **OntoAgri:** describes concepts in the domain of agriculture [2]

## Agriculture and Context-Aware Systems

Context awareness plays a key role in agriculture domain [15]. A context aware system senses its environment and adapts itself accordingly. In order to cater with variations in contextual information, a context aware system is required to perform distributed and parallel processing, especially in the domain of agriculture. An agriculture domain suffers from a range of issues ranging from irrigation and pest management to fertilization. In order for a context aware system to address these issues, following requirements needs to be addressed [16]:

- Acquisition of information related to weather, crop and soil. This includes information such as moisture level of soil, temperature, humidity, type of crop and its properties.
- Continuous (24×7) and real-time monitoring of land.
- Varying crop requirements at the same location.
- Varying fertilizer and water needs for different types of cropped land.
- Distinctive constraints of crops for varying weather, soil conditions and land.

The requirements highlighted above are based on specific needs for a problem. These requirements call for massively parallel and distributed processing in agriculture domain. This can enable monitoring of distributed terrains, dealing with varying crop requirements and employing specific solutions for particular portion/sector of land etc. Besides distributed processing, wireless sensor and actuator networks are needed for data acquisition from field as well as for actuation pertaining to different events. The raw level sensor data obtained can be used to compute high level contextual information that can be used by decision support systems for their operation.

## Context Modeling in Agriculture Domain

Context modeling enables acquisition of situational information based on currently sensed data. Also termed as situation identification [17], it can be defined as a technique to obtain an abstract view (higher level concepts) of complex, noisy, multi-dimensional and imprecise sensors data. A range of context modeling and reasoning approaches of different levels ranging from very simple to the complex models have been developed for the last 10years.These approaches can be divided into two main groups i.e. Specification based and learning based approaches [17]. Among the former approaches, ontology based modeling has been the most widely used technique [18].

Ontology is the formal and explicit representation of domain knowledge and a way to represent the relationships among the domain concepts. It provides integration of resources (such as over the web) described using ontology based metadata. Ontologies for several domains are built due to its power of persuasiveness, reasoning, inference and classification of knowledge. Ontology may also be formally defined as a 5-tuple as follows [19]:

O ={C, S, I, R, A}

where, O is the ontology being described, C is the collection of concepts, I is the set of instances of concepts with slots S, R is the restrictions imposed on concepts, instances, slots, and A is the set of axioms.

In the domain of agriculture, several efforts have been taken to model contextual information [20], [21-24]. AGROVOC and Advanced Ontology Service (AOS) project was proposed by Food and Agriculture Organization of the United Nations (FAO) for the development of agricultural ontologies based on their multilingual thesaurus [25-27]. The basic reasons for development of agricultural ontologies are multifold i.e.

Ensuring the semantic interoperability among interacting entities and thus enabling digital searching on web. Some of the examples are OntoCrop [22], Crop-Pest Ontology [23], AGROVOC, Irrigation Ontology [28] and AgriOnto [29] etc.

To model contextual information of agriculture characterizing a situation e.g. PLANTS [21] and onto Crop etc.

In the next paragraphs, the role of ontologies for context description is discussed in detail.

The PLANTS ontology [21] framework was developed based on the notion of mixed societies conceptualization [30]. It considers plant as a digital entity such as ePlant and describes the basic ingredients of a plant. The PLANT ontology is composed of two sub-layers: the PLANTS-CO (Plants core ontology) that defines a common vocabulary to ensure interoperability, and PLANT-HO (Plants Higher Ontology) that contains eEntity specific knowledge.

Similarly, the OntoCrop ontology was developed for the domain of Horticulture. The proposed ontology was used to develop an expert system that identifies pests in crop, different types of diseases and the disorders of some common vegetable crops. The system also deals with control of these diseases in greenhouse.

Considering the agricultural structure where the demand is based on the problems or requirement under consideration, ONTAgri ontology [31] is developed (Figure 1). It provides scalability and distributed operations, the basic demand of agriculture domain. It is based on service oriented approach to ontology development that allows extensions by inserting new agricultural services without changing the base ontology.

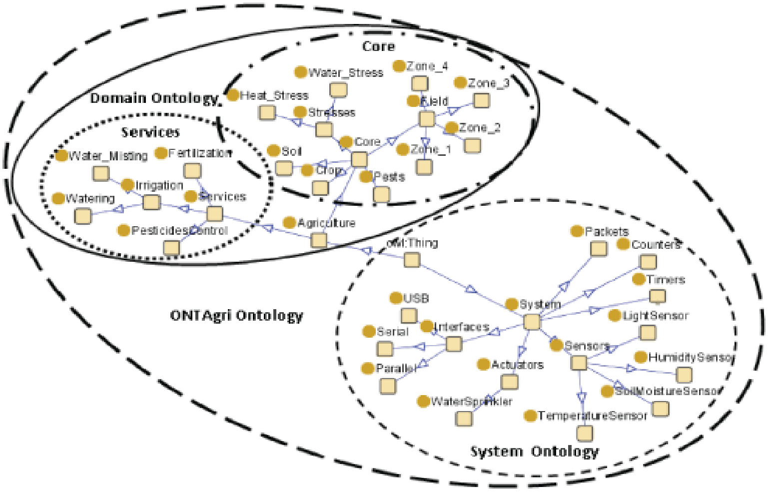


**Figure 1:** ONTAgri Ontology.

ONTAgri comprises two sub-ontologies:

i) System Ontology that can be called base ontology and Domain Ontology

ii) Domain ontology which itself comprises two sub-ontologies i.e. core and services ontology.

## System Ontology

It holds the concepts pertaining to actual hardware and software. The system ontology defines hardware and software components such as physical and logical sensors, actuation units (such as spraying system) and data acquisition interfaces etc. The different concepts of system ontology present inter-relationships with the concepts of core and service group for accomplishment of different functions of services.

## Domain Ontology

Domain Ontology provides the domain's core knowledge concepts like definition of land, crop, and services like irrigation, fertilizations, etc. It provides specification of domain to ensure semantic interoperability to support smart agriculture concept. The domain ontology comprises two sub-ontologies:

i) **Core ontology:** The Core subclass models the Agriculture domain by defining the concepts related to agriculture. In the core subclass includes definition of each concept; attributes pertaining to each concept, underlying relationships etc.

ii) **Service ontology:** The second group of domain ontology is services whose main objective is to model service based situation. This may include irrigation, fertilization and pesticides control etc. In addition, to provide support for semantic web, information service can also be introduced. To interconnect domain ontology to system domain concepts, well thought and precise relationships are desired. Furthermore, Semantic Web Rules (SWRL rules) can be employed to identify and initiate events and make decisions for actuation.

## Summary

This chapter discussed the Ontology and its importance in different domains and specifically in the domain of Agriculture. Several components of Ontology are also highlighted on which it comprises. There are various languages and tools that are used to develop Ontologies. The discussion about the tools and languages are also made part of this chapter.

Agriculture is the most important domain globally where researchers are working towards production of quality crops, increased yield per unit area, water and power conservation etc. Smart agriculture is the concept that is getting popularity due to its utilization towards better agricultural management. Ontology is one of the crucial factors of smart agriculture concept. Out of the many Ontologies discussed in this chapter, ONTAgri is the ontology that is developed specifically to deal with different problems of watering, pesticide spraying, fertilization etc.

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