Chapter 2

Literature Review

This chapter summarizes the overall scope of Precision Agriculture (PA) as well research and development taken place in Agriculture Expert System (ES). An overview is also presented on the research endeavors to apply on field sensor development, Wireless Sensor Network (WSN), remote sensing application and internet technology for agriculture expert system. The present status of the research efforts towards these directions in Indian farming condition is also covered.

Agriculture is a complex system and it is affected by large numbers of variables. The first section explains concept and need of precision agriculture for sustainable agriculture activity. The section helps to get holistic view on PA. Development in the field of PA in India is also covered in the section. Expert System (ES) works as a tool to manage variability in the agriculture. Expert System development for various processes in agriculture is quite mature and well explored field. The second section of the chapter presents literature review on in general expert system development methods and techniques adopted by the developers. Irrigation scheduling, nutrition management and pest control are important processes of agriculture system. Literature review on development of DSS for these processes is presented in this chapter. Geographic Information System (GIS) has very significant role in agriculture. GIS based Agriculture DSS are also covered in literature review.

Among all agriculture processes the irrigation scheduling has paramount importance. In depth review on various methods for irrigation scheduling is very essential to build up the research. A separate section is provided for the irrigation scheduling. The third section of the chapter covers
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the comparison of various approaches for irrigation scheduling. The latest development of DSS for irrigation based on water balance technique is discussed in this section.

Farming activities in US, European and other developed countries are very much different compare to Indian sub continental. To adopt the Agriculture DSS of western countries for Indian agriculture is not at all sensible option. So, to understand the problem, special attention is given to the Agriculture DSS developed in India. The last section of the chapter is on the Agriculture DSS in Indian perspective. With the help of entire literature review, the current progress, issues and challenges in the field of Agriculture DSS in Indian context is well emerged and it helps to prepare the problem formation for the proposed research work. The chapter is concluded with the unfolding on problem formation for the thesis.

2.1 Precision Agriculture

The concept of Precision Agriculture (PA) started in 1980s in developed countries like US, Canada and most of the countries of Western Europe. Precision Agriculture is the application of technologies and principles to manage spatial and temporal variability associated with all aspects of agriculture system for improving production and environmental quality (Pierce and Nowak 1999). In last three decades it has not only matured but also spread well across the world. This is mainly due to its greater impact on civilization. A comprehensive review on worldwide development of PA is available in (Zhang, Way and Way 2002). A simplified but very straight forward view on precision agriculture as meaningful combination of five “R”s is presented (Khosla 2010). These are right time, right amount , right place, right source and right manner of agriculture inputs like – water, fertilizer, pesticide, etc., Success of any precision agriculture system is mainly depends on its ability to bring the high productivity and profitability in agriculture system.
Another emerging challenge in the agriculture system is environmental concern. It is well documented fact that the over usage of pesticide is not only harmful to the mankind but also leave alarming footprints on the farmland. Many developed countries like US, European Nations, Australia, Denmark, etc., have initiated firm steps to curb the uncontrolled use of damaging agro-chemicals (Halberg, Verschuur and Goodlass 2005), (Skevas, Stefanou and Lansink 2014). The target oriented application of pesticide is now become mandatory in many countries. To enhance the productivity with optimal use of pesticide is new challenge in agriculture. A comprehensive approach to address this issue is emerged as Integrated Pest Management (IPM). The answer to challenge of high productivity with less impact on environment is possible with the use of technology in agriculture. Precision Agriculture addresses this issue very effectively.

2.1.1 Overview of Precision Agriculture

As mentioned in the preceding section, PA is to manage variability arise in the agriculture process. The present section discusses this variability in more details. This helps to clarify the aspects of PA to attain profitable and sustainable farming activity. PA is a systems approach towards agriculture process to manage low input, high yield and environmental sustainable conditions. Productivity is affected by variability in the following six groups (Zhang, Way and Way 2002). All can be variable both in time and space.

- Yield variability
- Field variability
- Soil variability
- Crop variability
- Variability in anomalous factors
- Management variability
Each farmland or the zone of the farm has different capability of production due to different conditions like soil types, environmental conditions and other geographic conditions like- slop, elevation, etc.; so, spatially each land has different response in terms of product yield. (Reyniers, et al. 2006). Different yield capacity of different farm can be interpreted as yield variability. Field variability means variation in the field topography like – elevation, slop, proximity with water source, etc. Soil variability is the variation in soil fertility because of difference amount of micronutrients in different field. The type of texture of soil is also a variable factor. Crop variability is variation in plant growth and duration of growth. Other anomalous factors like weed infestation, insect infestation, disease condition, wind damage etc., are also varying during the life cycle of the plant. All above mentioned factors affect the performance of agriculture process. An important aspect of PA is to understand the variability of these factors and its effect on the agriculture. Detection of these factors and corrective steps to minimize their effect on farm production is also an objective of PA. In general Precision Agriculture helps to achieve the optimum production in spite of yield, field, soil and all other variability. Various methods are suggested to mitigate the effects of this variability by one or another means (Sparovak and Schnug 2001), (Sogbedji, et al. 2001).

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Shatar 2004) and application of internet technology in agriculture (Cox 2002), (McCarthy, Hancock and Raine 2010), (Zhang and Goddard 2007).

2.1.2 Precision Agriculture in India

After independence, during 1960s, *Green Revolution* has played a vital role to make the country free from famine (Ryan and Asokan 1977). As a nation India is now self-sufficient in grain production. Proliferation of industries and urbanization has drastically reduced the farmland and agricultural resources to the great extent. Rise in population and limited resources has again opened up issues like productivity, sustainability, and profitability of agriculture system. Presently, India is on the list of top 10 countries producing major crops like wheat, rice, pulses, cotton etc. But, India is very much behind in terms of productivity for the same crops. (Shanwad, Patil and Gowda 2004). The situation demands improvement in the conventional processes of agriculture and adoption of technology.

Implementation of PA in developing and under developed countries faces many challenges. The hurdle is not only non availability of the technology but many other factors. These are lack of electrical power, insufficient water resources, pattern of land allocations among the farmers, awareness of PA concept among the farmers, and government policies. In spite of such difficulties nowadays it becomes almost inevitable to adopt modern technologies and practices in the agriculture system. This is mainly due to increase in the need of food grain and agricultural product as well influence of open market conditions. As a leading developing country, India has also started adopting PA in practice. A classification of PA system as ‘soft PA’ – cost effective solutions and ‘hard PA’ – with equipments such as Global Positioning System (GPS), Remote Sensing (RS), on the go sensors, etc., are presented. (Mondal and Basu 2008). Majority of
agriculture support systems in India are so called ‘soft PA’ type. High cost and non availability of modern equipments are major obstacles for the popularization of so called ‘hard PA’ in India.

2.2 Agriculture Expert Systems

Agriculture Expert System comprises computer based solution for one or more aspects of precision agriculture. Its aim is to improve productivity and profitability of agriculture system. It helps to conserve the natural resources by its optimum usage. Thus it makes the overall agriculture system sustainable. Expert System aims to achieve better performance of specialized problem with involvement of computer program which behave like an expert person. It helps to take decision with available data (or information) and some domain knowledge for unstructured and semi-structured problem. (Ford F. N., 1885). Agriculture being semi-structured problem, Expert System (ES) for agriculture system is much appropriate to address many issues. Survey on Agriculture Decision Support System (DSS) based on different modules of agriculture system like irrigation scheduling, soil fertility management, and pest management as well as various technology based systems like web based systems and GIS based systems are presented in the current section.

2.2.1 Overview of Expert Systems in Agriculture

In Agriculture domain, Expert System is developed as Decision Support System (DSS). It is computer based analysis and decision tool to help decision maker of agriculture. DSS was originated as a tool for operational research and management domain (Eom and Kim 2005). Use of DSS in agriculture system was started in the early years of 90s. Brief introduction on some early age DSS for agriculture like GRAPES, CALEX, Gossym-Comax, SIRATAc, COTFLEX, POMME, RCFD, etc., is given in (Plant 1993). A DSS for agriculture is neither a software package nor automation for agriculture. It is a combination of data (online and/or
offline), representation of domain expert knowledge, and user interface to achieve better decision for agriculture system to make it more profitable and sustainable. Majority of the researchers have addressed different processes of agriculture system separately. The next part of the section provides review of such systems.

2.2.2 Irrigation Scheduling

The important inputs in the agriculture system are seed, water, fertilizers and pesticides. Among this, water is considered as the most important inputs. Major threat to agriculture sector is ever decreasing water source for field irrigation. This has demanded the need of effective water management system for farm irrigation. To maintain the flow, a brief discussion on irrigation scheduling is covered in the current section. More detailed literature review on irrigation scheduling is presented later as separate section (section 2.3)

Irrigation scheduling is the process used by farmer to determine frequency and amount of irrigation. The conventional method to decide the need of water supply is based on information like- type of crops, variety of crops, and duration after last irrigation and growth stages of crop. The scientific study reveals that such approach is unable to find optimum requirement of the water. Expert System is one of the promising solutions for optimum irrigation issue. There are major three approaches used by researchers for irrigation scheduling:

- Weather based
- Soil based
- Plant based

Weather based method uses atmospheric temperature, humidity, sun radiation, wind velocity, soil texture, root zone depth, crop coefficient ($K_c$) and rain fall data as inputs. The water
requirement of the plant is calculated on the basis of current weather data like- sun radiation, atmosphere temperature, and wind velocity and air humidity (Richard G. Allen, 2005). Evapotranspiration ($ET$) represents the combined effect of evaporation and transpiration process. It is used to measure the water consumption of the plant.

Soil moisture content in the field is the direct indicator for need of irrigation for the farm. The hydrologic properties of soil are equally important to decide crops ability to transpire water from the roots. Permanent Wilting Point is the soil moisture level, below which plants can’t take up water from the soil and suffers water stress. Soil moisture sensor is used to measure available water in the soil. Measurement techniques for soil moisture content are based on tensiometer, neutron thermalization, electrical conductivity, dielectric properties, soil thermal properties, electromagnetic principles (D. A. Robinson, et al. 2008). WATERMARK (Irrometer) and EC5 (Decagon Devices) and are commercially popular electrical conductivity and dielectric based soil moisture sensors (Decagon 2010), (Irrometer 2011). Tensiometers and electrical resistance based sensors needs calibration when the type of soil is changed. Neutron thermalization and dielectric type sensors are quite stable in operation and do not require frequent calibration but they are higher in cost. Comparison of the performance of various sensors is given in (Hanson, Orloff and Peters 2000). Sufficient water availability in the soil is also depends upon type and texture of the soil. Irrigation scheduling based on soil based approach found for crop specific as well for generalized system (D. S. Intrigliolo 2004), (Erika Krugera 1999), (M. D. Dukes 2005).

Plant based approach uses either plant physiological response or plant tissue water status to estimate plant water need. A review of plant based irrigation scheduling methods are presented in (Jones, 2004) and references there in. Difference between plant canopy temperature and ambient temperature is good indicator of plant $ET$. This technique is successfully used by many
researchers for irrigation scheduling (Jones 1999), (W. L. Ehrler 1977), (Kirk L. Clawson 1991). In certain circumstances plant based method proved more accurate and better. (Goldhamer and Fereres 2004). It is reported that the automation of irrigation system based on leaf thickness measurement is equal or better in drip irrigation installation (Y Sharon 2000). This approach needs very sophisticated sensors. This approach is not widely used for irrigation scheduling.

### 2.2.3 Soil Fertility Management

Soil fertility is the inherent capacity of a soil to supply plant nutrients in adequate amounts, forms, and in suitable proportions to maximize plant growth. Level of various soil nutrition components like Nitrogen (N), Phosphorus (P), Potassium (K), Carbon (C), Magnesium (Mg), Calcium (Ca), Sulphur (S), and Manganese (Mn) have specific role in the growth and productivity of the plant. Short summary of effects of various nutrients on plant growth is provided in table 2.1. During sixties majority of research highlighted more and more use of fertilizers and micro nutrients to increase the yield.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Nutrients</th>
<th>Available Form</th>
<th>Useful For</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nitrogen (N)</td>
<td>Nitrate, NO₃ and Ammonia, NH₃</td>
<td>Chlorophyll and protein formation</td>
</tr>
<tr>
<td>2</td>
<td>Phosphorus (P)</td>
<td>Phosphate</td>
<td>Root and fruit formation</td>
</tr>
<tr>
<td>3</td>
<td>Potassium (K)</td>
<td>K₂O</td>
<td>Growth of leafs</td>
</tr>
<tr>
<td>4</td>
<td>Magnesium (Mg)</td>
<td>MgSO₄</td>
<td>Photosynthesis process</td>
</tr>
<tr>
<td>5</td>
<td>Calcium (Ca)</td>
<td>CaCO₃</td>
<td>Cell wall</td>
</tr>
<tr>
<td>6</td>
<td>Manganese (Mn)</td>
<td>MnSO₄</td>
<td>Seed development</td>
</tr>
<tr>
<td>7</td>
<td>Carbon (C)</td>
<td>Carbonate</td>
<td>Glucose formation</td>
</tr>
<tr>
<td>8</td>
<td>Sulphur (S)</td>
<td>Sulphate, -SO₄</td>
<td>Root and fruit formation</td>
</tr>
</tbody>
</table>

Table 2.1 Soil nutrients and their function
The success story of “Green Revolution” in India and other developing countries had fascinated the researchers towards the maximization of fertilizers and pesticide usage in agriculture. It was found that to increase the productivity; the use of chemical fertilizers (N, P and K) was increased in unrestrained manner. In China the study reveals that from 1960 to 2000 productivity of wheat increased three fold and to achieve that the farmers had increased the usage of chemical fertilizers almost five fold. (Lin Zhen a 2006). There is a paradigm shift of fertilizer usage in agriculture from 1990s, where optimal usage of nutrients became an important issue for sustainable agriculture. Compare to other nutrients, issues of nitrogen fertilization are found in large numbers in research literature. This is mainly due to its pivotal role in the high productivity and more general applicability across the different crops.

AFOPro is DSS for nutrient management, developed at University of South Carolina, United States. It helps to track nitrogen (N), phosphorus (P) and potassium (K) in the livestock manure generated (De and Bezuglov 2006). A comprehensive model for nitrogen balance between soil and plant uptake is presented in (Papadopoulos, Kalivas and Hatzichristos 2011). The paper proposed the fuzzy logic based model to decide the optimum amount of nitrogen fertilizers in the field. Some studies reveal that the soil fertility and pest resistance capacity of the plant has significant linkage. Undue use of inorganic fertilizers can cause nutrient imbalance and inferior pest confrontation of the plant. Issue of over fertilization and its solutions are discussed at a length in (Altieri and Nicholls 2003).

2.2.4 Pest Management

“Pest” is defined as any species, strain, or biotype of plant, animal, or pathogenic agent injurious to plants or plant products. In the simple way the pest includes insects, pathogens and weeds. There is growing concern over the effective use of pesticide and other pest control techniques for
higher farm production. In fact there is a great improvement taken place in pest control to protect farm products in last three decades. But the recent survey shows that there is almost 25-30 % losses in soybean and wheat and 30-40 % in maize, rice and potatoes found across the word (Beddington 2010). These data varies across the countries. The data shows that still there is a scope of improvement in pest management practices. The importance of pest management is acknowledged in last couple of decades when the studies on harmful effect of pesticide have been revealed by various research publications. On one side the pesticides served the mankind by saving the crop from the pest and diseases. The other side is the damaging effect of the pesticides on the ecology. European Union and United States have started taking early steps on the over usages of pesticides in farming. Study on risk analysis due to indiscriminate use of pesticides and environmental spill over is presented in (Skevas, Stefanou and Lansink 2014). So, now the farming community is looking for some supportive mechanism to decide when and how much to apply pesticides in the field. This has opened a new avenue in the field of agriculture decision support system- pest management system. Numerous efforts are made in the field of pest management. They can be generally classify as---

- Pest identification systems
- Pesticide advisory systems
- Infection modeling and disease growth prediction systems
- Disease forecasting systems
  - Weather based disease forecasting systems
  - Plant disease forecasting using aerobiological sampling methods

Pest identification system is computer vision system to recognize the plant disease symptoms at the early stages (Pydipati, Burks and Lee 2005), (Boissard, Martin and Moisan 2008). A comprehensive review of advance techniques for early plant disease detection is presented in
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(Sankarana, et al. 2010). Pesticides advisory system are digital repository which helps the farmers to precisely select the pesticide for the particular disease (Singh, Sharma and Dhandapani 2006), (Sankar, Raju and Chandra 2006).

![Disease Triangle Diagram](image)

Figure 2.1 Disease triangle

Weather plays an important role in the development of a disease. The importance of weather in the formation and spread of the diseases can explain with the disease triangle concept (Bos and Parlevliet 1995).

Disease triangle concept graphically presented in figure 2.1. In order to occur disease in the plant; three conditions must be happening simultaneously. First it is necessary to have a susceptible host plant in a susceptible stage of development. The second is the presence of an active pathogen and the third condition is a suitable environment for the pathogen to cause disease of the plant. It is clear that the weather condition has major role to play in the occurrence of any disease in the crop. This has opened up a new area of research known as Disease Forecasting System. Early forecasting warning system can provide reliable and timely information to the farmers to deal with the disease in more efficient way. There are two approaches for the early disease detection – (i) Plant disease forecasting using aerobiological sampling methods (ii) Weather based disease forecasting systems.
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The first approach is to use aerobiological sampling to detect the airborne microorganism which can cause the diseases in the field in large scale (Jedryczka, et al. 2008). Due to easy availability of weather data from the weather stations, the weather based disease forecasting methods are well explored and developed by the researchers (Soon Sung Hong, et al. 2010), (Magarey, Fowler, Borchert, Sutton, Colunga-Garcia, & Simpson, 2007), (Gleason, et al. 2008).

2.2.5 Web Based Systems

Penetration of Information Technology (IT) in agriculture science was late compare to other application area. During late 1990s researchers had started integrating Information Technology revolution in agriculture research. In a survey paper, the author has listed out the important areas of precision agriculture where the IT has influential role to play (Cox 2002). There are three major areas of IT applications in agriculture:

- Data acquisition using remote sensing and closer range sensing (WSN)
- Data utilization in modelling and control system
- Data communication between machine-machine, man-machine and man-man

Prior to the Information Technology era, the majority of expert systems were stand alone applications. They mostly confined within the research laboratory of the institutes. It was difficult to imagine their real usage in the field except few exceptional cases. Accessibility of expert system was paramount issue for the applications of expert systems. As the web technology matures as well become easy accessible to the general people, this problem is solved.

There are large numbers of web services found for the agriculture processes. In fact the web based agricultural expert systems found for almost all processes of agriculture. The system architect for web based agriculture expert system is as presented in figure 2.2.
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![Figure 2.2 Architecture of web based agriculture expert system (Antonopoulou, et al. 2010)](image)

Figure 2.2 Architecture of web based agriculture expert system (Antonopoulou, et al. 2010)

There are climate forecasting information systems like – AgClimate (Fraisse, et al. 2006). Successful implementation of web-based expert systems are MAjor FIeld Crops (MAFIC-DSS), VARIwise, WISE with larger geographic area and wide variety of crops (Antonopoulou, et al. 2010), (McCarthy, Hancock and Raine 2010), (Leib, Todd and Gary 2001). The attempts are also
made to reutilize the available web resources by developing the soil water balance and irrigation-scheduling models in Unified Modeling Language (UML) (Papajorgji and Shatar 2004).

2.2.6 GIS based Systems

A Geographic Information System (GIS) is system design to capture, accumulate, analyze, handle, and present all types of geographical data. It deals with the spatial information of the earth. The concern area of GIS could be wide range of applications like – planning, security, agriculture, environment, hydrology, etc. Agriculture is basically a spatial process. It is very much dependent of location. So, the integration of GIS with certain class of expert system of agriculture is very useful. GIS can handle the spatial databases of essential information for agriculture processes.

![System architecture of SDSS (Rayed 2012)](image-url)
These are data related to soil, water resources, pest epidemics and weather. Amalgamation of GIS technology with the DSS makes the Spatial Decision Support System (SDSS) (Rayed 2012). Generalised architecture for GIS based DSS is presented in figure 2.3. Application of GIS based expert system for the water resource and its conservation found in the literature (Mbilinyi, et al. 2007), (V.M.Chowdary, Rao and Sarma 2003). Soil mapping, classification and protection systems with GIS technology are also attempted (Zhu, et al. 2001), (Rosa, et al. 2004). GIS based systems are useful for the regional level functionality. Several milestone works for the irrigation scheduling using GIS are reported (P.S. Fortes a 2005), (Georgoussis, et al. 2009). Stesalit System is a commercial solution available which integrates the GIS and Remote Sensing functionality for different aspects of agricultural processes. It provides forecasting for pest management. This Web-based and GIS-based Agriculture Decision Support System is indigenously developed in India (Stesalit 2009).

2.3 Expert System for Irrigation Scheduling

Preceding section explores the expert systems for all kind of agriculture processes. Worldwide significant works for different functionality based agriculture expert systems are reviewed. Among all, the irrigation scheduling got maximum attention of research community. Ever reducing irrigation water on the earth and increasing demand for more and more farm productions are of prime concern for the scientific community for optimum usage of water in the field. One aspect is adoption of efficient method of irrigation like - sprinkler or drip irrigation systems. On other side the scientific method for irrigation scheduling has equal role to play for efficient usage of irrigation water. The next section of the chapter presents different methods used to develop expert system for irrigation scheduling. Their comparison, practical issues and challenges are also discussed in details.
2.3.1 Overview on Irrigation Scheduling Methods

There are three major approaches for irrigation scheduling. These are soil based, plant based, and weather based water balance (A.A. Andales, Chávez and Bauder 2011), (CROPWAT 2009), (Goldhamer and Fereres 2004), (Hanson, Orloff and Peters 2000), (Sharon and Bravdo 2000), (Dukes and Scholberg 2005), (Krugera, Schmidta and Bruckner 1999), (Intrigliolo and Castel 2004), (Jones 1999), (Kirk L. Clawson 1991). Soil based method depends on actual soil moisture level of the field for irrigation scheduling. Plant based methods indirectly estimate water stress in plant on the basis of measurement of canopy temperature, trunk diameter, leaf thickness etc. Weather based water balance method calculates the water deficit in the field on the basis of various meteorological data like temperature, humidity, wind velocity, solar radiation, and crop related data. Unlike to soil based and plant based methods, weather based water balanced method does not require costly and specific sensors for the measurement of soil moisture, canopy temperature and leaf thickness. Advantages and pitfalls of plant based irrigation scheduling are well presented in (Jones 2004).

Closed loop system or fully automated irrigation scheduling systems are not much popular. There are some works reported regarding development of such system (Sharon and Bravdo 2000), (Pierce, et al. 2006), (Hess 1996). Use of Wireless Sensor Network (WSN) for the irrigation scheduling is reported by many researchers (Ruiz-Garcia, Lunadei, et al. 2009). Successful implementations of many such systems in developed countries are found in the literature (Vellidis, et al. 2008), (Beckwith, Teibel and Bowen 2004). However, implementation of such system in India is always difficult as it involves quite a high cost of wireless sensors. Irrigation scheduling systems either based on web, mobile or GIS are more appealing due to wide penetration of internet and cellular network even to the interior part of the country. There
are several attempts found in these directions (Edson Murakami 2007), (Magarey, Fowler, Borchert, Sutton, Colunga-Garcia, & Simpson, 2007), (P.S. Fortes 2005), (Soon Sung Hong, et al. 2010).

2.3.2 Irrigation Scheduling Based on Water Balance

High cost of sensors and geographically limited scope of the plant and soil moisture based system have encouraged the researchers to explore more on water balance method based irrigation scheduling systems. Expert system for irrigation scheduling based on weather data have been developed by many researchers. (Hess 1996) (G. Naadimuthu 1999), (Georgea, Shendeb and Raghuwanshi 2000). Few commercial product based on this technique are also available. (ADCON 2010). A software package CROPWAT 8.0 is also based on the weather data based method. CROPWAT 8.0 is considered as benchmark in irrigation scheduling science. It is used to calculate crop water requirements and suggest irrigation scheduling based on soil, climate and crop data. It also helps to suggest irrigation schedules for different management conditions (CROPWAT 2009). Large scale project management for irrigation scheduling has been addressed with weather data based technique (Fortes, Platonov, & Pereira, 2005). Weather based approach for irrigation scheduling eliminates the need of sensors. The weather parameters are readily available with most of the weather stations. All these merits have made this approach very appealing but, there are still several scientific challenges present in this method. The next section elaborates all these challenges and issues.

2.3.3 Issues and Challenges

A reference evapotranspiration rate ($ET_0$) is vital information for irrigation scheduling based on water balance method. $ET_0$ indicates the water consumption of the plant. So, the accurate measurement of $ET_0$ influences the accuracy of irrigation scheduling techniques. Due to
difficulty in direct measurements of evapotranspiration, estimation of evapotranspiration with the help of the atmospheric variables is proposed by many researchers. Development and modification of representative equation for $ET_0$ was very popular during 1940 to 1990. (H. J. Farahani, et al. 2007). It covers most inclusive Panman-Monteith (PM) equation to the simplest Hargreaves equation. Comparison of all equations for $ET_0$ is well presented in (R. E. Yoder 2005). Most accurate equation for estimation of $ET_0$ like Panman-Monteith needs large number of weather variables. Therefore, the implementation difficulty increase manifold for such equation. On the other hand simplified equation given by Hargreaves needs only temperature and solar radiation to measure to estimate $ET_0$ (Hargreaves and Allen 2003).

In spite being highly accurate method, Panman-Monteith (FAO-56 PM) is not practically useful for irrigation scheduling purpose. The equation needs six atmospheric variables - solar radiation, wind speed, air temperature, humidity data, vapor pressure and soil heat flux. It is very difficult to get all these variables from the weather stations.

Accurate estimation of evapotranspiration rate with limited weather data is yet an open scientific challenge. History of the development of equations for $ET_0$ estimation is quite comprehensive (Farahani, Howell, & Shuttleworth, 2007). The Hargreaves equation, as equation 2.1, has generated the highest attention among all other methods (Hargreaves and Allen 2003). This is because it needs minimum weather data. The required data by the Hargreaves equation are maximum day temperature, $T_{\text{max}}$, minimum day temperature, $T_{\text{min}}$ and extraterrestrial solar radiation, $R_a$. These data are normally available at most of the weather stations.

$$ET_0 = C_H (T_{\text{max}} - T_{\text{min}})^{E_H} (T_{\text{mean}} + 17.8) R_a$$

---------- (Equation 2.1)

Under the nominal climate condition, values of constants $C_H$ and $E_H$ are proposed as 0.0023 and 0.5 respectively.
Minimalism of such equation pays the price in terms of accuracy. Limited weather data based methods shows considerable inconsistency and inaccuracy in the estimation of the \( ET_0 \) (Jianbiao, et al. 2005). It has been reported that the Hargreaves equation is quite inaccurate to estimate the \( ET_0 \) under extreme weather conditions. It overestimates for hot and humid conditions (Subburayan, Murugappan and Mohan 2011). In case of windy location, the Hargreaves equation underestimates \( ET_0 \) (Martinez-Cob and Tejero-Juste 2004). Error in the \( ET_0 \) estimation using the Hargreaves equation under non-ideal climate condition is reported by many authors for different climate conditions (D.T.Jensen, et al. 1997), (Geroge 1989).

As presented in the chronological evolution of Hargreaves equation (Hargreaves and Allen 2003); it is reported that the effect of humidity, cloudy condition and wind gust is indirectly considered in the Hargreaves equation. As these effects are not considered explicitly, the Hargreaves equation does not provide accurate estimates of the \( ET_0 \) in extreme weather condition. The calibration of \( C_H \) and \( E_H \) values [Equation (2.1)] for different climate conditions is accepted approach to accomplish improved estimation from the Hargreaves equation. Large number of endeavors found in the literature on calibration of the Hargreaves equation for specific location. Location specific calibration of \( C_H \) and \( E_H \) are presented for different climate conditions like arid and cold (Tabari and Talaee 2011), cold and humid (Ravazzani, et al. 2012), semiarid (Mohawesh 2011), humid (Ruiz-Canales, et al. 2012) and different locations like high and low elevation (Ravazzani, et al. 2012) and coastal and inland (Mendicino and Senatore 2012).

The methods published for calibration are based on lengthy experimental procedure. Each one of these methods is valid for confined location only. Even this calibration is only valid for the specific season of the concerned location. The experimental calibration method is not a pragmatic approach. There is a need for universal method which is capable to provide accurate
calibration of the Hargreaves constants $C_H$ and $E_H$. This helps to eliminate the need of empirical study and location specific calibration. Problem of inaccuracy of the Hargreaves equation and its location specific calibration are major challenges in the implementation of water balance based method for irrigation scheduling.

2.4 Agriculture ES in India

Each country has different issues and methods pertaining to agriculture. Therefore, successful agriculture expert system for one country may not be useful to other country. Several study on required features of Agriculture ES for specific country are found in literature. A study on the Australian farmers need provides useful guideline for developing DSS for Agriculture farming conditions. (Nguyen, Wegener and Russell 2006). In attempt to build the expert system for India, a special attention is required to pay towards expert system developed for Indian context.

A global platform, Decision Support System for Agro-technological Transfer (DSSAT) is used by many researchers to develop crop growth models, cropping system model, and root zone water management with Indian context. (Arora, Singh and Singh 2007), (Timsina, et al. 2008). Many crop models developed in western countries are successfully evaluated for Indian crops. (Singh, Tripathy and Chopra 2008), (Mall, et al. 2004.). These studies are mainly on the plant growth model of popular Indian crops.

Irrigation efficiency in India is very low compare to other developed countries. Efficient irrigation scheduling is the answer to this problem. There are some attempts made in India to develop indigenous agriculture support system. Mathematical modeling for crop production and nutrition transfer for specific crops are presented in (Bhatia, et al. 2008), and (Singh, Tripathy and Chopra 2008). Primitive weather information based support system U-Agri (Ubiquitous Agriculture) is presented in (Koshy, et al. 2008). COMMONSenseNet (Panchard, et al. 2007)
and Crop-9-DSS (Ganesan, 2007) are Agri-DSS for irrigation scheduling and pesticide management for limited area using Wireless Sensor Network (WSN). Wireless Sensor Network (WSN) is used in these systems to collect the field parameters. This is one of the major constraints in implementation of these systems in large area. The majority of Indian farmers are marginal. This situation does not permit the use of costly hardware in the field. A commercial project called “mkrishi” is developed and launched by TCS (www.tcs.com). It provides information on weather, soil, fertilizer and pesticide that are specific to their plot of land. It is paid service and provides support only on weather and agriculture market related data. There are other few success stories of farm advisory systems also. The web based system like – eSagu, Intelligent advisory System for Farmers (IASF) are effectively used by the farmers (Ratnam, Reddy and Reddy 2005), (CDAC 2010).

In spite of heavy loss of farm productivity by the pest every year, there is little has been done in the area of crop protection. There are few attempts found for the expert system development for pesticide management in India. Major focuses of research are on expert system development for pest diagnosis and system development for curative and preventive measures. Disease forecasting is largely unexplored. Pesticide Advisor is the system developed to provide advice to the farmers regarding suitable pesticide for the concern pest. It is a digital repository work as an advisor (Singh, Sharma and Dhandapani 2006). Expert System for Pest and Disease on Different Field Crops in India (ESPDDFCI) is an expert system helps to identify pests and diseases on the basis of various distinguishable symptoms. It is nonspecific to crop and supports different languages on India (Sankar, Raju and Chandra 2006). Indian Cotton Insect Pest Management (ICOTIPM) and Expert System for Management of Malformation (ESMMDM) are the example
of crop specific expert pest advisory systems developed in India (Vennila, Majumdar and Ramasundaram 2004), (Chakrabarti and Chakraborty 2006).

2.5 Problem Formation

Profitability and sustainability of agriculture systems mainly depend on three essential aspects. They are irrigation scheduling, pest management and nutrition management. The third aspect farmland nutrition has very slow variability. Typically, the nutrients present in the field changes vary slowly. Government initiatives like - soil testing and soil health card worked very effectively in this regards. The soil health cards provides information like what are the level of different nutrients present in the field as well which one is more suitable crop for the field to the farmer. Therefore, nutrition management is not must soughted problem.

The most prominent problem areas of agricultural system are effective irrigation scheduling and pest management. Nonscienctific approach for irrigation scheduling not only damaging the crop productivity but also responsible for wastage of very precious water. A serious threat to sustainable agriculture in North Gujarat due to water wastage is presented in a white paper (Lall, et al. March 2011). Soil and Plant based methods for irrigation scheduling are not suitable in Indian agriculture systems due to financial and logistical situation. In general sensor based standalone irrigation scheduling methods are not useful due to its high cost and operational complexity. Expert System for irrigation scheduling based on weather based water balance is one of the promising solutions in Indian context.

Water balanced based irrigation scheduling requires information related to water consumption of plant. Water consumption of the plant is represented as evapotranspiration, $ET_0$. Accuracy of water balance method for irrigation scheduling is largely depends on accurate estimation of evapotranspiration rate ($ET_0$). Due to difficulty in the measurement of $ET_0$, estimation is well
accepted practice. Several attempts are made to establish analytical relationship between meteorological data and $ET_0$. The study reveals that the Hargreaves equation is inaccurate and inconsistence. In spite of lower accuracy, Hargreaves equation found to be more suitable in actual implementation of irrigation scheduling because it needs minimum weather data for the estimation of $ET_0$. Calibration of the equation constants, $C_H$ and $E_H$ for different climate conditions is required (Equation 2.1) to improve accuracy of the Hargreaves equation. The calibration procedures are lengthy and location specific. There is a need of a generalized calibration method to make the Hargreaves equation more pertinent and effective. In the present research work, non experimental, generalised and accurate calibration method for the Hargreaves equation is planned. Further, to make the calibration method usable, it is necessary to develop user friendly computer tool.

It has been observed that earlier attempts in development of expert systems lack various important features such as generalized framework, scalability of system to incorporate different crops and its variety. It also faced issues in ease in use and accessibility by the end user who is farmers. Current state of art information and communication technology provides opportunity to extend the real benefit of such system to the end users. Therefore a web-based expert system is one of the most promising solutions of existing problem in agriculture.

The research is aim at developing web based expert system by investigating suitable generalised design framework for its development which also provides scalable, reusable, and user friendly solution for the irrigation scheduling and other crisis management e.g. pest management. It is also necessary to minimize developmental and operational cost of the system to extend the reach and application of system to large mass making it low cost solution. Looking at above discussion, several features and functionality are considered for the proposed web based system.
Chapter 2

These are listed below:

- Development on the open source platform
- Scalability in terms of crops and their variety
- User friendly operation
- Easy up gradation of knowledge base
- Low cost model for the farmers
- Increased accessibility through the mobile application
- Flexible structure to incorporate other aspects like pest management in the farm.

In summary the overall problem definitions for the proposed research work are –

i. To propose the solution for non-experimental, non location specific and easy to use calibration method for the Hargreaves equation constants $C_H$ and $E_H$

ii. To create user friendly and open source computer tool for the calibration of the Hargreaves equation constants $C_H$ and $E_H$

iii. To develop an open, scalable, reusable, low cost web based expert system for irrigation scheduling based on generalized design framework for few common crops of Gujarat.

iv. To improve the accessibility of the expert system among the farmer community by providing interface through mobile device to the farmers.