THESIS ON

AUTOMATION OF DRIP IRRIGATION

SUBMITTED BY

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THESIS CERTIFICATE

This is to certify that the thesis titled **AUTOMATION OF DRIP IRRIGATION** submitted to iitm, submitted by **GADDE VENKATA SAI KUMAR**, to the Indian Institute of Technology Madras, Chennai for the award of the degree of Dual Degree, is a bona fide record of the research work done by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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I take this opportunity to thank my family and my friends for providing me support through my graduation.

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ABSTRACT

Irrigation is one of the major consumer of water especially ground water resources. The ground water resources are depleting across the world because of over exploitation in order to improve the yield of the crop. But to the ignorance of the farmers, over irrigation always reduce the yield of the crop. So, proper management of water for the purpose of irrigation is very necessary for conservation of resource and also to improve the yield of the crop by abnormal percentages. Research is being done on geo spatial techniques wherein large areas can be monitored by using satellite technologies, aerial vehicles etc. But considering the case of India, where 80% of the farmers possess less than 5 acres of land, geo spatial techniques are useful but are not affordable and are also not customizable. A search for alternative approach is done in this project and a feasible alternative control system is proposed with necessary results and simulations.

Primarily the parameters which can be obtained from the field were identified and the control system is built in matlab using these parameters. They are soil moisture content and pore water pressure. Soil moisture content can be measured using a sensor based on resistance measurement or capacitance measurement. Pore pressure head is measured using the tensiometer. Curve fitting is used to find the Water retention parameters (Van Genuchten Parameters alpha and n). A new parameter is proposed to decrease the neural network training error, to increase the resolution of finding the soil property. Simulation was done for 108 soil samples. Significant decrease in the error was observed.

Once the properties of the soil are known, proper decision has to be taken considering the various possible parameters. Various parameters are type of soil, normalized water content in the soil, part of the day, rainfall prediction, stage of the crop and available water for irrigation. Based on the above properties, the amount of irrigation water to be applied has to be calculated. Fuzzy Logic control was selected to maintain the water between the two limits PWP and the FC. A control system was built in Simulink to study the dynamics of the fuzzy logic control system. The output of the fuzzy logic system is converted into pressure with linear interpolation and given as the top boundary condition for the Richards equation. The water content at the depth after simulation is given as input into the fuzzy logic system. For initial parameters to start the loop, memory blocks were used. Water content staying within the limits PWP and FC was observed.

CHAPTER 1

INTRODUCTION

Irrigation is the main life line for food production in India. Dual cropping in India is only possible because of irrigation, as India has very concentrated rainfall in 6 months and remains dry during the other half, with some exceptions. The different types of irrigation systems are multi-purpose river valley projects, canals, tube wells, wells etc. Recent innovations have come up with better water management through sprinkler irrigation, drip irrigation and micro irrigation [1]. Better water management practices if not properly managed may not be effective than a normal tube well. There are majorly two advantages of managing irrigation processes. First comes the water conservation. Increase in dependence on irrigation across the country leads to the depletion of ground water table. With proper management, water can be conserved. Second, comes the increase in the productivity. With appropriate supply of water during critical stages of the plant growth, the productivity can be increased by at least 50% in certain crops and up to 100% in certain crops. There is empirical evidence for the increase in productivity obtained through experiments in Tamil Nadu. This model has not been used because of the lack of guidance to the farmers which was there in the case of experimental study. This project is intended to fill the gap between the farmers and the knowledge. We can find very few control systems in the market to control the irrigation in the field [9]. Irrigation management requires many variables to be taken as input like weather parameters, soil parameters, and crop parameters and to optimize the application of water. To optimize the costs, we need part of the system to be centralized and part of the system to be decentralized. To reduce the cost and increase the efficiency, a novel method is proposed in this report for better and efficient irrigation scheduling with minimal cost. Artificial intelligence technique comprising fuzzy logic control is used for the decision part of the irrigation system, neural networks is used to find the important property of the soil [9]. To understand the functioning of the system Richard’s equation is solved using finite difference method to obtain the moisture and the pressure values with given boundary conditions at a certain depth of the given column of soil [3]. Earlier application of electronics was on static machinery such as grain dryers. Most recent technology like digital electronics and the commercial availability of the microprocessors have facilitated application of new control systems. Agriculture always takes place in an unstructured environment, for example a leaf has same shape (for particular species), but in detailed engineering terms it is completely different. Conventional vehicle platforms, equipped with technology are being designed by john Deere for customized applications. Basically technology in agriculture combines agriculture and information, influences awareness of our ecology and to maintain and improve efficiency. The framework of precision agriculture focuses on a concept of fit between different variables, precision agriculture provides the possibility to do the right thing at the right time, at the right place in the right time. Precision agriculture helps in providing precise inputs like water, fertilizer, insecticides [12]. Getting accuracy in field measurements is difficult due to the confounding factors, environmental challenges, complex and dynamic nature of biological chemical systems [8].

1.1. IRRIGATION SCHEDULING

Irrigation scheduling is simply to know when to irrigate and how much to irrigate. An effective irrigation schedule helps to maximize productivity while minimizing water and energy use. The following factors contribute to develop a workable and efficient irrigation schedule:

- Soil properties
- Soil-water relationships
- Type of crop and its sensitivity to drought stress
- Stage of crop development
- Availability of a water supply
- Climatic factors such as rainfall and temperature.

The soil is composed of three major parts - air, water, and solids. The solid component forms the framework of the soil and consists of mineral and organic matter. The solid fraction is made up of sand, silt, and clay particles. The proportion of the soil occupied by water and air is referred to as the pore volume. The pore volume is generally constant for a given soil layer but may be altered by tillage and compaction. The ratio of air to water stored in the pores changes as water is added to or lost from the soil. Water is added by rainfall or irrigation. Water is lost through:

- Surface runoff
- Evaporation (direct loss from the soil to the atmosphere)
- Transpiration (losses from plant tissue)
- Percolation (seepage into lower layers) or drainage.

As a plant extracts water from the soil, the amount of PAW in the soil decreases. The amount of PAW removed since the last irrigation or rainfall is the depletion volume.

Potential evapotranspiration is controlled by atmospheric conditions and is higher during the day. Plants must extract water from the soil that is next to the roots. As the zone around the root begins to dry, water must move through the soil toward the root. Daytime wilting occurs because PET is high and the plant takes up water faster than the water can be replaced. Therefore the availability of water in the soil is very less. As the plant extracts water, the soil immediately adjacent to the roots dries. If the rate of water movement from moist zones is less than the PET, the plant temporarily wilts [7]. At night when PET decreases to near zero, water steadily moves from the wetter soil to the drier zone around the roots. This process of wilting during the day and recovering at night is referred to as temporary wilting. Proper irrigation scheduling reduces the length of time a crop is temporarily wilted.

1.2. DIFFERENT TYPE OF SOILS

Soils are a very complex natural resource, much more so than air and water. Soils contain all naturally occurring chemical elements and combine simultaneously solid, liquid and gaseous states. Moreover, the number of physical, chemical and biological characteristics and their combinations are nearly endless. No wonder then that many different approaches have been proposed to come to a sensible grouping of different soils. Also soil classification systems were developed for different purposes.

The soils are majorly divided into 12 categories depending upon the amount of sand, silt and clay amounts. They are majorly clay, sand, silt, sandy clay, silty clay, clay loam, silty clay loam, loam, silt loam, sandy loam, loamy sand, sandy clay loam. Soil textures are classified by the fractions of each soil (sand, silt, and clay) present in a soil. Classifications are typically named for the primary constituent particle size or a combination of the most abundant particles sizes. A fourth term, loam, is used to describe a roughly equal concentration of sand, silt, and clay, and lends to the naming of even more classifications. Soil separates are specific ranges of particle sizes. The smallest particles are clay particles and are classified as having diameters of less than 0.002 mm. The next smallest particles are silt particles and have diameters between 0.002 mm and 0.05 mm. The largest particles are sand particles and are larger than 0.05 mm in diameter. Furthermore, large sand particles can be described as coarse, intermediate as medium, and the smaller as fine. Different countries have their own particle size classifications.

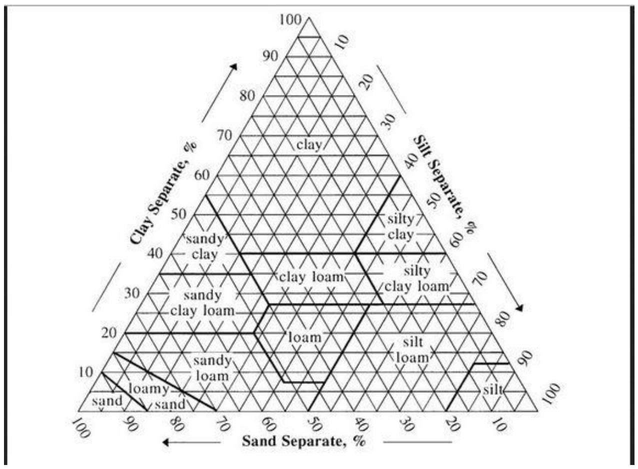


Fig.1.1. Soil classification triangle

1.3. VOLUMETRIC WATER CONTENT

Volumetric water content is defined mathematically as the ratio of volume of the water to the total volume which is sum of volume of soil, volume of water and the air space.

$$\theta = \frac{V_W}{V_T} \tag{1.1}$$

$$V_T = V_s + V_v = V_s + V_w + V_a \tag{1.2}$$

V_w = Volume of water

V_T = Total Volume

V_s = Volume of the soil

V_a = Volume of the air

1.4. PERMANENT WILITING POINT

Permanent wilting point (PWP) is defined as the minimal point of soil moisture the plant requires to not wilt. If moisture decreases to this or any lower a plant wilts and can no longer recover its turgidity when placed in a saturated atmosphere for 12 hours. The physical definition of the wilting point (symbolically expressed as θ_{pwp} or θ_{wp}) is defined as the water content at -15000 cms of pressure head. However, it is noted that the PWP values under field conditions are not constant for any given soil but are determined by the integrated effects of plant, soil, and atmospheric conditions. But it can be used as a reference value for other parameters.

1.5. FIELD CAPACITY

Field Capacity is the amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement has decreased. This usually takes place 2–3 days after rain or irrigation in pervious soils of uniform structure and texture. The physical definition of field capacity (expressed symbolically as θ_{fc}) is the bulk water content retained in soil at −0.33 bar of hydraulic head or suction pressure. There is a limitation in the measurement of field capacity and it is affected by so many factors. Precisely, it is not a constant for a particular soil, yet it does serve as a practical measure of soil water-holding capacity. Field capacity is characterized by measuring water content after wetting a soil profile, covering it (to prevent evaporation) and monitoring the change of soil moisture in the soil.

1.6. SOIL PORE PRESSURE (PORE WATER PRESSURE)

Pore water pressure refers to the pressure of groundwater held within a soil or rock, in gaps between particles. In the unsaturated zone, the pore pressure is determined by capillarity and is also referred to as tension, suction. Pore water pressures under unsaturated conditions (vadose zone) are measured in with tensiometer. Tensiometer operate by allowing the pore water to come into equilibrium with a reference pressure indicator through a permeable ceramic cup placed in contact with the soil.

1.7. SATURATED HYDRAULIC CONDUCTIVITY

Hydraulic conductivity, symbolically represented a K, is a property that describes the ease with which a fluid (usually water) can move through pore spaces or fractures. It depends on the intrinsic permeability of the material, the degree of saturation, and on the density and viscosity of the fluid. Saturated hydraulic conductivity, K_{sat}, describes water movement through saturated media.

$$\mathrm{K} = \frac{\mathrm{QL}}{\mathrm{Aht}} \tag{1.3}$$

The hydraulic conductivity of a soil is a measure of the soil's ability to transmit water when submitted to a hydraulic gradient. Hydraulic conductivity is defined by Darcy's law, which, for one-dimensional vertical flow, can be written as follows:

$$\mathrm{U} = -\mathrm{K}\frac{\mathrm{dh}}{\mathrm{dz}} \tag{1.4}$$

Where U is Darcy's velocity (or the average velocity of the soil fluid through a geometric cross-sectional area within the soil), h is the hydraulic head, and z is the vertical distance in the soil. The coefficient of proportionality, K, is called the hydraulic conductivity. The term coefficient of permeability is also sometimes used as a synonym for hydraulic conductivity. The hydraulic conductivity is defined as the ratio of Darcy's velocity to the applied hydraulic gradient. The dimension of K is the same as that for velocity, that is, length per unit of time (LT^{-1}). More specifically, the hydraulic conductivity determines the ability of the soil fluid to flow through the soil matrix system under a specified hydraulic gradient. The soil fluid retention characteristics determine the ability of the soil system to retain the soil fluid under a specified pressure condition. The hydraulic conductivity depends on the soil grain size, the structure of the soil matrix, the type of soil fluid, and the relative amount of soil fluid (saturation) present in the soil matrix. The important properties relevant to the solid matrix of the soil include pore size distribution, pore shape, tortuosity, specific surface, and porosity. In relation to the soil fluid, the important properties include fluid density, and fluid viscosity.

1.8. WATER RETENTION CURVE

Water retention curve is the relationship between the water content, θ and the soil water potential, Ψ . This curve is characteristic for different types of soil, and is also called the soil moisture characteristic curve. It is used to predict the soil water storage, water supply to the plants and soil aggregate stability. The general features of a water retention curve, volume water content, θ, is plotted against the matric potential, Ψ .

At potentials close to zero, a soil is close to saturation, and water is held in the soil primarily by capillary forces. As θ decreases, binding of the water becomes stronger, and at small potentials (more negative, approaching wilting point) water is strongly bound in the smallest of pores, at contact points between grains and as films bound by adsorptive forces around particles.

Sandy soils will involve mainly capillary binding, and will therefore release most of the water at higher potentials, while clayey soils, with adhesive and osmotic binding, will release water at lower (more negative) potentials. The water holding capacity of any soil is due to the porosity and the nature of the bonding in the soil.

$$\theta(\Psi) = \theta r + \frac{\theta s - \theta r}{(1+(\alpha|\Psi|)^{n})^{1-\frac{1}{n}}} \tag{1.5}$$

$\theta(\Psi)$ = Water retention curve

$|\Psi|$= Suction Pressure

θs = Saturated Water Content

θr = Residual Water Content

α, n – Van Genuchten Parameters

CHAPTER 2

METHODOLOGY

Evapotranspiration is the amount of water evaporated and transpirated. This model uses the weather parameters and crop type to compute the amount of water moving upward due to the weather parameters like wind, solar energy etc. This is used to understand the amount of water lost into the atmosphere. Evapotranspiration is used to manage the irrigation event with more efficiency. As we do not exactly know the dynamics of water underground, Penman Monteith equation can help to calculate the amount of water to be applied. The irrigation management cannot be completed with evapotranspiration. In situation like rainfall, in situations like drought, etc. we need to know the parameters of the soil to understand the need to irrigate the farm. In order to understand the properties of the soil, we identified certain properties which are attainable in the field. With the help of parameters identified, neural network approach is used to find the more general property of the soil which is hydraulic conductivity. Hydraulic conductivity is the ease with which water can flow inside the soils.

Once the properties of the soil which can classify the soil in a better way were identified, fuzzy Logic control was used as the decision part of the control system. A set of new parameters were considered in the decision part as they play a very major role in irrigation management. The properties were included by considering the variables the farmers take into cognizance when they have to make the irrigation decisions. A novel system is proposed in this report with regard to the irrigation management using local parameters. Intense experimental validation is demanded before adopting this system into practical applications. Advanced computation techniques are used to understand the complex environment system. The below figures show the process flow chart.

2.1. EVAPOTRANSPIRATION

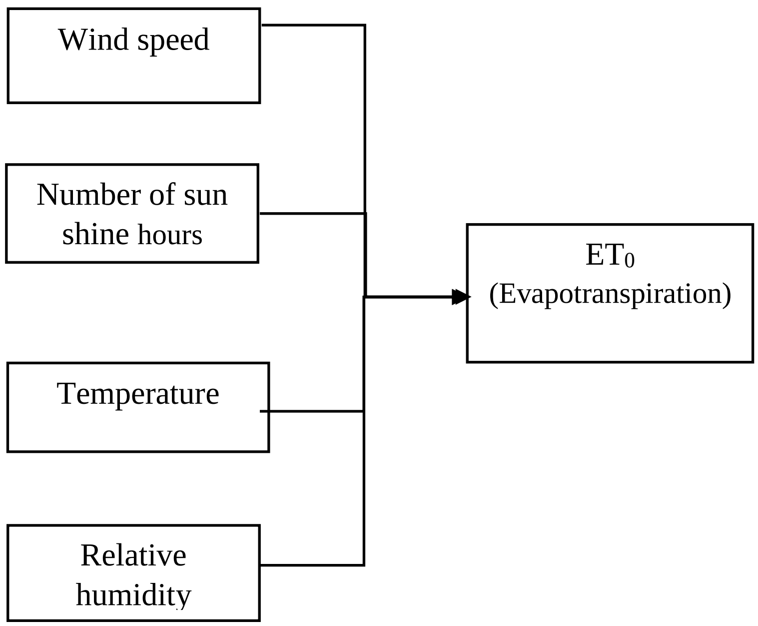


Fig.2.1. Evapotranspiration flow chart

2.2. PROPERTIES OF SOIL

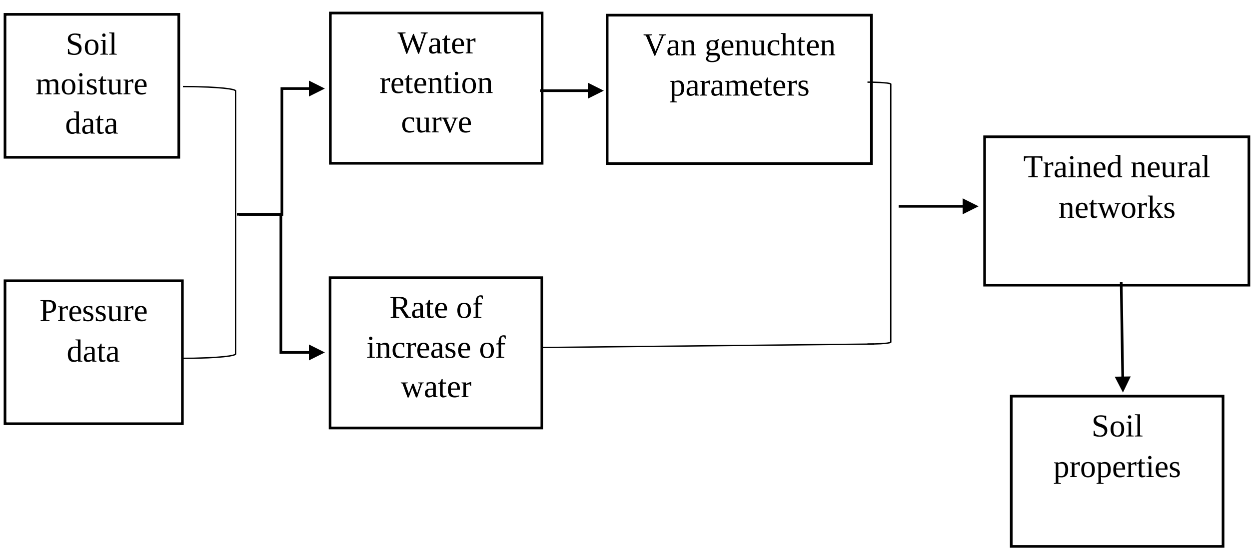


Fig.2.2. Backward finding of soil properties flow chart

2.3. DECISION SYSTEM

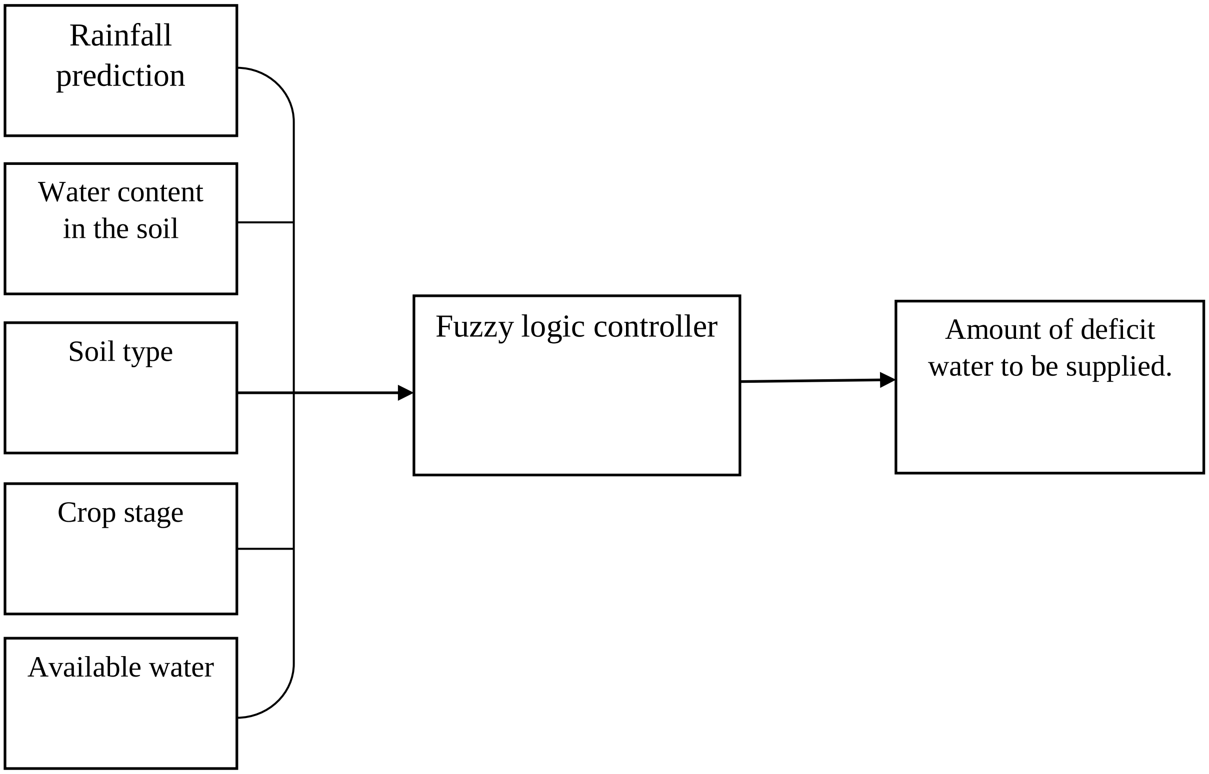


Fig.2.3. Decision system flow chart

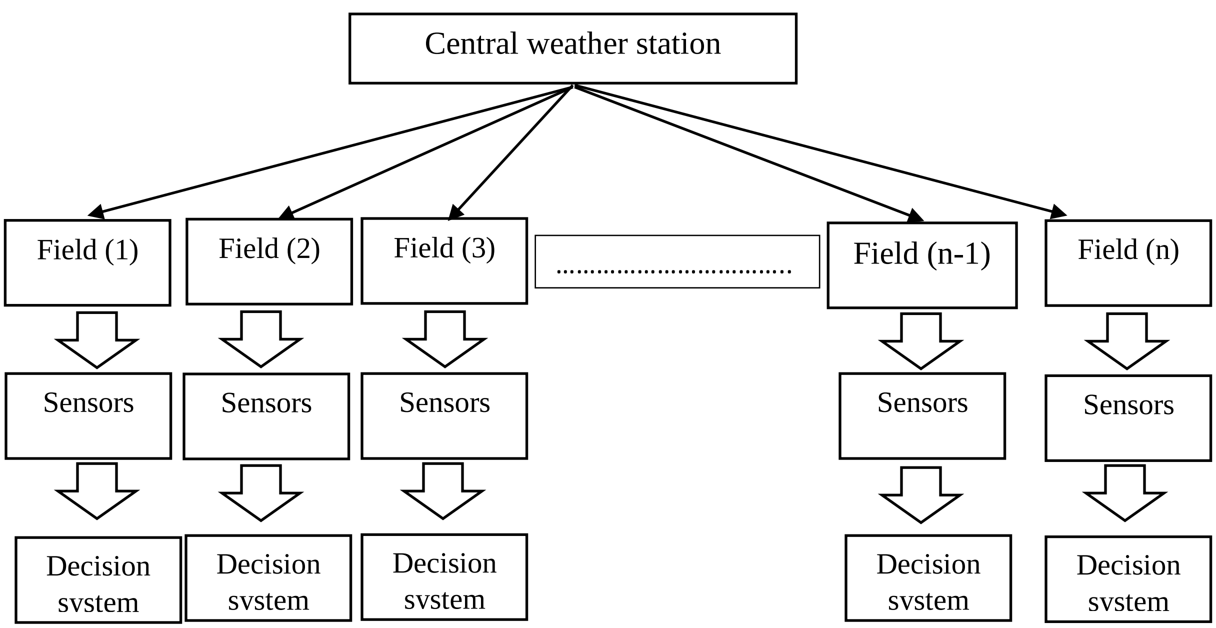


Fig.2.4. Flow chart for the system architecture

CHAPTER 3

EVAPOTRANPIRATION

Evapotranspiration is to calculate the amount of water escaping the field through evaporation and transpiration. This amount when subtracted from the quantity of water supplied helps to understand the water flow in the soil. So Matlab is used to construct the mathematical model of penman- monteith equation. Values of 7 parameters are collected for Chennai weather including temperature, humidity, wind speed, latitude. Three parameters z – height at which wind speed is acquired, Zsea – height of the land from the sea level, J – number of day between 1 and 365 are generated to understand their impact on output.

Function ET_0 = myfunction (Tmin, Tmax, Wsp, RHmin, RHmax, n, z, L, Zsea, J)

- T = Temperature
- Wsp = Wind speed
- RH = Relative humidity in air
- n = number of sun shine hours

The evapotranspiration needs four sensors to be run continuously to get the daily data. Every farm doesn’t need a wind speed sensor, temperature sensor, relative humidity sensor. So a central weather station which can transmit the weather data to the equipment placed in the field through wireless network is recommended. This can reduce the cost and the capital equipment required.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (3.1)$$

ET_o = Reference Evapotranspiration [mm/day]

R_n = Net radiation at the crop surface [MJ m^{-2} day^{-1}]

G = Soil Heat Flux

T = Mean daily air temperature at 2 m height [°C]

U_2 = Wind speed at 2 m height [m s^{-1}]

e_a = Saturation vapor pressure [kPa]

e_s = Actual vapor pressure [kPa]

$(e_s - e_a)$ = Saturation vapor pressure deficit [kPa]

Δ = Slope vapor pressure curve [kPa °C^{-1}]

Υ = psychometric constant [kPa °C^{-1}]

$$P = 101.3x\left(\frac{293-0.0065Z}{293}\right)^{5.26} \tag{3.2}$$

P = Atmospheric Pressure [kPa]

Z = Elevation above sea level [m]

$$\Upsilon = \frac{C_p P}{\varepsilon\lambda} \tag{3.3}$$

Υ= Psychometric constant [kPa °C^{-1}]

P = Atmospheric pressure [kPa]

λ = Latent heat of vaporization, 2.45 [MJ kg^{-1}]

C_p = Specific heat at constant pressure, 1.013 10^{-3} [MJ kg^{-1} °C^{-1}]

ε = Ratio molecular weight of water vapor/dry air = 0.622

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27T}{T+237.3}\right)\right]}{(T+237.3)^2} \tag{3.4}$$

Δ = Slope of saturation vapor pressure curve at air temperature T [kPa °C^{-1}]

T = Air temperature [°C]

$$e^o(T) = 0.6108\exp\left[\frac{17.27T}{T+237.3}\right] \tag{3.5}$$

$e^o(T)$ = Saturation Vapor pressure at air temperature T (kPa)

T = Air temperature [°C]

$$e_a = \frac{e^o(T_{min})\frac{RH_{max}}{100} + e^o(T_{max})\frac{RH_{min}}{100}}{2} \tag{3.6}$$

e_a = Actual vapor pressure [kPa]

$e^o(T_{min})$ = Saturation vapor pressure at daily minimum temperature [kPa]

$e^o(T_{max})$ = Saturation vapor pressure at daily maximum temperature [kPa]

RH_{max} = Maximum relative humidity [%]

RH_{max} = Minimum relative humidity [%]

$$P = 101.3\left(\frac{293-0.0065Z}{293}\right)^{5.26} \tag{3.7}$$

P = Atmospheric Pressure

Z = Elevation

$$RH = 100\left(\frac{e_a}{e^o(T)}\right) \tag{3.8}$$

RH = Relative Humidity

e_a = Actual Vapor Pressure

$e^o(T)$ = Saturation vapor pressure at the mean temperature

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)] \tag{3.9}$$

R_a = Extraterrestrial Radiation

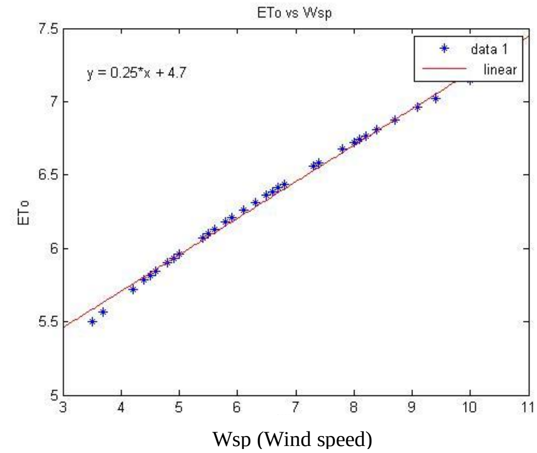
G_{sc} = Solar constant

d_r = Inverse relative distance earth sun

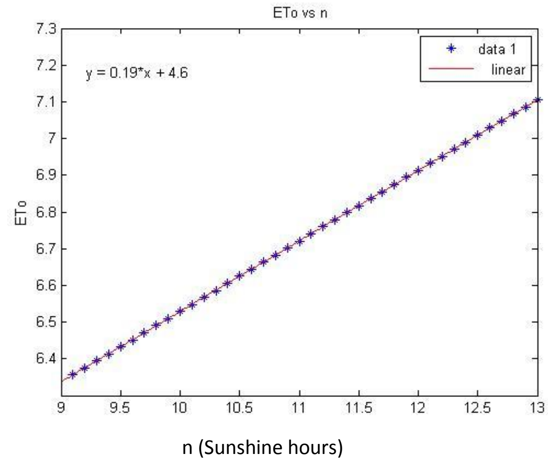
ω_s = sunset hour angle

ω_s = Sunset hour angle

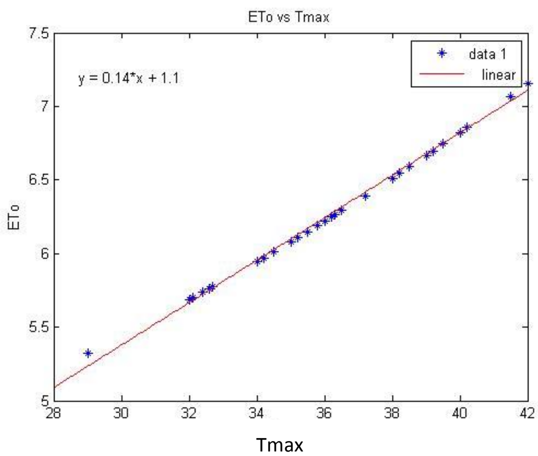
ω_s = Solar decimation



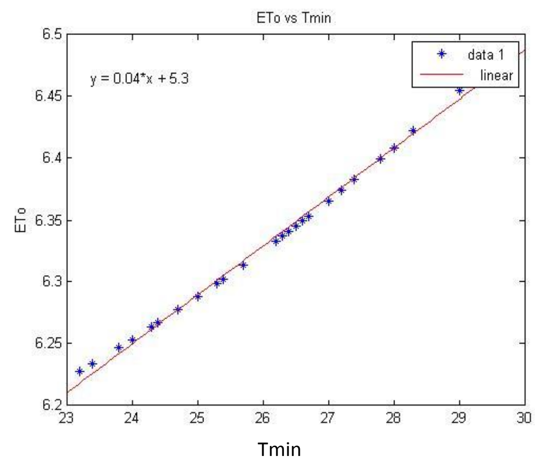
(a)Variation of ET_0 with wind speed



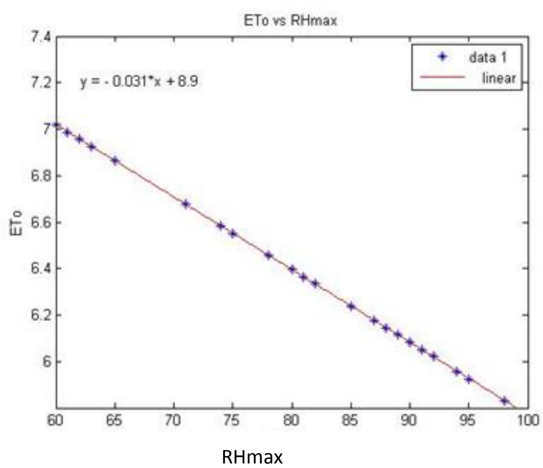
(b) Variation of ET_0 with sunshine hours



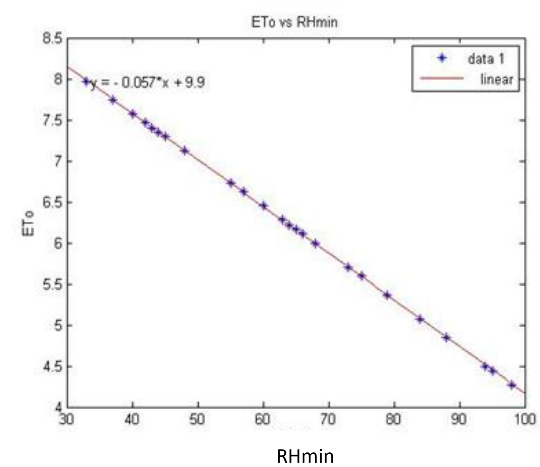
(c) Variation of ET_0 with T_{max}



(d) Variation of ET_0 with T_{min}



(e) Variation of ET_0 with RH_{max}



(f) Variation of ET_0 with RH_{min}

Fig.3.1. Variation of ET_0 with various input parameters

The above analysis was done to understand the influence of different parameters on the evapotranspiration. This analysis was used later while considering the input parameters for the fuzzy logic control. The amount of water lost through evapotranspiration was also calculated. The above result are an outcome of the modelling of Penman Monteith Equation in matlab with the meteorological parameters of Chennai for consecutive 30 days procured from a weather forecasting website. The evapotranspiration model is not sufficient to automate the irrigation process as the model is unaware of the conditions present in the soil. It is unaware of the type of the soil, soil properties, how much to irrigate and when to irrigate. If the deficit amount of water is applied in a single splash, water may get wasted because of the runoff over the land. Certain weather conditions like rainfall event is not taken into consideration. Finally the rate of application of water should depend upon the type of the soil. Sandy soils absorbs more water but excess addition may lead to more percolation loss. Clay soils absorb water slowly as they have very low saturated hydraulic conductivity. For clayey soils, water have to be applied slower than sandy soils. The retaining capacity is also different for different soils. The amount excess amount of water greater than the retaining capacity of the soil should be completely avoided.

CHAPTER 4

MOVEMENT OF WATER IN THE UNSATURATED ZONE

4.1. VADOSE ZONE

The vadose zone, also termed as the unsaturated zone, is the part of Earth between the land surface and the top of the phreatic zone i.e. the position at which the groundwater (the water in the soil's pores) is at atmospheric pressure. Hence the vadose zone extends from the top of the ground surface to the water table. Water in the vadose zone has a pressure head less than atmospheric pressure, and is retained by a combination of adhesion, and capillary action. If the vadose zone envelops soil, the water contained therein is termed soil moisture. In fine grained soils, capillary action can cause the pores of the soil to be fully saturated above the water table at a pressure less than atmospheric. The Richards equation is often used to mathematically describe the flow of water, which is based partially on Darcy's law.

The Richards equation represents the movement of water in unsaturated soils. It is a non-linear partial differential equation, which is often difficult to approximate since it does not have a closed-form analytical solution. Darcy's law was developed for saturated flow in porous media. To this Richards applied a continuity requirement, and obtained a general partial differential equation describing water movement in unsaturated non-swelling soils. The transient state form of this flow equation, is known commonly as Richard’s equation.

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left[k(\theta)\left(\frac{\partial\Psi}{\partial z} + 1\right)\right] \tag{4.1}$$

Discretization of the differential equation.

$$\frac{\theta^{n+1,m+1} - \theta^{n}}{\Delta t} - \frac{\partial}{\partial z}\left(K^{n+1,m}\frac{\partial H^{n+1,m+1}}{\partial Z}\right) - \frac{\partial K^{n+1,m}}{\partial Z} = 0 \tag{4.2}$$

The key to the method is expansion of $\theta^{n+1,m+1}$ in a truncated Taylor series with respect to H, about the expansion point$H^{n+1,m}$.

$$\theta^{n+1,m+1} = \theta^{n+1,m} + \frac{d\theta}{dh}(H^{n+1,m+1} - H^{n+1,m}) + 0(\delta^2) \quad (4.3)$$

$$C_i^{n+1,m}\frac{\delta_i^m}{\Delta t} - \frac{1}{(\Delta z)^2} x \left[K_{i+1/2}^{n+1,m}(\delta_{i+1}^m - \delta_i^m) - K_{i-1/2}^{n+1,m}(\delta_i^m - \delta_{i-1}^m)\right] =$$
$$\frac{1}{(\Delta z)^2}[K_{i+1/2}^{n+1,m}(H_{i+1}^{n+1,m} - H_i^{n+1,m}) - K_{i-1/2}^{n+1,m}(H_i^{n+1,m} - H_{i-1}^{n+1,m})]$$
$$+ \frac{K_{i+1/2}^{n+1,m} - K_{i-1/2}^{n+1,m}}{\Delta z} - \frac{\theta_i^{n+1,m} - \theta_i^n}{\Delta t} = (R_i^{n+1,m})_{MPFD} \quad (4.4)$$

Where

$$C_{i-1} = \frac{1}{12}(C_{i-1}^{n+1,m} + C_i^{n+1,m})$$

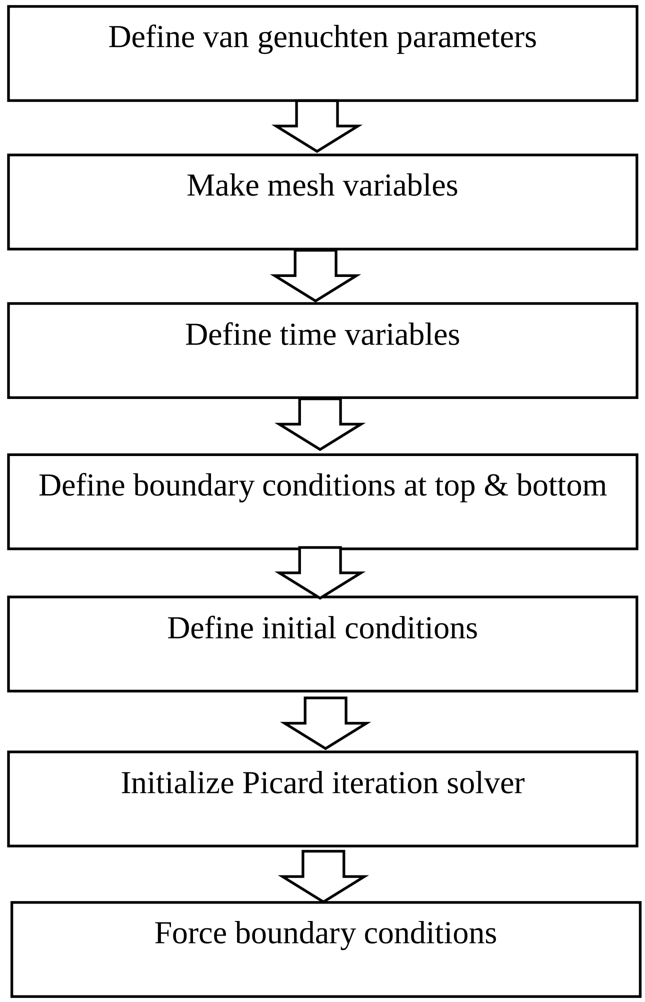
$$C_i = \frac{1}{12}(C_{i-1}^{n+1,m} + 6C_i^{n+1,m} + C_{i+1}^{n+1,m})$$

$$C_{i+1} = \frac{1}{12}(C_i^{n+1,m} + C_{i+1}^{n+1,m})$$

$$K_{i-\frac{1}{2}}^{n+1,m} = \frac{1}{2}(K_{i-1}^{n+1,m} + K_i^{n+1,m})$$

$$K_{i+\frac{1}{2}}^{n+1,m} = \frac{1}{2}(K_i^{n+1,m} + K_{i+1}^{n+1,m})$$

4.2. FLOW DIAGRAM



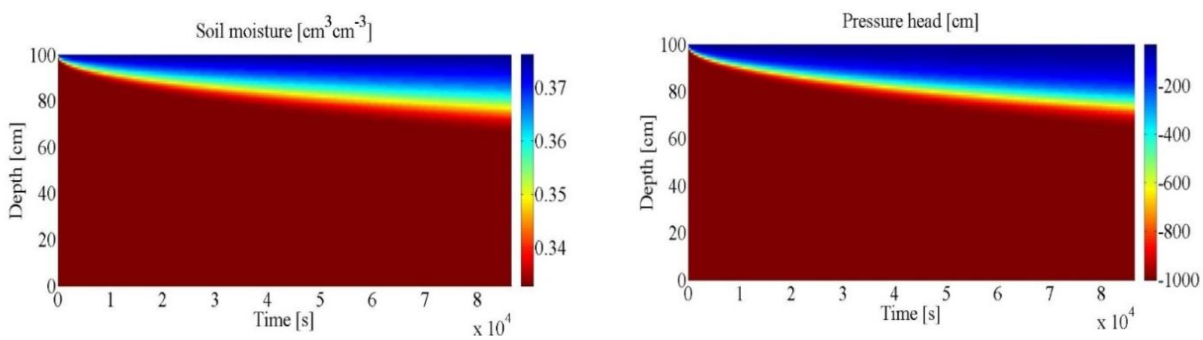
4.3. INPUT DATA

Stopping tolerance
Alpha (Van genuchten parameter)
n (Van genuchten parameter)

Theta_S (Saturation water content)
Theta_R (Residual water content)
Ksat (Saturated hydraulic conductivity)
Depth & depth interval
Time & time interval

4.4. SIMULATION

Simulation was done for 108 different soil samples with 9 samples belonging to each broad category of soils among the 12 categories. The simulation result of one soil sample is attached below for illustration. Fig. 4(a) shows the movement of water downward with given initial boundary conditions. Fig. 4(b) shows the pressure head values at various depths changing with time. The red portion of the figure. 4(a) is the soil containing the water given as the initial boundary conditions. The increase in the blue portion of the image below shows the gradual movement of water down the soil.



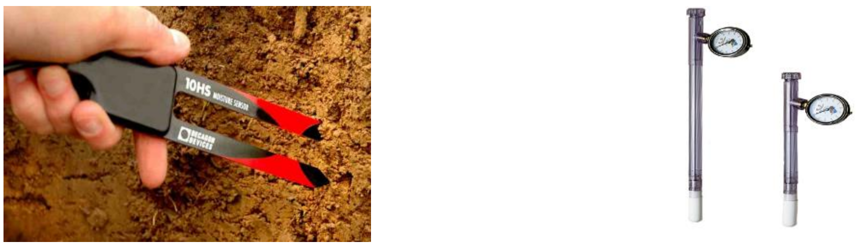
(a) Soil Moisture vs Depth and time (b) Pressure head vs Depth and time

Fig.4.1. Variation of water content and pressure head with time and depth for silty loam soil

CHAPTER 5

BACKWARD FINDING OF SOIL PROPERTIES

The obtainable parameters from the soil are soil moisture content and pore pressure. These sensors are considered as the primary equipment for the modelling of the control system.



(a) Soil moisture sensor (b) Tensiometer

Fig.5.1. Sensors used for backward finding of the soil properties.

Local soil classification is a necessary part of the control system as it is used in the decisions to be taken by the control system (Fuzzy Logic). Two major properties necessary for the management of irrigation are permanent wilting point and the field capacity. The soil characteristics are necessary to make decisions of how much water to use and when to use. The soil has to be classified locally. We have two properties which can be measured with low cost and with minimal complexity.

5.1. BACKWARD FINDING OF THE SOIL PROPERTIES

Moisture content at a certain depth and the pressure head at certain depth are two measurable properties. With the help of continuous values with time at the same depth, we can find the van Genuchten Parameters using curve finding algorithm. To give an input to mimic the real situation, a noise is added to the values taken from the simulation of the Richards equation. Van genuchten parameters depends upon the soil physical properties like sand particles diameter, pore spaces, packaging etc. The van genuchten parameters are constant for a particular soil and does not depend upon the amount of moisture content and the pressure head.

CHAPTER 6

NEURAL ANALYSIS

6.1. NEURAL NETWORKS

Neural networks are very good at function fit problems. A neural network with enough elements called neurons can fit any data with arbitrary accuracy. They are particularly well suited for addressing non-linear problems. Two parameters which are dependent on the shape and structure of the soil i.e. alpha and n are found through curve fitting algorithm. The two limits for the management of water for irrigation are the permanent wilting point (PWP) and the field capacity (FC). Residual water content is difficult to obtain with in-field measuring techniques. Residual water content (Theta R) is measured in the laboratory after heating the soil in oven for 24 hours. In place of this variable we have to use some other variables which are characteristic of the physical properties of the soil. We include this into our model so that an individual characteristic of the soil is included and the predictability of the soil will also increase.

Slope of moisture content change at a particular moisture content at a certain depth is obtained. The easily obtainable parameters are the van genuchten parameters. Saturation water content is difficult to obtain in the field because of the water percolation due to the gravity. A new variable is taken after many trial and error methods. This is also used as input to train the neural network. Performance is measured in terms of mean squared error, and shown in log scale. It rapidly decreased as the network was trained. Performance is shown for each of the training, validation and test sets. Fig. 6(e) shows the variation of $\frac{d(\theta)}{dt}$ with θ. At small θ (water content), the rate is higher as the suction pressure in soil is high. As θ increases the $\frac{d(\theta)}{dt}$ decreases and this gave us a new variable. Fig. 6(b) shows the variation of variable C with different soils i.e. hydraulic conductivity.

$$C = \frac{1}{\theta}\left(\frac{d(\theta)}{dt}\right) \tag{6.1}$$

6.2. NEURAL NETWORK STRUCTURE

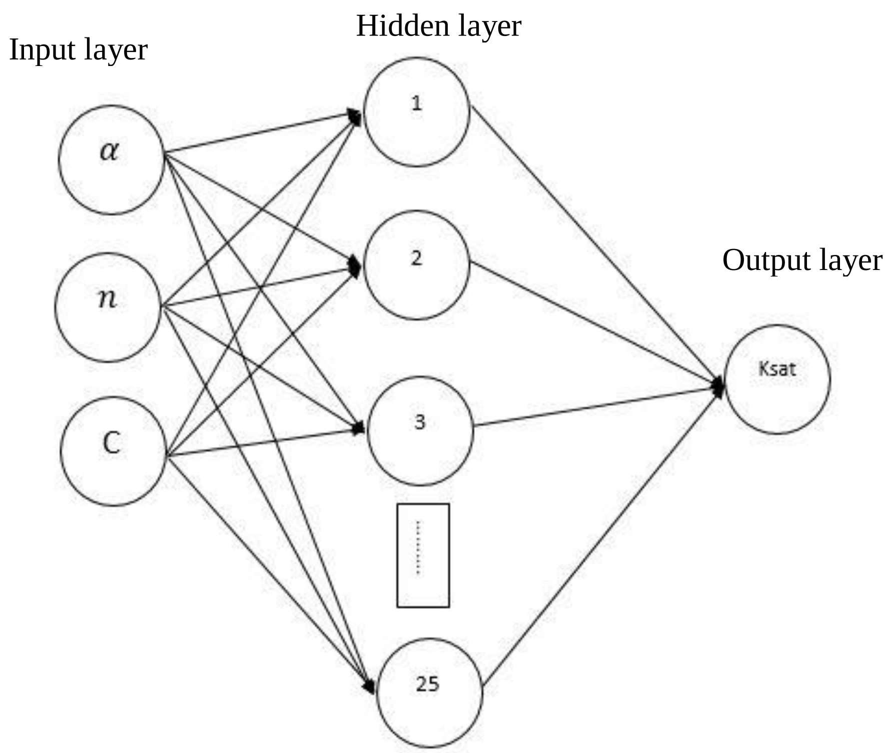
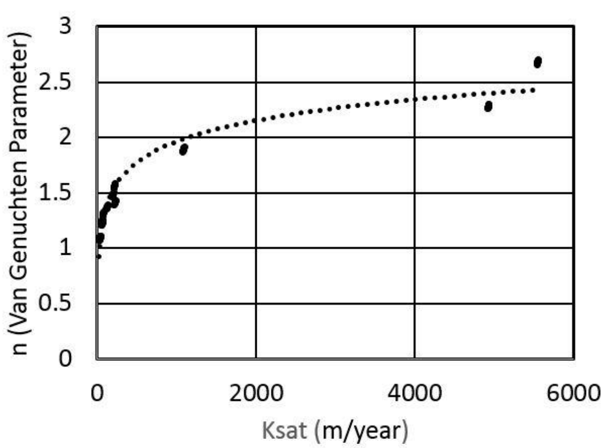
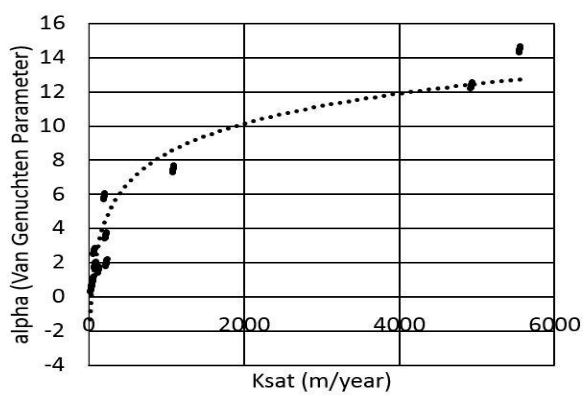


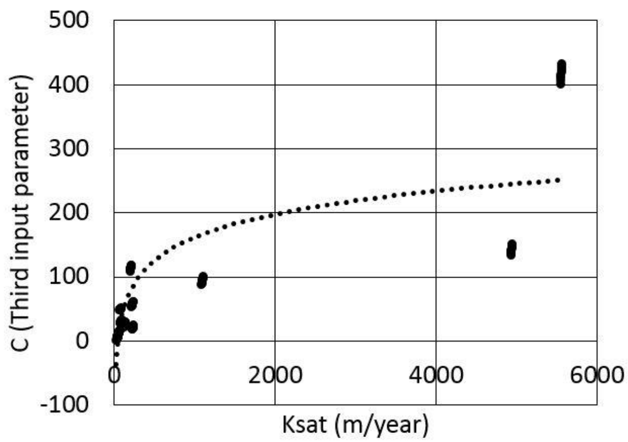
Fig.6.1. Neural Network structure with 3 inputs and 25 Neurons in the hidden layer.



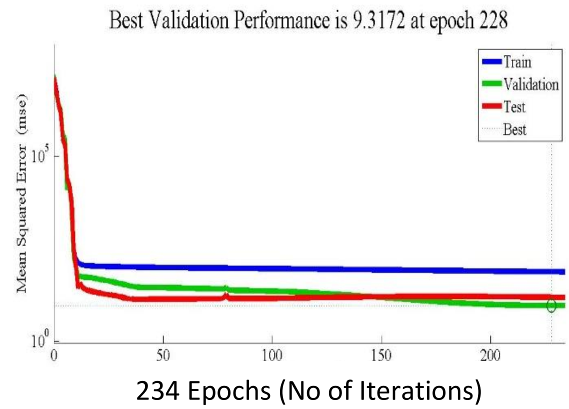
(a) Variation of n with Ksat



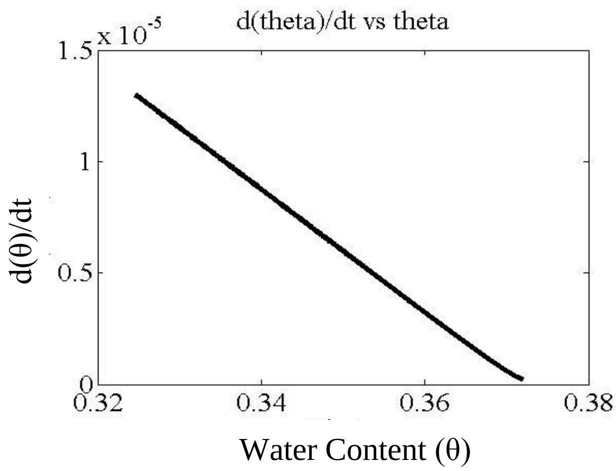
(b) Variation of alpha with Ksat



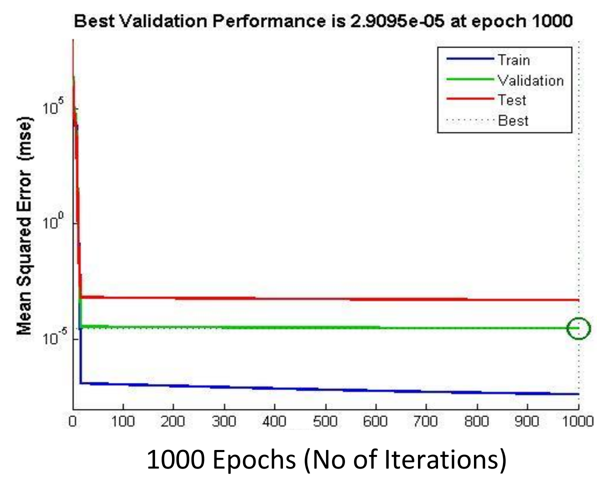
(c) Variation of C with Ksat



(d) Performance of Neural Network 1



(e) Variation of rate of change of water content d(θ)/dt with water content (θ)



(f) Performance of Neural Network 2

Fig.6.2. Neural network structure performance measurement

Less performance was observed when there were two parameters, than the performance when three input parameters were considered. The mean square error when two variables were considered was 9.3172 and the mean square error when three variables were considered was 2.9095e-05.

CHAPTER 7

FUZZY LOGIC

Fuzzy logic is a form of many-valued logic that deals with approximate, rather than fixed and exact reasoning. Compared to traditional binary logic (where variables may take on true or false values), fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. Furthermore, when linguistic variables are used, these degrees may be managed by specific functions.

This is the decision part of the control system. The decision of how much water to be applied and when to apply the water are taken with the help of artificial intelligence through fuzzy logic controller. Multiple input parameters are considered with one output parameter that is the fraction of deficit amount of water to be applied. Fuzzy logic can be used to improve the efficiency of the system by precision application of the water. If the rainfall is predicted to fall in next 2 days, the irrigation has to be avoided except when the crop is in the critical stage. This can be done to decrease the wastage of water. The system should not irrigate when the rainfall is predicted to fall on the same day. Fuzzy rules are based on these criteria based on common sense. The analytical skills of a farmer who has no technical knowledge is simply applied using the fuzzy logic system.

We do not have any relationships either mathematical or theoretical between the various inputs considered here and the output that is the amount of water to be given to the plants in an optimized way. So fuzzy logic controller was adopted. The common sense of a farmer can be programmed using the fuzzy logic. The most basic parameters or factors a farmer considers are given below:

- Rain prediction
- Moisture content in the soil – the farmer knows this by his knowledge of past water irrigation schedules.

- Temperature
- Available water, if adequate amount of water is available, then the water can stored as a reserve for future purposes rather than using it.
- Stage of the crop, is very necessary in taking decisions as the water has to be applied adequately in the critical stages of the crop development.

Output: The output is a fraction between 0 and 1.This output of the fuzzy logic is multiplied with the amount of water deficit in the soil. This is converted into pressure which is given as boundary condition to the Richard's simulation.

7.1. FUZZY RULES

The base of fuzzy rules includes a series of lingual rules which are extractable from any of the following resources by using expert's information:

- Physical rules governing dynamic equations of the system.
- Data from existing controllers.
- Experimental knowledge obtained from the expert and experienced individuals. If the expert's knowledge is employed, there is no need for mathematical model of the system and this is one of the great advantages of fuzzy systems.

7.1.1. TIME OF THE DAY

From a water conservation standpoint, daytime is a poor time to irrigate. Evapotranspiration is the combination of (a) the loss of water by transpiration of plants, and (b) evaporation from soil and plant surfaces. Evapotranspiration is greatest during the hottest hours of the day (10:00 am to 4:00 pm). This is when plants work the hardest to deal with the stress associated with mid-day climatic factors such as high temperatures, strong solar radiation and lower humidity. It is best to take a more preventative approach and prepare plants for this stress rather than a curative approach and irrigate plants when they are already stressed. In addition, water applications from sprinklers are more susceptible to drift and evaporation because of the previously mentioned climatic factors and because wind speeds are typically higher during the day. Estimates of water loss during daytime irrigation range from 20% to 30%, depending on humidity, wind speed, and temperature.

The best time of day to begin irrigation is after nightfall. The irrigation cycle should end early enough before sunrise to allow excess water to soak into the landscape so that the leaves will dry in the normal time period. Night-time temperatures and wind speeds are much lower, which means lower evaporative losses during irrigation. Night-time humidity is higher, which also reduces evaporation. There is no sun, so solar radiation does not contribute to water evaporation. Estimates of water loss during night-time irrigation are approximately 15%, once again depending on humidity, wind speed, and temperature.

7.1.2. STAGE OF THE CROP

Water use rate is a function of the crop's stage of development. The reduction in crop yield or quality resulting from drought stress depends on the stage of crop development. For a given level of stress, the yield reduction would be four times greater at the silking stage than at the knee-high stage. From the yield standpoint, applying irrigation water at silking would be worth four times more than if the same amount of water was applied during the knee-high stage. Knowledge of this relationship is most useful when the irrigation capacity or water supply is limited. When water is in short supply, irrigation should be delayed or cancelled during the least susceptible crop growth stages. The susceptibi1ity of corn to dry stress at various stages of development is shown in Figure below for illustration. The most critical irrigation period typically begins just before the reproductive stage and lasts about 30 to 40 days to the end of the fruit enlargement or grain development stage. This stage is considered as critical stage.

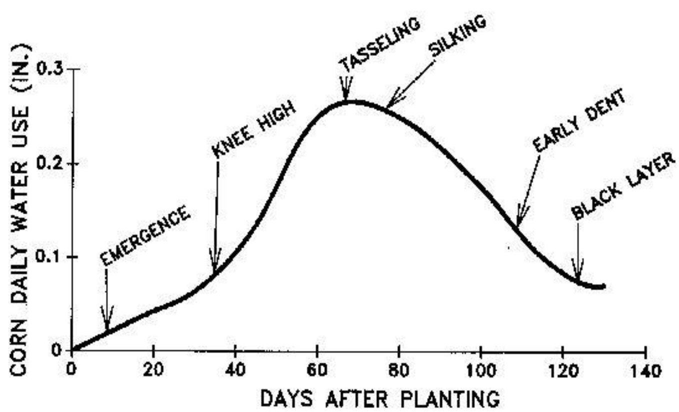


Fig.7.1. Corn daily water use with days after planting

Source: www.usda.com

7.1.3. WEATHER FORECASTING

The irrigation can be delayed for some time if rainfall is predicted in near future, i.e. within half to 1 day. If the rainfall prediction is within 2-4 days, just the amount of water required can be applied. If the rainfall prediction is more than 4 days then the water can be used as usual. If the weather is cloudy, the evapotranspiration is less and therefore the plant stress is also less.

7.1.4. TYPE OF THE SOIL

Type of the soil affects the amount of water to be applied. If the soil is sandy and the amount of water available is less and if the temperature is high, there is no need of irrigating as the any amount of water applied will just percolate downwards and will get evaporated. Sandy soils have a low water storage capacity and a high infiltration rate. They therefore need frequent but small irrigation applications, in particular when the sandy soil is also shallow. Under these circumstances, sprinkler or drip irrigation are more suitable than surface irrigation. On loam or clay soils all three irrigation methods can be used, but surface irrigation is more commonly found. Clay soils with low infiltration rates are ideally suited to surface irrigation. When a variety of different soil types is found within one irrigation scheme, sprinkler or drip irrigation are recommended as they will ensure a more even water distribution.

7.1.5. AVAILABLE AMOUNT OF WATER

The available amount of water is also an important criteria in managing the irrigation water. Decisions have to be taken considering other parameters also. For example rainfall prediction or temperature during the event of irrigation. If the amount of water available is low and the temperature is high then the irrigation could possibly be avoided because the evapotranspiration is high in the day time. If the amount of water available is high then the irrigation amount could possibly be lower just to suffice the heat of the sun. Necessary amount of water can be supplied the later night.

7.1.6. NORMALIZED WATER CONTENT

Normalized water content is the ratio of difference between the water content and residual water content and the difference between saturated water content and residual water content.

$$\mathrm{NWC} = \frac{\theta - \theta_R}{\theta_S - \theta_R} \tag{7.1}$$

Normalized water content for the purpose of irrigation scheduling has to be different from the above defined normalized water content as the upper and lower limits for the purpose of growing crops are permanent wilting point on the lower side and field capacity on the upper side.

$$\mathrm{NWC} = \frac{\theta - \theta_{PWP}}{\theta_{FC} - \theta_{PWP}} \tag{7.2}$$

7.1.7. OUTPUT

The output of the system is to maintain the amount of water in the soil up to the field capacity. The amount of water to be supplied is to fill the deficit amount of water in the soil. The output of the fuzzy logic is between 0 and 1. The amount of deficit water to be filled by irrigation is only given as low medium and high in the fuzzy logic rules tentatively. But the actual amount of water to be given is calculated by the fuzzy logic controller. The boundary condition being varied here with the actuation of fuzzy controller is the pressure of the water on the top surface of the soil. The pressure at the top surface of the soil is considered as the source of water.

7.2. DECISION VARIABLES FOR MEMBERSHIP FUNCTIONS

Table (1): Fuzzy logic membership functions of input variables

TEMPERATURE	DECISION VARIABLE	FUZZY LOGIC
0 – 20	Low	[0 0 0.2 0.33]
20 – 35	Normal	[0.2 0.33 0.53 0.66]
35- 45	High	[0.53 0.66 1 1]
STAGE OF THE CROP	DECISION VARIABLE	FUZZY LOGIC
Initial	Depends on Available water, and other variables	[0 0 0.4]
Critical	Full Irrigation	[0.1 0.5 0.9]
Harvest	Depends on Available water, and other variables	[0.6 1 1]
RAINFALL PREDICTION	DECISION VARIABLE	FUZZY LOGIC
Today	No irrigation	[0 0 0.3 0.45]
Tomorrow	Part of irrigation	[0.275 0.4 0.6 0.725]
2 Days	Full irrigation	[0.55 0.7 0.85 1]
TYPE OF SOIL	DECISION VARIABLE	FUZZY LOGIC
Sandy soils	Low	[0 0 0.20.33]
Silty soils	Normal	[0.2 0.33 0.66 0.8]
Clayey soils	High	[0.66 0.8 1 1]
AVAILABLE WATER	DECISION VARIABLE	FUZZY LOGIC
0-0.5	Low	[0 0.33 0.66]
0.5 – 1	High	[0.33 0.66 1]
NWC	DECISION VARIABLE	FUZZY LOGIC
Less than PWP	Negative	[0 0 .15 .25]
(0 to 0.5)x NWC	Low	[.2 .3 .45 .55]
(0.5 to 1) x NWC	High	[.45 .55 .70 .8]
More than NWC	Saturation level	[0.75 0.85 1 1]
OUTPUT	DECISION VARIABLE	FUZZY LOGIC
0 – 0.25	None	[0 0 0.2 0.3]
(0.25 – 0.50) x (1 – NWC)	Low	[.2 .3 .5 .6]
(0.50 to 0.75) X (1 – NWC)	Medium	[.45 .55 .75 .85]
(0.75 to 1) x (1 – NWC)	High	[0.7 0.8 1 1]

7.3. ILLUSTRATION

A single case is taken in detail to understand the application of fuzzy system in irrigation scheduling. The crop is at the critical stage. Understanding the effect of different parameters is shown below.

Table (2): Illustration 1

OUTPUT	DECISION VARIABLE	FUZZY LOGIC
Water content	0.0767	Low
Rainfall Prediction	0.0772	Today
Available Water	0.7990	High
Temperature/ Day	0.1390	Day – Day& Cloudy
Output	0.2000	None

The water content is low, and even though the available water is high and the temperature is low, the output is none. The main judging variable here is the rainfall prediction. The rainfall is predicted today, i.e. on the same day and therefore there is no need for irrigation. One more variable can be added where in the amount of rainfall predicted is known. Complete crop dynamics can be taken into consideration here and water can be conserved as better as possible using the fuzzy logic controller.

Table (3): Illustration 2

OUTPUT	DECISION VARIABLE	FUZZY LOGIC
Water content	0.0767	Low
Rainfall Prediction	0.4970	Tomorrow
Available Water	0.7990	High
Temperature/ Day	0.6510	Night
Output	0.8000	High

The water content is low, the available water is high and part of the day is night, the rainfall is predicted to fall tomorrow, the output is high. The main judging variable here is the water content which is low and the part of the day which is night and the adequate amount of water available. One more variable can be added wherein the amount of rainfall predicted is known.

Table (4): Illustration 3

OUTPUT	DECISION VARIABLE	FUZZY LOGIC
Water content	0.5	Medium
Rainfall Prediction	0.5	Tomorrow
Available Water	0.5	Half low and half high
Temperature/ Day	0.284	Day and cloudy
Output	0.497	Low

The water content is medium, the available water is half low and half high and part of the day is day and cloudy, the rainfall is predicted to fall tomorrow, the output is low. The main judging variable here is the critical stage of the crop based on which these rules are written. Even though the water content is medium, and it is day and cloudy, the output is low, because of the high available water. When the crop is in the critical stage it is recommended to irrigate frequently in small amounts rather than giving the crop long dry periods. Long dry periods reduce the yield. \

Table (5): Illustration 4

OUTPUT	DECISION VARIABLE	FUZZY LOGIC
Water content	0.728	Partly Medium and high
Rainfall Prediction	0.759	After 2 days
Available Water	0.575	Less low and More high
Temperature/ Day	0.0531	Day
Output	0.311	Low

The water content is partly medium and partly high, the available water is less low and high and part of the day is day, the rainfall is predicted to fall 2 days later, the output is low. The main judging variable here is the critical stage of the crop based on which these rules are written. Even though the water content is medium, and it is day, the output is low, because of the high available water. When the crop is in the critical stage it is recommended to irrigate frequently in small amounts rather than giving the crop long dry periods. Long dry periods reduces the yield of the crop. If the available water is less, then irrigation in the day time is not recommended. But in the above case, the available amount of water is more of high and therefore low irrigation is obtained as outcome.

CHAPTER 8

CONTROL SYSTEM MODEL

A control model is built in Simulink to understand the efficiency of using the fuzzy logic controller. Known inputs are the type of the soil and the stage of the crop. The stage of the crop is critical. Fuzzy system is designed by considering the four input variables, time of the day, rainfall prediction, water content in the soil, and available water. This simulation is done to understand the efficiency of including the new variables.

This is compared with the basic strategy of irrigation management. The basic strategy of irrigation management considers only one variable which is the soil moisture content. If the soil moisture content is below certain level, the pump is actuated and if it is above the value, the pump is not actuated.

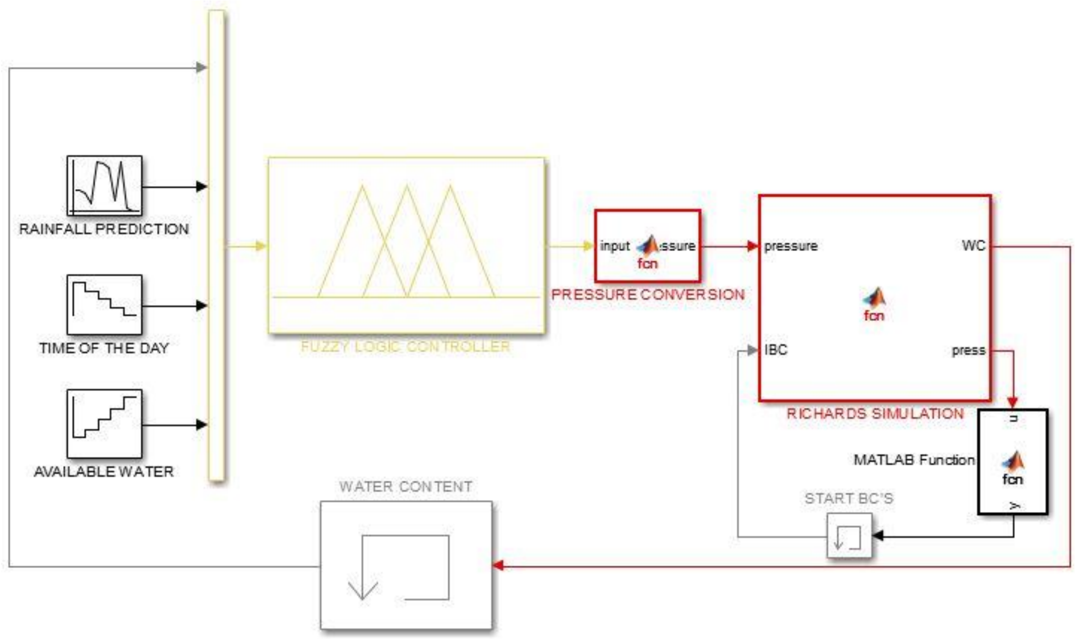


Fig.8.1. Simulink block diagram of control system model

8.1. INPUTS

The water content input is taken as feedback from the simulation. For initiation of the simulation, very less value is stored in the memory block. A random function is selected for the rainfall prediction. For the time of the day, ‘repeating sequence stair’ function is selected from the Simulink library. For the available water input again the ‘repeating sequence stair function’ is selected. Fuzzy logic toolbox from the Simulink library is directly used.

8.2. CONTROL SYSTEM FUNCTIONING

The control system is designed to simulate the real life scenario. The Richards equation is used to simulate the flow of water in the soil. Pressure conversion block in the control system converts the output of the fuzzy logic controller and sends it as an input into the Richards simulation block. The output of the pressure conversion block is the pressure at the top layer of the soil column matrix which is given as boundary condition.

```
If input < 0.3
   Pressure =-1; %Stop Flag
Else
   Pressure = (1-input)*100;
```

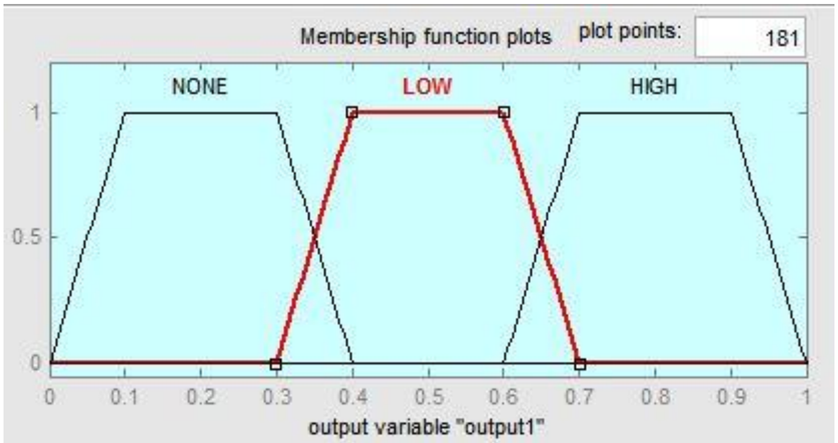


Fig. 8.2 Fuzzy controller output membership function

The continuity in the soil matrix has to be maintained to understand the continuous output of the controller. The pressure of the soil matrix at the end of every simulation is given as initial boundary conditions to the Richards equation solver Simulink block. The memory block is used to store the initial values of the moisture content in the soil matrix at the start of the control loop.
In real life scenario, the water either evaporates or percolates into the soil with time or may be consumed by the organic matter present in the soil including the plants. After every one simulation certain pressure value is added to the soil matrix therefore decreasing the water content through the entire soil matrix. This reduction is done to compensate the water loss in the real life situation. The results below is for continuous working of the control system for 100 hours. Each cycle time period is 1. Total cycle time is 100.

8.3. SIMULATION RESULTS

The above Simulink model is run for 100 time steps with each time step equivalent to 3600 seconds of Richard's equation simulation. Simulation results are shown below for silty loam soil. The water content at a depth of 10cms is recorded and shown in a graph with time.

Table (6): Input parameters for the control system

SIMULATION PARAMETER	VALUE
Type of soil	Silty Loam
Initial pressure	-5000 cms
Pressure conversion factor	100
Compensation	-1000 cms
Boundary condition	Constant Head (-5000 cms)

Table (7): Input parameters for the silty Loam soil

SOIL PARAMETERS	VALUE
Ksat(Saturated Hydraulic Conductivity)	227 (m/y)
Alpha	2
N	1.41
Theta_S	0.45
Theta_R	0.067

The field capacity and permanent wilting point are calculated from the van genuchten equation using the above soil properties. Theta at -316 cms of pressure which is Field Capacity is 0.2431. Permanent wilting point at -15000 cms comes out to be 0.1039. The soil water content has to stay between these limits for the proper health of the plants.

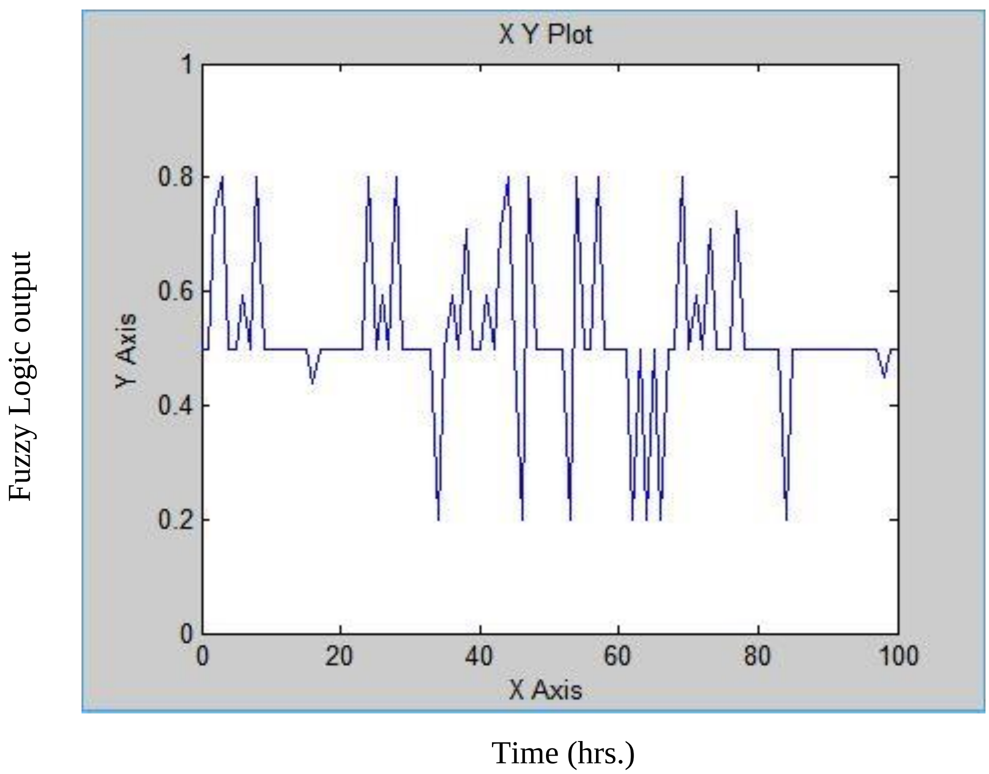


Fig.8.3. Variation of fuzzy logic output with time for silty loam soil

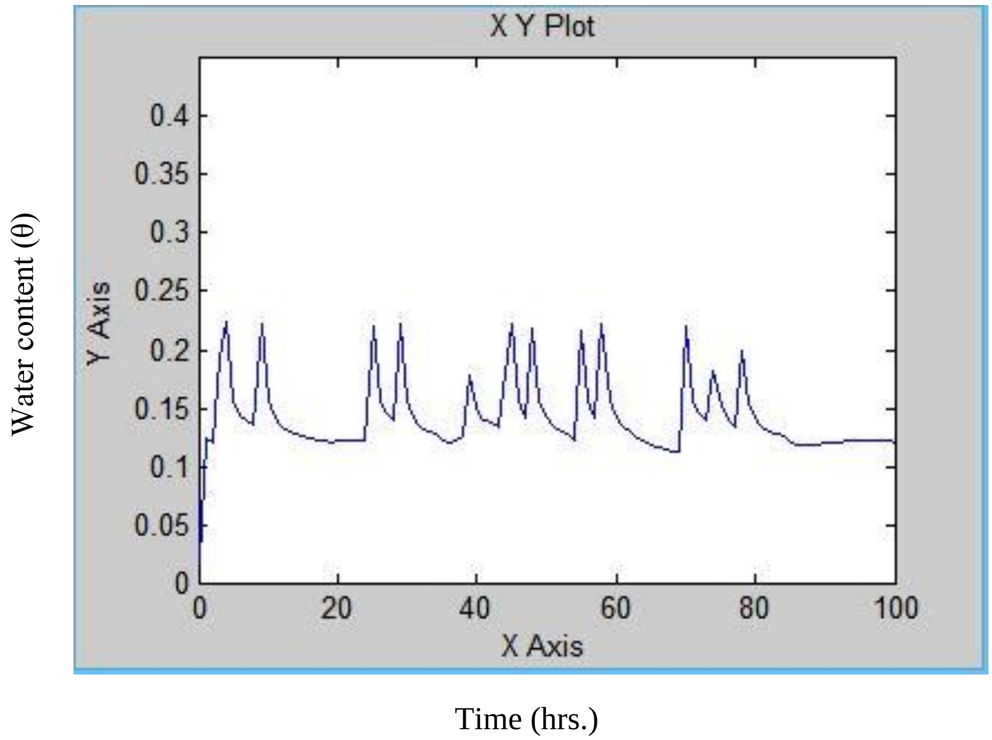


Fig.8.4. Variation of water content in the soil with time with pressure conversion factor (PCF) =100

8.4. OBSERVATIONS

Fig.8.3.a shows the variation of water content with time. The initial water content was set at 0.01 and therefore the graph started at 0.01. The troughs in the graph are formed because of the pressure reduction done to compensate the water loss in the real life situation. Assumption is made that the water is lost by the same amount through the entire length. The simulation can be improved by giving a function to the compensation of the water loss with the depth in the soil. Permanent wilting point of the soil is 0.1039 and field capacity is 0.2431. As it can be seen from the result above the water content in the soil is fairly maintained between the two limits without crossing any of them. Objectives achieved with the control system

- The maintenance of water content between the two limits, PWP and FC.
- Successful working of the control system with new parameters proposed which are rainfall prediction, available water in the tank, and the time of the day.

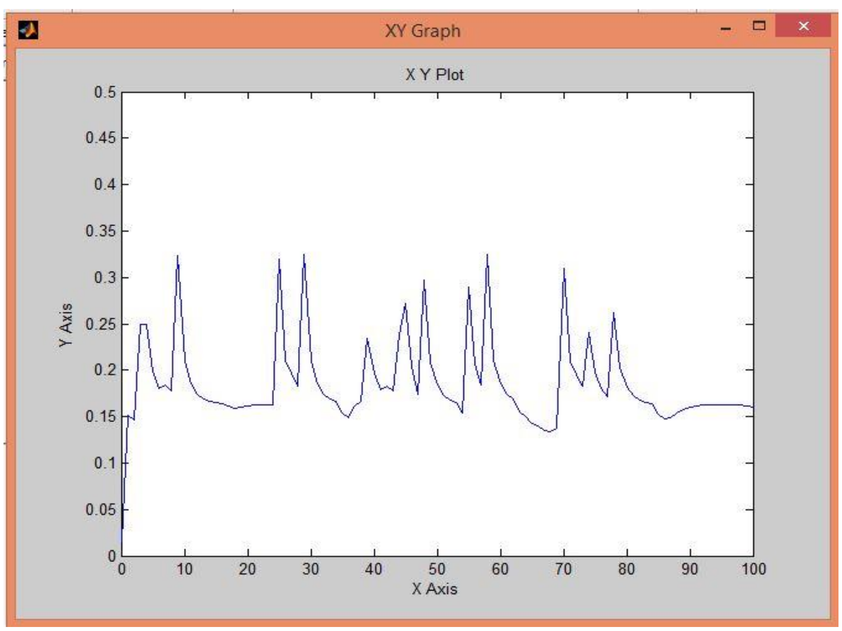
- The basic controller which depends up on the threshold value maintains the water content at the same level. But in the above case the system sorts of reduces the amount of water to be applied by maintaining the soil water content within the limit.

8.5. CUSTOMIZATION FOR DIFFERENT CROPS

The basic objective of the above control system is to maintain the water content in the soil between two limits, the PWP and the Field Capacity (FC). There is a limitation to the aforesaid criterion. All crops cannot sustain in high amount of water. If the soil is maintained at FC levels, the soils may get damaged. To avoid this problem we can change the pressure conversion factor (PCF) which is multiplied with the fuzzy logic output to change the limits.

Water content with time

Water content (θ)



Time (hrs.)

Fig.8.5. Water content in the soil with pressure conversion factor (PCF) = 10

Plants which demand high amount of water need high amount of water to be supplied as the boundary condition, which in our simulation is low pressure. For PCF = 10, the upper limit is reaching up to 0.34. The PCF (Pressure conversion Factor) depends upon the type of the crop.

For groundnuts it can be high and for tomato whose yield is highly dependent on the water levels, the PCF is kept low.

The Fig.8.3.a shows the variation of water content with time for PCF =100. The upper limit is at 0.225. Clear distinction can be seen between the Fig.8.5 and Fig. 8.6 shows the variation of water content with time for PCF = 10 and PCF = 1000 respectively.

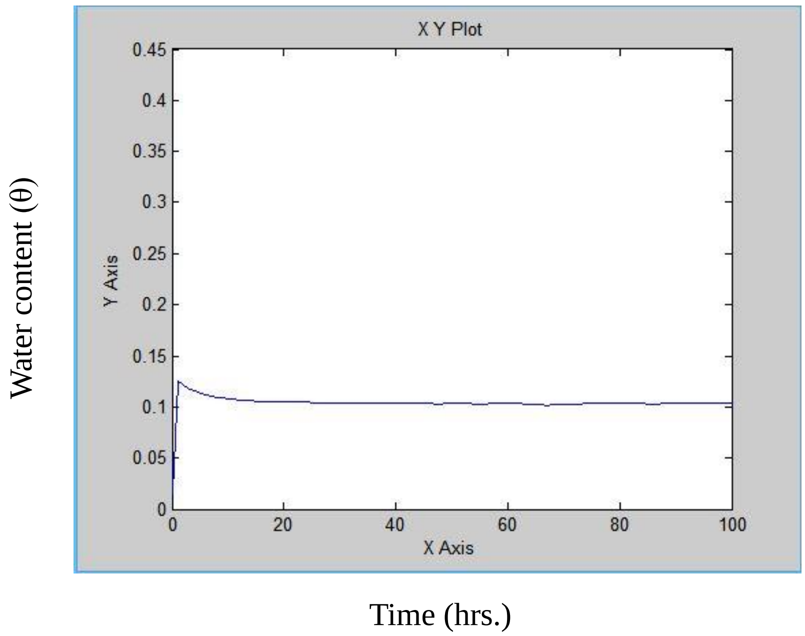


Fig.8.6. Water content in the soil with pressure conversion factor (PCF) = 1000

CHAPTER 9

CONCLUSIONS

9.1. CONCLUSIONS

- The concept of irrigation and the various factors which affect the water content in the soil are well understood.
- Artificial Intelligence techniques are very necessary to understand the relationship between the various environmental factors as there are no strict mathematical models which defines the relationship between them.
- Evapotranspiration model is not sufficient to automate the irrigation as it is not taking the soil dynamics into consideration.
- Water content and the pressure values at tentatively the same point in the soil, were used to find the Van Genuchten Parameters using the curve fitting toolbox in the matlab.
- The two Van genuchten parameters were used to find the type of the soil by training a neural network with two inputs as alpha and n and the output as the hydraulic conductivity. The mean square error observed was very high.
- To make the neural network structure more accurate, a new parameter was used which could increase the resolution of finding the type of soil. The mean square error obtained was very less.
- The next part of the irrigation process is the decision making. Decisions like how much to irrigate, when to irrigate are taken with the help of fuzzy logic controller. Fuzzy rules were formed based on the common analytical thinking of a farmer. Accurate fuzzy rules can be formed with expert practical knowledge. Basic set of rules were formed here to understand the response of the control system.
- A Simulink model was built comprising the fuzzy logic block and the Richards equation block. The output of the fuzzy logic block is given as the boundary condition to the Richards equation with the help of pressure conversion factor. Water content at particular depth is monitored and is given as feedback to the fuzzy logic controller. A compensation block was

added in which a certain amount of pressure is added in every cycle to compensate the evapotranspiration loss in the real life scenario. This fuzzy system is customizable based on the type of crop.

9.2. FUTURE WORK

Feasibility of the system was studied using the virtual simulations. But experimental validation is necessary before adopting this control system. Experimental setup can be constructed with the help of an Arduino Board, a soil moisture sensor, and a tensiometer, a small water pump and plastic pipe fitting the pump. To make the study simpler, first the experiment can be done with a single plant and a small container. The properties of the soil has to be identified using the lab chemical techniques which are available in soil centers.

The moisture data and the pore pressure data has to be obtained continuously. Van Genuchten Parameters can be identified from the pressure and the moisture data. For the decision part of the system, we need to simulate the physical parameters. For the rainfall a small sprinkler can be used. For light, a photo diode can be used wherein we can set the threshold. Image processing comes in very handy in the decision part of the system. The stage of the crop can be fed by the researcher or an image processing technique can be used to find the stage of the crop. Image processing can also be used to find the size of the plant, height of the plant which can be given as input to the neural networks and also the decision system. This above system has to be compared with a normal threshold control system and the amount of water conserved has to be calculated practically. Influence of some of the practical difficulties like soil organic content, soil inorganic fertilizers etc. should be considered while validating the experimental results with the above control system. After implementation of this control system on the basic experimental setup, the scale of the project can be enlarged.

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