12-2016

OPTIMIZATION OF IRRIGATION DECISION IN CORNSOYWATER

Dharmic Payyala
University of Nebraska-Lincoln, payyala.dharmic@gmail.com

OPTIMIZATION OF IRRIGATION DECISION IN CORNSOYWATER

By

Dharmic Payyala

A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Computer Science

Under the Supervision of Professor Jitender Deogun

Lincoln, Nebraska

December, 2016

OPTIMIZATION OF IRRIGATION DECISION IN CORNSOYWATER

Dharmic Payyala, M.S.

University of Nebraska, 2016

Advisor: Jitender Deogun

A crop simulation model is used to estimate crop production as a function of weather conditions, soil parameters, and plant related inputs. These crop simulation models are extensively used by farmers, corporations and policy makers for agronomical planning and decision making. CornSoyWater is one such application which provides irrigation recommendation for soy and corn farmers using hybrid maize and soy sim models. As this is a simulation technology, the accuracy of results depends on the quality of data provided to it. One such important input parameter is weather data. CornSoyWater simulates field and crop conditions by retrieving the updated weather data from nearest weather station for that field. However, the closest weather station could be far enough that the simulation model cannot rely on that weather station's data. Currently, in CornSoyWater twenty miles is considered as the threshold distance beyond which the nearest weather station's data might not represent the field conditions. A significant number of fields which produces corn and soybean does not have access to weather station within the threshold distance, which arises the necessity to optimize the existing models to work for real-world scenarios. In this thesis, we solved this problem using a new approach which uses quantification of the shape, distance, and position of weather stations to choose the optimal ones and performs inverse distance weighing on them. The results demonstrate that this approach works well for those fields which don't have access to weather stations within the threshold distance.

ACKNOWLEDGMENT

I would like to express my sincere gratitude to my advisor Professor Jitender Deogun for his continuous support, guidance, and encouragement throughout the course of my master's study and research. I am thankful for giving me the opportunity to work with him. I am very grateful to Professor Haishun Yang for sharing his expertise in crop modeling with me which were essential to complete this thesis. I would like to thank Professor Vinod Variyam for being on my thesis committee and for his invaluable time in critical reading this thesis.

Table of Contents

List of Figures

Chapter 1

Introduction

As per UN Food and Agriculture Organization Asia-Pacific, it is more likely that there will be a drastic increase in food demand as the population is expected to hit 10 billion people by 2050. So, it is very important to increase food production with minimal usage of resources like water, land and fertilizers. To increase food production, it is crucial to understand crops and their behavior in different environments. As the processes in nature are complex, technology is of great help in simplifying them. One such efficient method is to use crop modeling.

1.1 Crop modeling

A model can be defined as a representation of an object or a process used to describe a phenomenon that cannot be experienced directly. Most of the times the models are mathematical and run on computers. Models are often developed by scientists to predict things and are used as a tool to understand and explain their research better.

A crop model helps estimate crop yield as a function of weather conditions, soil conditions, and choice of crop management practices. Farmers, policy makers use modeling tools in planning and to support the decision making in agriculture. Also, these crop models are used by scientists to test their assumptions and fill knowledge gap regarding crops.

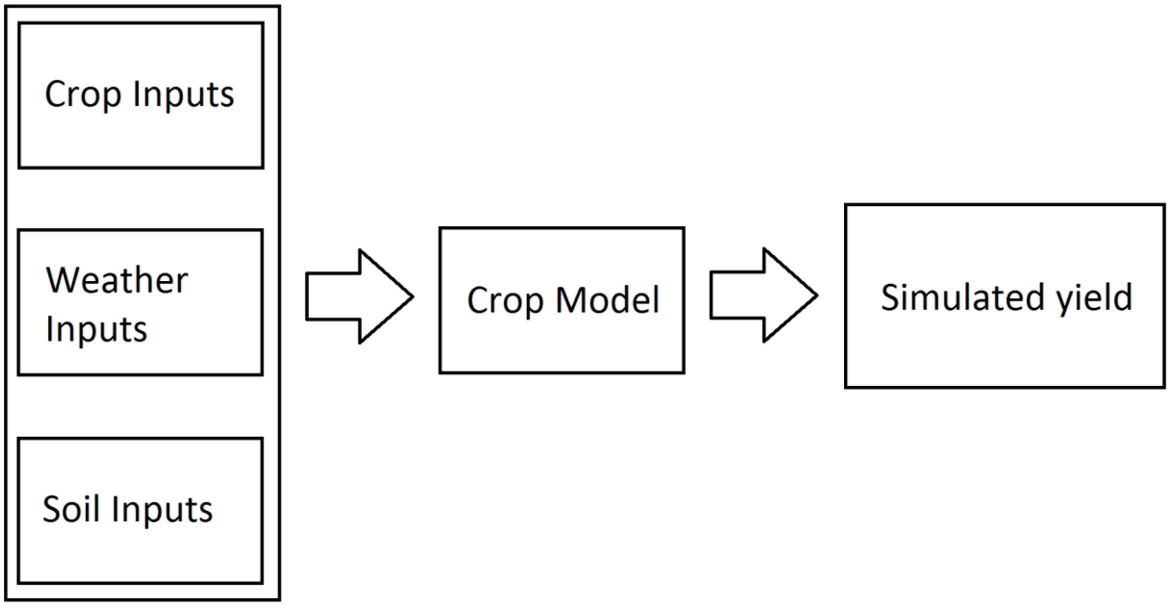

Figure 1.1: A graphical representation of crop modeling in a high-level view along with presumable inputs and outputs.

Crop modeling can be broadly classified into three categories.

1.1.1 Statistical models:

Statistical models are constructed based on the historical yield data from large regions like counties and use that data to identify trends related to increase in yield, and variation based on climatic conditions. Although statistical models are well known for simplicity, it has some limitations. Statistical models are better than convectional historical predictions but doesn't fit for those applications which demands more reliable predictions. Some examples of the statistical models are step down regressions and correlation.

1.1.2 Mechanistic models:

Mechanistic models emulate fundamental mechanisms of soil and plant processes and uses them to simulate the desired scenario. These models involve complex computations and require detailed inputs. As these models use continuous evolution it requires a small time step to simulate. These models are based on physical selection and can explain the relationship of influencing dependent variables.

1.1.3 Functional models:

Functional models simulate complex processes by using the simplified functions. The computational complexity of these functions is lesser compared to that of mechanistic models, yet they deliver results that are reasonably accurate. These types of simulations usually run daily and are required to be updated every day.

Although there are fundamental differences in the working of these models, every approach has its own uniqueness and applications. A recent review states that most of the crop modeling tools are not fully up to the task. So, there is a necessity to improve and optimize the crop models irrespective of the approach it uses.

1.2 Irrigation

Irrigation is the process of watering the land to make it ready for agriculture. Irrigation is a vital process in agriculture. It is used in agriculture as a source of water for plants and sometimes used for revegetation of dry soil during lesser rainfall. Irrigation not only act as source of water for plants but also protects them against frost and weed. Irrigation also prevents soil consolidation. Irrigation acted as a backbone for agriculture for over 5000 years. Various methods have been developed by different cultures. Some of the prominent irrigation methodologies are discussed below.

1.2.1 Surface irrigation

Surface irrigation is a method of irrigation in which the water flows on the surface of the field. This is also known as flood irrigation as the field is subjected to near flooding. This is mostly used method of irrigation from the history and is still used in most of the regions. Usually in this irrigation method the water is pumped through motor or manually by humans in to the fields which are divided into smaller grids. Although this is not the most efficient method of irrigation, if appropriate management of crop is done it could yield efficiency between 70 to 90 percent. This type of irrigation is more suited to flat lands and for medium to fine textured soil types which allow lateral spread of water.

Figure 1.2: Basin flood irrigation of wheat

1.2.2 Subsurface irrigation

Subsurface irrigation is a method of irrigation in which water is applied from below the soil surface and is absorbed upwards. A solution of water and nutrients are supplied through the trough for a short period and the excess is collected for recycling. Usually it requires sophisticated equipment and management and is expensive. Though it is expensive it could lower the labor as it is automated and requires less maintenance. Usually this is used in commercial greenhouse production.

Figure 1.3: Subsurface irrigation

1.2.3 Sprinkler irrigation

Sprinkler irrigation is a method of irrigation in which water is sprinkled to the crops through a high sprinklers or guns which resembles rain. These sprinklers can be installed permanently in a position or installed temporarily and can be moved after sprinkling a certain amount of water or they can also be mounted on moving platforms which travel continuously across the field. Some of the most commonly used sprinkler systems are center pivot, side roll, wheel line and wheel move. Center pivots are usually 1250 to 1300 feet long and can be used to irrigate about a 130 acre circular area.

Figure 1.4: A center pivot system from end to end

Figure 1.5: Wheel line irrigation system

1.2.4 Localized irrigation

Localized irrigation is a method of irrigation in which water is dispensed through a low pressure piped network in small streams or drops. This can be used in all soil types as rate of emission is very low. It is also known as micro irrigation. It is the most water efficient method of irrigation. When managed properly the field water efficiency ranges from 80 to 90 percent which is significant.

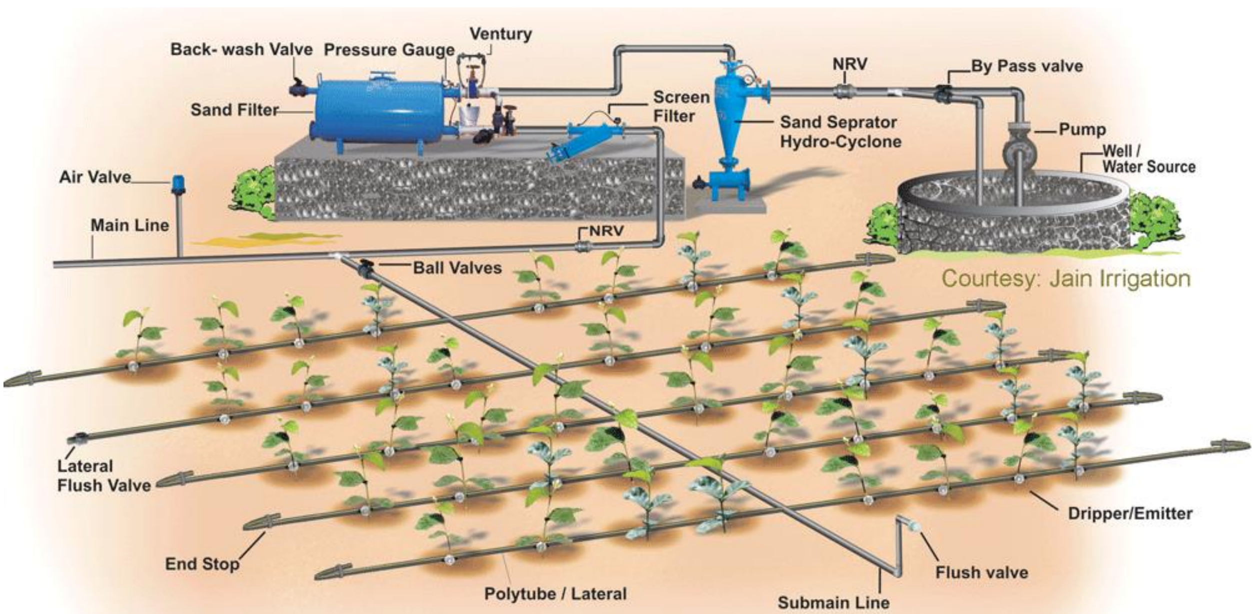

Figure 1.6: Drip irrigation layout and its parts

One important fact regarding irrigation is that the over irrigation does not bring higher yield instead it wastes water. Also, water demand depends on the stage of the plant. So, it is very important to understand water needs of crops so that we can give them required amount of water at an appropriate time.

Most of the farmers' daily routine related to irrigation management is to check the weather data every morning and go to field with a soil moisture sensor and check every field and crop stage to make irrigation decision, which takes too long, require technical expertise and sometimes confusing.

1.3 Motivation

This thesis mainly focusses on the development of efficient irrigation models for corn and soybean crops which minimizes the water usage and optimizes irrigation timing and increases the yield of the crop. It not only limits water usage rather acts as a decision-making tool for farmers independent of their agronomical experience. As the processes related to nature are complex, it also helps researchers to study and understand crop dynamics as efficiently as possible.

1.4 Contributions

The crop model depends on inputs like weather data, soil parameters, and plant related inputs. Among all the inputs weather data is considered one of the most significant as the plants are more sensitive to the weather. Some of the weather parameters on which crops depends are temperature maximum, temperature minimum, solar radiation, precipitation, wind speed and humidity. As this is simulation technology, the predictions of the models are directly related to the accuracy of the data. Although we have so many weather sources, the precision and frequency of the data from most of the sources could not be used for farming purposes. The ideal choice is to have a weather station in every field which constantly records weather data of the field. However in reality, the weather stations that can be used as a source are sparsely distributed. Twenty miles is considered as threshold distance between the weather station and farming field to say that the weather data is reliable. As most of the fields are not in threshold distance, there is a need to optimize the model for the current scenario. So, we developed a new method which could extend the threshold distance thereby covering more fields than usual with minimal sacrifice in accuracy.

1.5 Outline

This thesis is organized as follows. Chapter 2 explains about the related work which is done up to now related to irrigation models of corn and soybean in Nebraska. Chapter 3 explains about the current problem and the newly developed solution to overcome the challenge. Chapter 4 concludes the thesis with a possible future work.

Chapter 2

Related work

There have been numerous models and applications developed related to different crops to address various challenges. Some of the such crop models developed for irrigation recommendation are hybrid maize and soy water. Hybrid maize is a crop model developed for corn and soy water for soy bean. Currently these models are developed to work in Nebraska, but they can be extended other regions but providing it with required weather date.

2.1 Hybrid maize model

Hybrid maize is a crop simulation model used to describe the process of maize growth and development in relation to weather data, soil data and crop management using mathematical formulations. The main purpose of this model is to make the farmers, crop consultants and researchers to understand how the weather and management practices impact crop yield and the ways to increase the yield to maximum. It also calibrates available soil water and crop water stress based on the inputs, so that farmers can know when to irrigate the fields.

Hybrid maize model simulates the growth of maize under water-limited conditions and weather data which is updated every day. Some of the features of the this models are that it enables the user to access the overall yield potential of the field, evaluates the yield potential based on different planting dates and plant population, provides irrigation recommendation, evaluates actual growth and forecasts the yield at different stages of the crop.

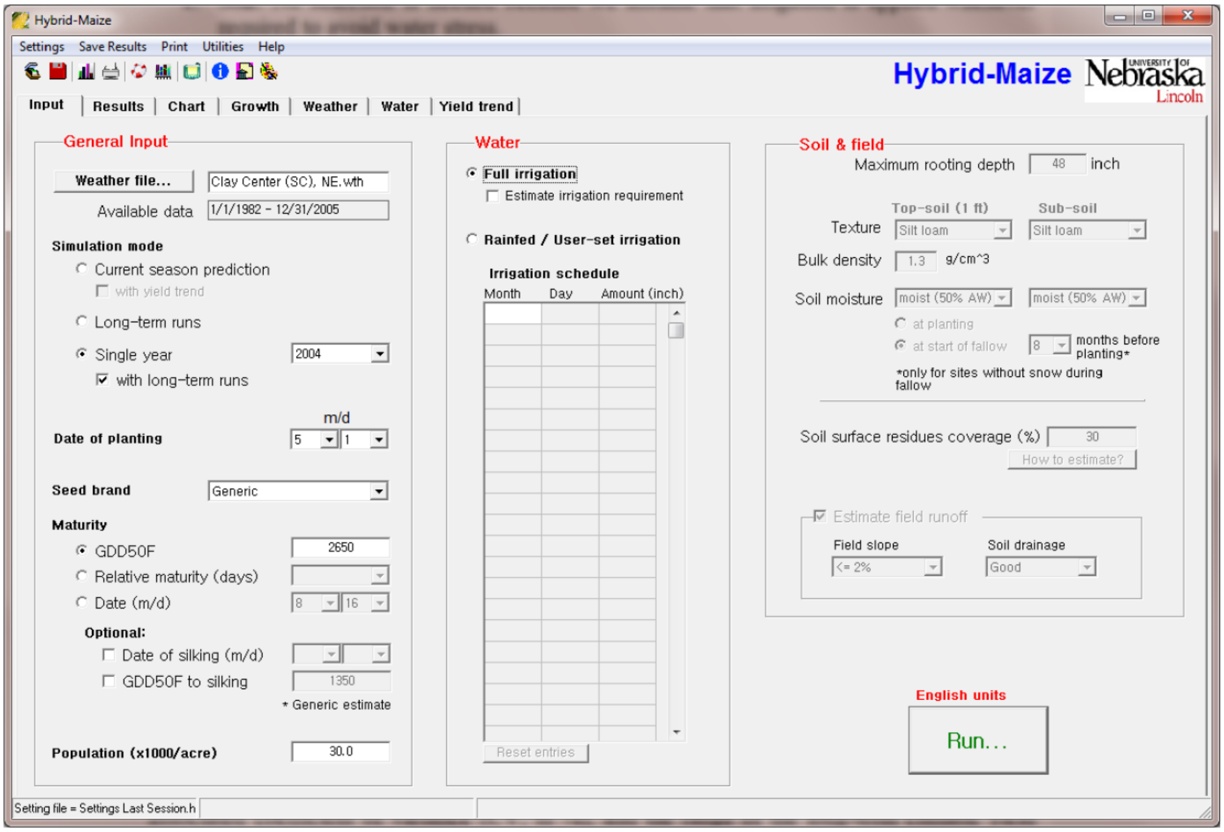

Figure 2.1: Hybrid-maize model along with inputs.

The inputs are divided into three categories i.e. generic inputs which contain weather data, date of planting, seed brand, population and maturity of the crop, water input which could be irrigated or rain fed and third being soil properties.

Hybrid maize model is evaluated in rainfed and irrigated maize systems of North America, the simulated results and actual results are nearly close.

2.2 Soy water model

Soy water is a soybean simulation model that simulates based on photosynthesis, biomass accumulation. Despite taking only two genotype specific and two crop management specific inputs the model produces reasonable accuracy in simulating growth and yield under optimal growth conditions.

Some of the features of soy water is it estimates daily crop ET values for the soybean crop, produces cumulative amounts of soil water depleted by the crop on each day of the growing season by taking rainfall, irrigation and plant specific inputs from farmers. It aids them to schedule irrigation in timely manner, which in turn allow optimization of yields and minimizes the usage of irrigation water and energy in agriculture.

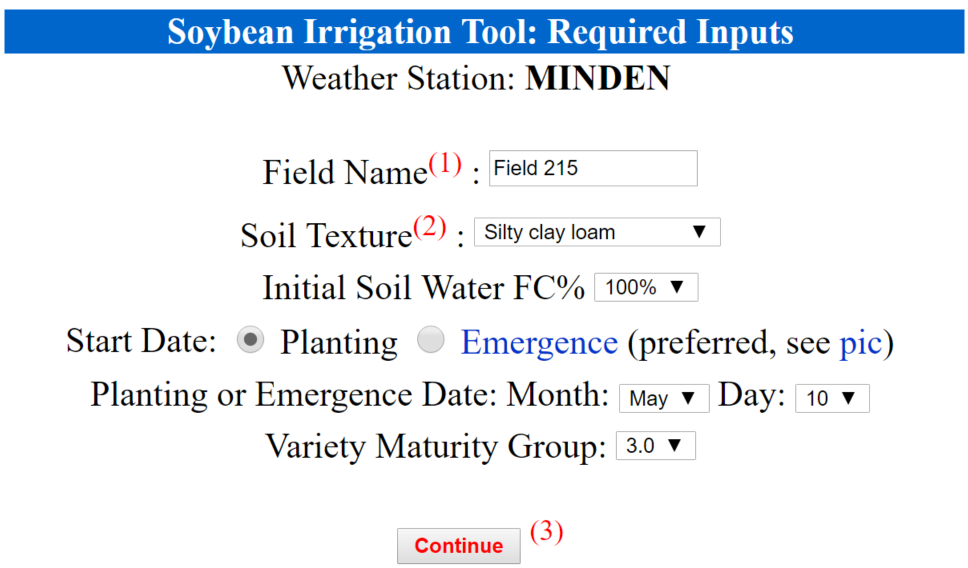

Figure 2.2: Soy water inputs

The major important inputs of soy water model are soil texture of the field, initial soil water, planting date, maturity group of the crop along with weather data from nearest weather station.

A summarized output table is generated to aid farmers related to irrigation decision making which is as shown below in which the important output is cumulative soil water depletion.

Date Click on a date to enter Irrigation and rainfall data	Vegetative Stage	Reproductive Stage	Historical Crop Water Use	Cumulative Historical Crop Water Use	Actual (to date) + Historical (thereafter) Crop Water Use	Cumulative Actual (to date) + Historical (thereafter) Crop Water Use	Cumulative Historical Rainfall at the Weather Station	Actual (to date) Rainfall at the Weather Station	Rainfall at the User's Field	Cumulative Rainfall at the User's Field	Irrigation at the User's Field	Cumulative Irrigation at the User's Field	Cumulative Water Input (Rain + Irr)	Cumulative Effective Water Input	Cumulative Soil Water Depletion
Date	V	R	WUh	WUhc	WUa	WUac	Rhc	Rws	R	Rc	I	Ic	TotW	Wlefc	Dep
05-10-2016			0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-11-2016			0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-12-2016			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-13-2016			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-14-2016			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-15-2016			0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-16-2016			0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-17-2016			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-18-2016			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-19-2016			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-20-2016			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-21-2016			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-22-2016			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-23-2016			0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-24-2016			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
05-25-2016	VE		0.02	0.02	0.02	0.02	0.13	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.02
05-26-2016			0.02	0.04	0.02	0.04	0.26	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.04
05-27-2016			0.02	0.06	0.01	0.05	0.39	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.05

Figure 2.3: Outputs from soy water simulation model.

2.3 CornSoyWater

CornSoyWater is an irrigation recommendation app which aids farmers in irrigation planning and decision making by taking weather data, soil parameters and crop specific inputs of the field. It is developed using hybrid maize and soy water as core engines for simulation. Whenever a field is created its nearest weather station within the threshold distance is retrieved along with its weather data as required. It also retrieves soil parameters of the field automatically based on latitude and longitude of the field.

Some of the important features of CornSoyWater is automatic retrieval of weather data and soil parameters of the field based on latitude and longitude of the field, calculation and forecast of crop water stress and available soil water, irrigation scheduling is made easier, a central control panel to manage all the fields using google maps.

The inputs of CornSoyWater are similar to that of hybrid maize and soy water, however the outputs in CornSoyWater are significantly different. The outputs include a summary table which includes available water in active rooting zone, initial available water down to active rooting depth, total amount of rainfall, irrigation, water consumption since planting and water losses including canopy interception and drain below user chosen maximum rooting depth.

Results summary (up to today, inches)	
3.4	Current available water balance within the active rooting zone
2.2	Initial available water down to active rooting depth at planting
6.8	Total rainfall amount since planting
2.0	Total irrigation amount
15.5	Water consumption (i.e., total crop ET) since planting
1.1	Water losses, including canopy interception and drain below user-chosen maximum rooting depth

Figure 2.4: Simulated results summary table of a field in CornSoyWater

Apart from summary table it also generates two graphs related to total available water within active rooting zone, rainfall, irrigation, crop water stress. One of the graph shows the results for the past week along with 10-day forecast, whereas the other graph shows the results from date of planting along with 10-day forecast. Both the graphs are included below.

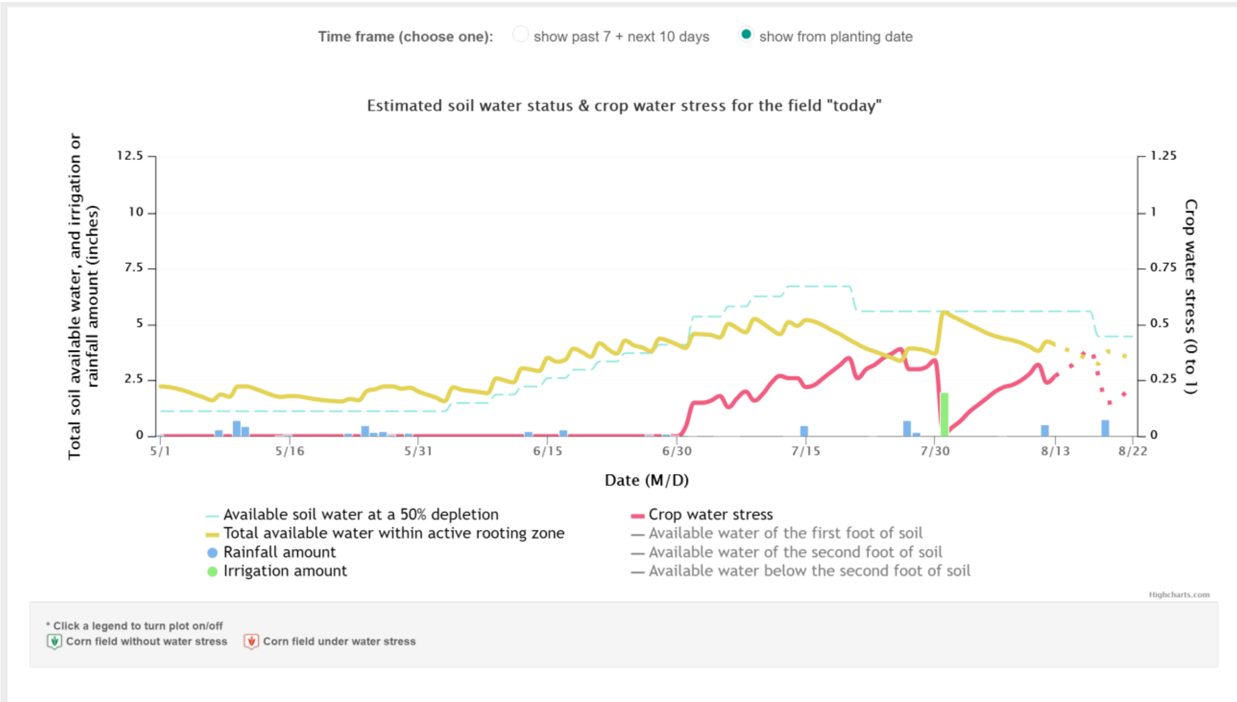

Figure 2.5: Simulated results from the date of planting along with ten day forecast for a field.

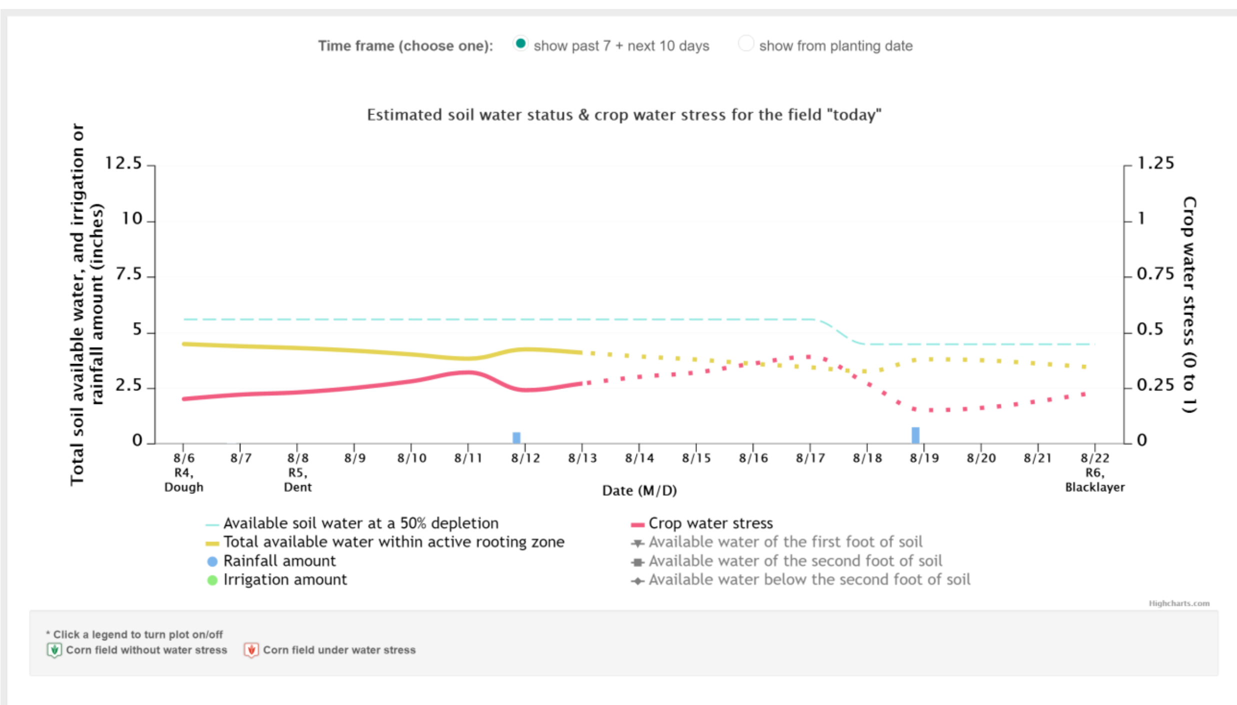

Figure 2.6: Simulated results for the last seven days along with 10-day forecast for a field.

2.4 Results comparison

After comparing the simulated results with actual results from the fields, it is concluded that CornSoyWater simulated pattern is consistent with measured daily soil water balance. The results of a fields in Lincoln recorded in 2013 and 2014 is displayed below.

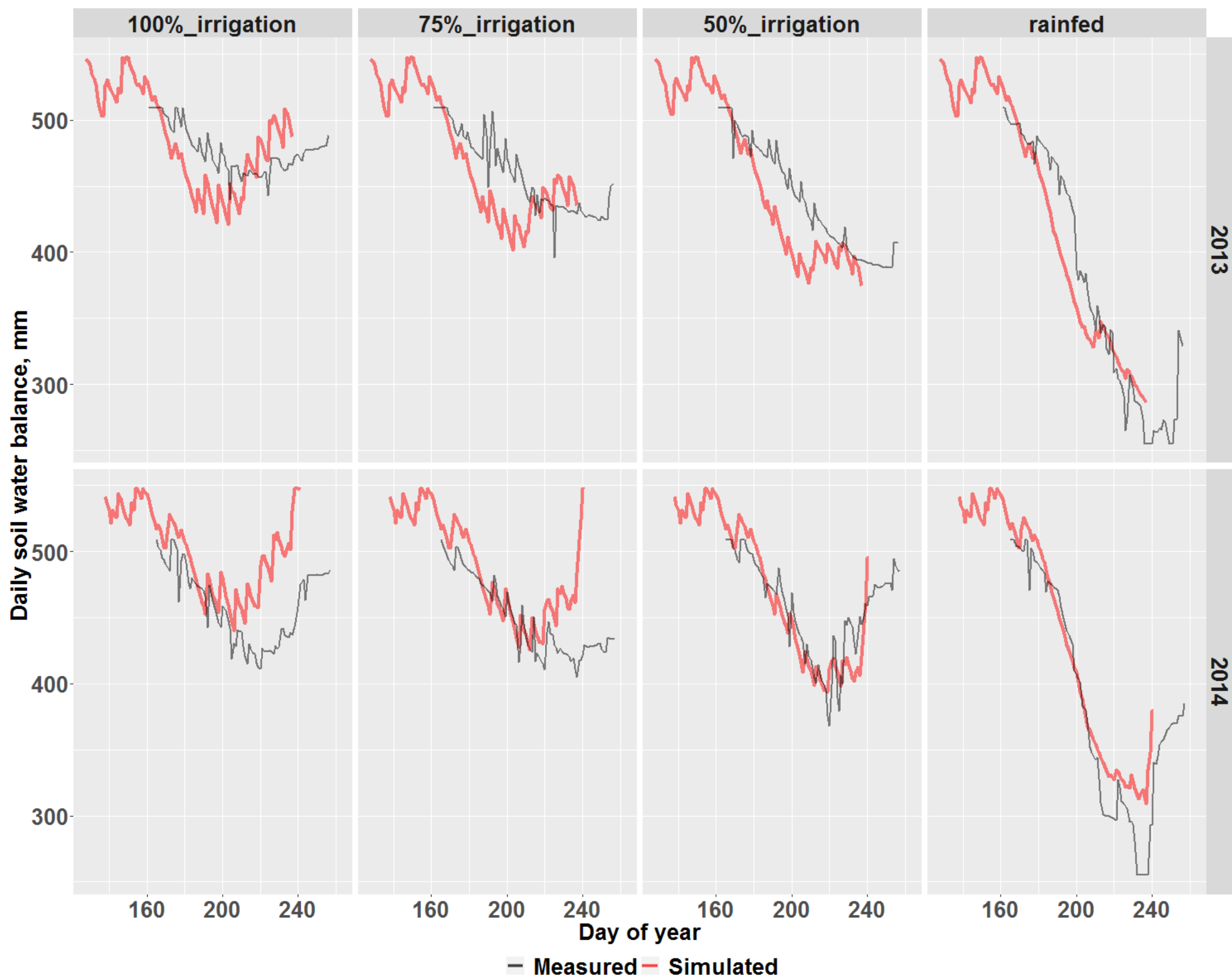

Figure 2.7: Comparison of simulated and actual results of daily soil water balance of fields

If we compare the results the simulation results are very close with rain fed fields and is dependable for the rest of the field scenario.

Some of the advantages of using CornSoyWater over traditional practice is that it's consistent, time-saving and the user doesn’t need to have technical expertise related to agriculture. Moreover such applications could be integrated into machines to make the irrigation process automated.

Chapter 3

Implementation

The CornSoyWater runs simulation by using weather data from nearest weather station. However, the nearest weather station may not be close enough to represent weather conditions of field. In CornSoyWater twenty miles is considered to be threshold distance beyond which the weather data does not represent the field climatic conditions. As significant number of fields doesn't have access to weather station with in threshold distance there is a need to optimize the model to work for real world scenarios. The current problem is solved as follows.

3.1 Problem statement

The problem of picking optimal weather stations can be mathematically formulated as follows, for a given set of n weather stations $W = \{w_1, w_2, w_3 \ldots\ldots w_n\}$ and a field F, find the three weather stations $W_R = \{w_i, w_j, w_k\}$ that more accurately represent the field conditions where $W_R \subset W$ and $w = \{lat, lng\}$ where lat and lng are latitude and longitude of corresponding weather station.

Here let's assume $D = \{d_1, d_2, d_3 \ldots\ldots d_n\}$ represents the distance of each weather station from the field. As we have n weather stations we will have nC_3 combinations of W_R's from which we need to pick the optimal W_R that represents field weather conditions more accurately than others.

The factors that influence the selection of optimal W_R are as follows.

1. The shape of the triangle formed by weather stations.
2. The distance of field from weather stations.
3. The position of the field inside the triangle formed by weather stations.

To solve this, we need to quantify the above factors and use them collectively in decision making. The quantification of the above factors can be done as follows.

3.2 Quantifying shape

The importance of this parameter in calculating W_R is that it quantifies the shape of the triangle formed by weather station and enables us to determine which triangle is less or more irregular in nature. This is a new triangle parameter which can also be referred as the degree of irregularity of a triangle. The desired general properties of Q_s are listed below.

- Regular/Equilateral triangles should have zero degree of irregularity.
- Similar triangles should have the same degree of irregularity.
- Proportionate to the irregularity of a triangle.

After studying and analyzing various concepts of triangles, one such new parameter discovered in our research that has all the above properties is obtained using Napoleon triangles.

"In geometry, Napoleon's theorem states that if equilateral triangles are constructed on the sides of any triangle, either all outward or all inward, the centers of those equilateral triangles themselves form an equilateral triangle." [1]

According to Napoleon's theorem,

- Area of inner Napoleon triangle of a triangle with sides a, b, c and area Δ is

$$Area(inner) = \frac{\sqrt{3}}{24}(a^2 + b^2 + c^2) - \frac{\Delta}{2} \geq 0$$

- Area of outer Napoleon triangle of a triangle with sides a, b, c and area Δ is

$$Area(outer) = \frac{\sqrt{3}}{24}(a^2 + b^2 + c^2) + \frac{\Delta}{2}$$

The value of Q_s is the ratio of area of inner Napoleon triangle to the area of outer Napoleon triangle i.e.

$$Q_s = \frac{Area(inner)}{Area(outer)} \quad or \quad Q_s = \frac{\frac{\sqrt{3}}{24}(a^2 + b^2 + c^2) - \frac{\Delta}{2}}{\frac{\sqrt{3}}{24}(a^2 + b^2 + c^2) + \frac{\Delta}{2}}$$

The studied properties of Q_s along with proofs are listed below.

3.2.1 The value of Q_s ranges from 0 to 1

"In mathematics, Weitzenböck's inequality states that for a triangle of side lengths a, b, c and area Δ, the following inequality holds." [2]

$$a^2 + b^2 + c^2 \geq 4\sqrt{3}\Delta$$

Rearranging the above inequality gives

$$\frac{\sqrt{3}}{24}(a^2 + b^2 + c^2) - \frac{\Delta}{2} \geq 0$$

and we know that below equation holds true for all triangles, as all values in the equation are greater than 0.

$$\frac{\sqrt{3}}{24}(a^2 + b^2 + c^2) + \frac{\Delta}{2} > 0$$

Substituting the above two equations in Q_s gives the following results.

$$Q_s = \frac{\frac{\sqrt{3}}{24}(a^2+b^2+c^2) - \frac{\Delta}{2}}{\frac{\sqrt{3}}{24}(a^2+b^2+c^2) + \frac{\Delta}{2}} \geq 0$$

From, the above equation, we can clearly state that the minimum value of Q_s is 0.

Now, let us assume the following,

$$p = \frac{\sqrt{3}}{24}(a^2+b^2+c^2),\ q = \frac{\Delta}{2}$$

We know that p > 0, q ≥ 0 for a triangle. Substitute p and q in Q_s gives

$$Q_s = \frac{p - q}{p + q}$$

The value of the above equation is maximum when the value of q is minimum, and we know the minimum value of q is 0 i.e. for collinear points. Substituting q = 0, in the above equation yields the following.

$$Q_s = \frac{p}{p} = 1$$

Therefore, the maximum value of Q_s is 1.

3.2.2 Q_s is 0 for all the regular/equilateral triangles

"In mathematics, Weitzenböck's inequality states that for a triangle of side lengths a, b, c and area Δ, the following equality holds if and only if the triangle is equilateral." [3]

$$a^2 + b^2 + c^2 = 4\sqrt{3}\Delta$$

Substituting the above equation in Q_s, yields the following result.

$$Q_s = \frac{\frac{\Delta}{2} - \frac{\Delta}{2}}{\frac{\Delta}{2} + \frac{\Delta}{2}} = 0$$

Therefore, for every equilateral triangle, the value of Q_s is 0, which means the regular triangles have 0 degree of irregularity.

3.2.3 Q_s is 1 for collinear points

We know that the area formed by collinear points is 0 i.e. $\Delta = 0$. Substituting $\Delta = 0$ in Q_s gives the following result.

$$Q_s = \frac{\frac{\sqrt{3}}{24}(a^2 + b^2 + c^2)}{\frac{\sqrt{3}}{24}(a^2 + b^2 + c^2)} = 1$$

Therefore, the max value of the Q_s i.e. 1 occurs when the three points are collinear.

3.2.4 The value of Q_s is equal for similar triangles

Let us consider two similar triangles of sides a, b, c and ka, kb, kc where k is a ratio of corresponding sides of similar triangles; then their areas are Δ and $k^2\Delta$ respectively.

Let us calculate the value of Q_s for both the triangles.

For the first triangle:

$$Q_s = \frac{\frac{\sqrt{3}}{24}(a^2 + b^2 + c^2) - \frac{\Delta}{2}}{\frac{\sqrt{3}}{24}(a^2 + b^2 + c^2) + \frac{\Delta}{2}}$$

For the second triangle

$$Q_{sk} = \frac{k^2\left(\frac{\sqrt{3}}{24}(a^2+b^2+c^2) - \frac{\Delta}{2}\right)}{k^2\left(\frac{\sqrt{3}}{24}(a^2+b^2+c^2) + \frac{\Delta}{2}\right)} = \frac{\frac{\sqrt{3}}{24}(a^2+b^2+c^2) - \frac{\Delta}{2}}{\frac{\sqrt{3}}{24}(a^2+b^2+c^2) + \frac{\Delta}{2}} = Q_s$$

Therefore, we can conclude that similar triangles have the equal Q_s value.

3.2.5 The value of Qs is proportionate to irregularity of triangle

For proving this, we consider a unit triangle and study the equation in one dimension at a time.

Let us consider the following example.

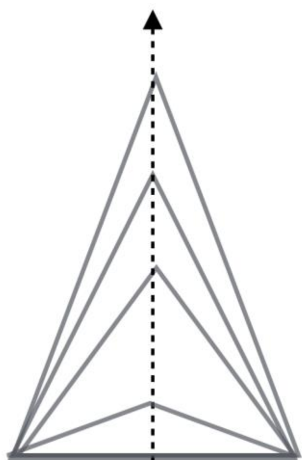

Figure 3.1: Different triangles with same base and different heights

Here in this triangle the base value remains constant and we increase the height as desired. According to our assumption, the value of Qs for triangle with minimal height should be closer to 1 as we increase the height of the triangles the value of Qs should decrease and reach 0 for equilateral triangle and thereafter if we keep increasing the height, the value of Qs should reach 1. The plotted graph for the above scenario is as follows, when value of base is considered as constant and equal to 1 and the other two sides are equal.

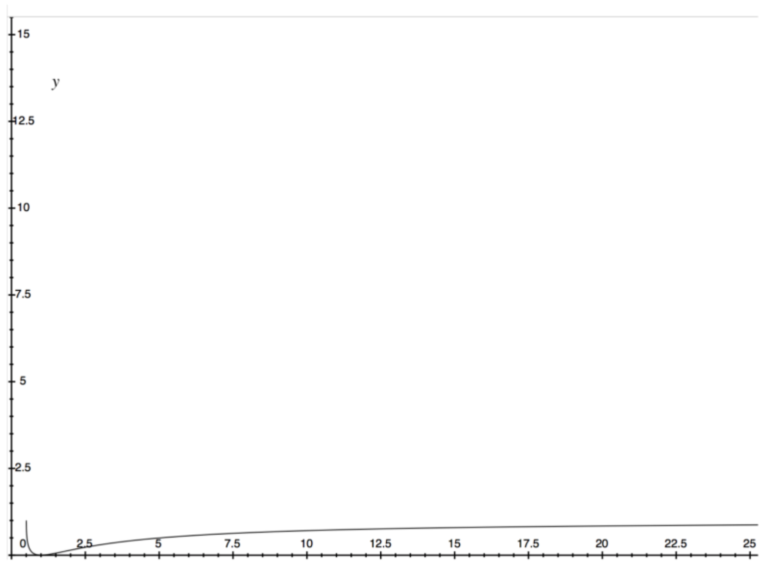

Figure 3.2: Relation between Qs and height of the triangle

In the above graph, Qs value is plotted on y-axis and height is plotted on x-axis. If we observe the results of the graph, it exactly matches with our assumption that the value of Qs should be near to 1 and as we increase the height the value of Qs should reach 0 when the triangle is equilateral and again should increase with increase in height and reach 1 eventually when the three points become collinear. So, the value of Qs behaves as expected in vertical direction.

Let us study the behavior of Qs function for three triangles below when we move them horizontally. According to our assumption, the value of Qs should always increase when we move horizontally irrespective of triangle but the initial values should be different for all the three triangles. If the triangle is equilateral, then it will start from 0 and end at 1. But for other triangles, they initially should start with some value and eventually should become 1.

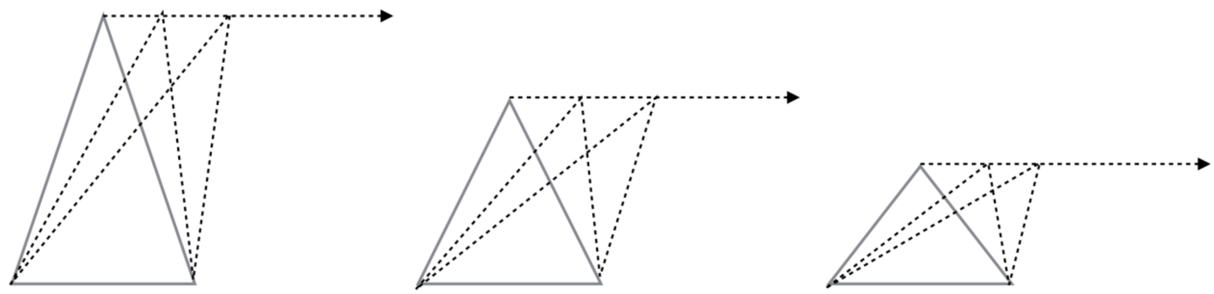

Figure 3.3: Sliding three triangles with same base and different height horizontally

All the above triangles have constant base value of 1 and their corresponding graph are plotted with Qs on y-axis and angle of their base in radians on x-axis.

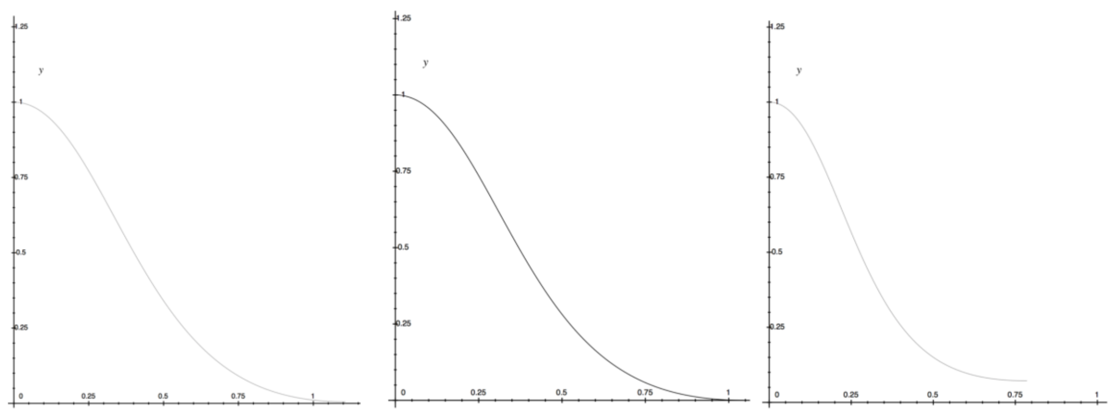

Figure 3.4: Relation between angle of the base of triangles to Qs for all the three triangles.

By observing the graphs, all the three graphs are accordance to our assumption that Qs initially will be start with some value and always increases and reaches 1. The middle graph is for equilateral triangle, which is the reason its Qs value is exactly from 0 to 1.

As, the new parameter Qs satisfies all the requirements, it is termed as degree of irregularity for a triangle based on which we can decide how much it is deviated from its regular shape.

We want this value as low as possible while calculating optimal W_R.

3.3 Quantifying distance

The importance of this parameter in calculating W_R is that it quantifies the distance of the field from all the three weather stations. For a, given weather stations tuple $W_R = \{w_i, w_j, w_k\}$, Q_d is the mean of distances of weather stations from field i.e.

$$Q_d = \frac{(d_i + d_j + d_k)}{3}$$

The value of Q_d purely depends on the distance of the field from weather stations and as that distance increases the value of Q_d increase and vice versa.

We want this value as low as possible while calculating optimal W_R.

3.4 Quantifying position

The importance of this parameter in calculating W_R is that it quantifies the position of the field inside the triangle. For a, given weather stations tuple $W_R = \{w_i, w_j, w_k\}$, Q_p is the distance between the centroid of triangle formed by W_R and the field.

The value of Q_p is minimal for the fields which are at the center of the triangle and increases as the field moves farther from center and is equal for the fields which are in symmetrical locations of the triangle if there are any.

We want this value as low as possible while calculating optimal W_R.

After calculating the three quantified values Q_s, Q_d, Q_p for all nC3 W_R's, we pick the W_R whose product of Q_s, Q_d, Q_p is minimum as optimal W_R.

3.5 Inverse distance weighting of weather data

Let the distance of weather stations $W_R = \{w_i, w_j, w_k\}$ be $D_R = \{d_i, d_j, d_k\}$ respectively. The weather data for the field is calculated as follows.

$$W_F = \frac{\left(\frac{w_i}{d_i}+\frac{w_j}{d_j}+\frac{w_k}{d_k}\right)}{\left(\frac{1}{d_i}+\frac{1}{d_j}+\frac{1}{d_k}\right)}$$

The calculated weather data is used for the field simulation to get better results.

3.6 Results

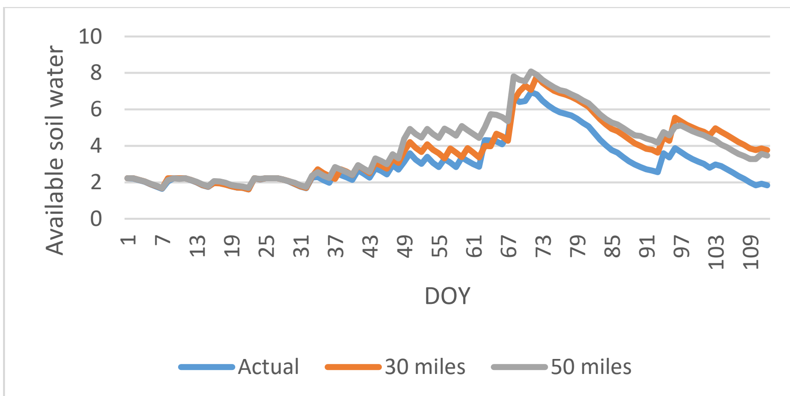

Figure: 3.5 Relation between simulated available water with increase in distance

The above approach yields good results. One such result for a field with increase in distance of weather stations is plotted in the above graph. As we can observe the increase in distance causes the simulated available soil water deviate from actual result which is expected result.

This method can also be used for weather stations below 20 miles, as it increases the data quality. A few other applications of this method include filling of missing weather data of weather stations, detection of malfunctioning weather stations.

Chapter 4

Software technologies and tools

4.1 Software technologies

Over the years many software technologies have been invented to ease the development of software applications in order to make them easy to maintain and extend. In a rapidly growing application it is very important to practice and use efficient software technologies to ensure the quality and scalability of application. In an effort to develop most elegant application that is maintainable and scalable, many technologies have been used during the development of CornSoyWater and these technologies are listed below.

4.1.1 Design patterns

In software engineering, design patterns are the reusable solutions to commonly occurring design problems. It is a template to solve the problem. Mostly these are used in object-oriented programming and it defines the relationship between objects and classes. These are classified into creational patterns, structural patterns and behavior patterns based on their properties and usage.

Some design patterns are applied at architectural level and are classified as architectural design patterns among which Model-View-Controller also referred as MVC is very prominent.

MVC is a software design pattern in which the objects are assigned one of the three roles. It not only assigns the role but also defines the way in which objects should interact with each other. The model component deals with data layer of the application in which data can be stored and retrieved from databases or repositories whereas the view component acts as UI logic for the application using which the user interacts with application and controller acts as a mediator between model and view components to process all incoming requests, perform business login and redirect to the user to appropriate view.

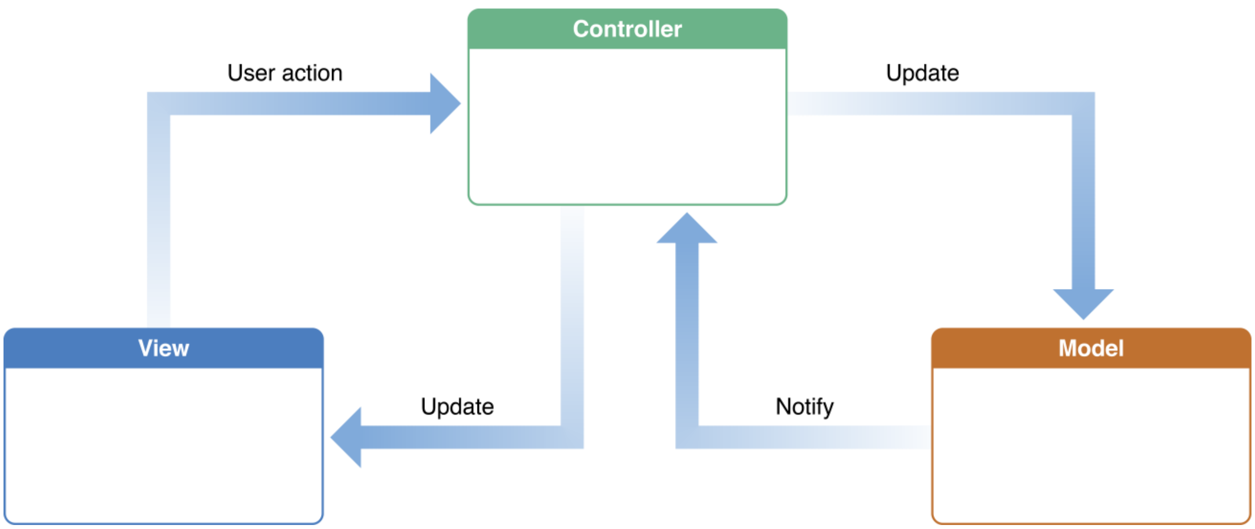

Figure 4.1: MVC design pattern

4.1.2 Frontend framework

As we are in rapid app development age, there is a greater need for robust frontend JavaScript framework that enables quick development of apps with minimal effort and maximum performance. They usually enforce structure so that the code can be reusable and easy to maintain. Frontend JavaScript frameworks usage has increased dramatically over the recent years and some of the prominent frameworks are angular, react, amber, vue etc. In CornSoyWater vue.js is used as frontend framework. Some of the features of vue.js is that it uses MVVM design paradigm and has a very easy to understand and use API. It also demonstrates minimalism so that developers can use components that is required for the application.

4.1.3 Backend framework

Backend frameworks are crucial when implementing the project as most of the core parts of the application depends on it. Almost every language has frameworks developed commercially or through the developer community. Most of the business logic is implemented using them as well as security and database interactions. So, it's important to choose right framework for the application development according to the needs. In CornSoyWater Laravel is used as backend framework. Some of the core features of the framework is that it supports MVC design pattern. Most of the design patterns required for initial development is already available, so that it save a lot of developer time. It has security measures to prevent SQL injection, XSRF attacks.

4.1.4 Database

All the data related to the application is stored in a structural form in database. There are different types of databases in which relational database and object oriented database are prominent. These databases are developed over time by many companies and communities according to their needs among which MYSQL, Microsoft SQL, DB2 etc. became popular. In CornSoyWater MYSQL database along with Eloquent ORM as it is open source and has many database engines to choose from according to the need of the application. Also, it is economical and is one the easily available database on cloud platforms.

4.1.5 UI/UX

UI and UX stands for user interface and user experience. UI/UX development one of the key component of the software application as the user interacts with the application using it. So, it is important to design the UI/UX efficiently so that the application is easy to use for intended audience. There are many UI/UX frameworks developed for different platforms and requirements among which Bootstrap, Foundation, Ionic etc. are mostly used. For the development of CornSoyWater Bootstrap framework is used as it is easy to extend, add and edit UI components. It is written in both SASS and LESS which gives developer flexibility to develop new components with greater efficiency.

4.2 Tools

Generally, software tools are used to make the software development a delight by making repeatable tasks easy to do and manage. Also, these can be used during development to track the project status and version them. The tools that are used in the development of CornSoyWater are listed below.

4.2.1 Version control

Version control is a process of recording changes related to a file or set of files over time. It is a vital process during software development and gives a team the capability to work on the same project or file simultaneously. Many version control methodologies and tools came in to existence since it usage increased among which GIT, Mercurial, CVS are widely used in software development. In CornSoyWater, GIT is used for source control as it is economical and easy to use.

4.2.2 Code deployer

Code deployer is used to deploy code from repository to the servers. These come in handy when you have an application that has to be deployed and distributed among many servers. This ensures the scalability of the app when the application becomes huge. In CornSoyWater Envoyer is used as a code deployer. Some of the features of Envoyer are zero downtime deployment where the code from repository is deployed to server without the server going down and support for integrating repositories like GITHUB and Bitbucket. It can deploy to multiple servers and also can execute custom commands according to schedule and order.

4.2.3 Server configuration

As the application complexity and size increases there will be greater demand to deploy new servers and configure them. It is always good to configure the servers through tools so that all the servers will be in sync. There are many tools developed to achieve this among which Docker, Chef and Forge are popular. They are developed for different audiences and has some good features. For development of CornSoyWater, Forge is used to configure servers as it supports cloud based servers from many vendors along with its ease of use makes it a great choice. Apart from these features it enables us to configure load balancing servers easily so that the traffic is evenly distributed among your servers. Cronjobs can be easily initiated with the simple terminal present through the UI. Horizontal scaling of the application is made easier as the servers can be created and deployed in minutes using forge. The Forge configured servers comes with pre-configured firewall to ensure the application is secure.

4.2.4 Text editor

Text editors are very important for developers during software development and also used by testers to debug the applications. Most of the latest text editors supports intellisense and are lightweight, without the need for using heavy IDE's. There are many text editors developed by different companies in which some are commercial and some are free and open source. Some of the prominent text editors today are atom, sublime, visual studio code, notepad++. For the development of CornSoyWater atom is used as the text editor. Some of the core features of this editor is that it operates on free license, it has a built-in package manager. It also has a smart auto completion

4.2.5 Cloud infrastructure

Cloud infrastructure has become prominent in the recent years as it is robust and easy to maintain. The services usually offered are ranges from providing storage to the applications to deploying standalone servers to deploy applications. There are different cloud infrastructure providers among which AWS, Digital Ocean, Microsoft Azure etc. are mostly used. Each of these have different target customers and different products. In CornSoyWater servers are deployed using Digital Ocean as they are affordable and easy to deploy servers. Some of the core features of Digital Ocean is that a new server with root access can be deployed in 55 seconds and the cloud instances are installed with SSD which makes the service faster. The server management is made easy by giving the team access to the server rather than for a single individual. Also, the servers can be provided with high available storage so that the server doesn't run out of memory. All the servers can be configured easily with simple interface and API. Also, the servers are distributed across the world in order to ensure low latency of the application if used globally. Apart from Digital Ocean, AWS

S3 storage is used in CornSoyWater so that it can used as a shared storage among all the servers. This ensures scalability of the application as all the files required by the serves will be available centrally rather than restricting them to single server. This makes the server stateless which is key property needed to do horizontal scaling of serves.

Chapter 5

Conclusion and future work

5.1 Conclusion

Understanding of crop behavior with different climatic conditions is very important to increase the yield of the crop to face mostly likely food crisis in future. In order to do that crop simulation is the best way. Mostly the accuracy of these models depends on the weather data provided to them. Currently, most of the fields don’t have a weather station within threshold distance which arises a situation to optimize existing models to work for real world scenario. In this thesis, we developed a new method which can be used by fields without access to a weather station in threshold distance and still get reasonable results. These types of simulations not only increase yield or the crop rather helps in preserving the valuable resourced like water and fertilizers.

5.2 Future work

With a significant increase in food demand in future, the necessity to optimize irrigation models is increasing. So, we are planning to collect more real-time data from fields to understand and improve the existing models along with an increase in density of weather stations to accurately predict the yield and plant stage, stress levels and available soil water in the soil which leads to easy farming of large fields with less usage of resources.

Languages and tools used

Software technologies and methodologies used during development of CornSoyWater app are listed below.

- Server: Ubuntu
- Version control and code deployment: GIT, Envoyer
- Cloud services: Digital Ocean and AWS
- Backend: Laravel, PHP
- Frontend: JavaScript, Bootstrap

Bibliography

[1] https://en.wikipedia.org/wiki/Napoleon%27s_theorem

[2] https://en.wikipedia.org/wiki/Weitzenb%C3%B6ck%27s_inequality

[3] https://en.wikipedia.org/wiki/Weitzenb%C3%B6ck%27s_inequality

[4] https://en.wikipedia.org/wiki/Irrigation

[5] https://upload.wikimedia.org/wikipedia/commons/a/ae/LevelBasinFloodIrrigation.JPG

[6] https://nrcca.cals.cornell.edu/soil/CA3/CA0324.php

[7] https://nrcca.cals.cornell.edu/soil/CA3/CA0324_clip_image002_0002.jpg

[8] https://en.wikipedia.org/wiki/File:Dripirrigation.png

[9] https://en.wikipedia.org/wiki/File:Center_Pivot.jpg

[10] https://en.wikipedia.org/wiki/Crop_simulation_model

[11] http://www.wamis.org/agm/pubs/agm8/Paper-12.pdf

[12] http://hprcc-agron0.unl.edu/cornsoywater/public_html/Home.php

[13] http://hprcc-agron0.unl.edu/soywater/intro.html

[14] http://cropwatch.unl.edu/cornsoywater-intro-15

[15] https://developer.apple.com/library/content/documentation/General/Conceptual/DevPedia-CocoaCore/MVC.html

[16] https://en.wikipedia.org/wiki/Model%E2%80%93view%E2%80%93controller

[17] https://en.wikipedia.org/wiki/Version_control

[18] https://en.wikipedia.org/wiki/Software_design_pattern

[19] https://www.tutorialspoint.com/mvc_framework/mvc_framework_introduction.htm

[20] https://vuejs.org/v2/guide/

[21] https://forge.laravel.com/features

[22] https://www.digitalocean.com/

[23] Han, J.C., Payyala, D., H.S. Yang, 2016. CornWater: An Irrigation Decision Support for Corn Fields. *Agronomy Journal*, *under review*.

[24] https://dl.sciencesocieties.org/publications/meetings/download/pdf/2015am/91651