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MASTER THESIS

**EVALUATION OF IRRIGATION SCHEDULING STRATEGIES FOR ENHANCED
IRRIGATION EFFICIENCY AND WATER CONSERVATION – IN PERKERRA
IRRIGATION SCHEME, KENYA**

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Examiner 1

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DECLARATION AND RECOMMENDATION

DECLARATION

I declare that this research proposal is my original work and has not been submitted to any other University for the award of any degree.

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ABSTRACT

Irrigation scheduling refers to the process of defining the most desirable irrigation frequencies and depths. It helps the farmer to know when to irrigate, water flow rate(quantity), and duration of water supply to the farm. It is meant to avoid negative effects of under or over-irrigation. Improper irrigation activities can lead to irrigation water loss by percolation and surface runoff, soil erosion due to surface runoff, leaching of the useful minerals through percolation, high energy consumption in pumping irrigation water and increase in operation and maintenance cost. Irrigation scheduling can help in reducing such problems and boost productivity. Proper irrigation scheduling will increase farm output and efficient use of water by; minimizing loss of water through runoff and deep percolation, optimizing yield and quality of crops, optimizing costs of pumping that will then save on the energy required and finally reducing the operation and maintenance cost. There is a need to carry out irrigation scheduling study in order to come up with appropriate prediction methods and other measures of reducing leaching of important minerals by percolation and soil erosion (siltation) through surface runoff in the irrigation fields. The main objective of this research is to investigate the most appropriate irrigation interval taking rainfall into consideration.

Data collection will include measurements of the soil types, crops sampling, evapotranspiration, soil water monitoring, meteorological data and bed level surveys. The determined results will then be used to determine the most efficient and reliable schedule for future irrigation and also to provide needed information for improvement of irrigation interval for Perkerra Irrigation scheme. The knowledge acquired from the research with Perkerra Irrigation Scheme will also be applied to the real operational potential of schemes with similar conditions as Perkerra Irrigation Scheme. In this study, I briefly review irrigation strategies used in the past/currently used for conserving water in the irrigation fields. Then we define the major strategy that suits the Perkerra region. These measures incorporate the water supply, the amount of water to be conserved, time and space. Knowing the crop water requirements (CWR) is necessary for better irrigation practices, scheduling and efficient use of water since the water supplied by rainfall is very minimal. I will use a CROPWAT model in this project to develop an efficient irrigation schedule for the main crops being grown in Perkerra Irrigation Scheme.

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LIST OF SYMBOLS

AfDB – African Development Bank
ASALs - Arid and Semi-Arid Lands
AW – Available Water
BMP - Best Management Practice
cb – centibars
CU – Uniformity Coefficient
CR - Capillary Rise
CWR – Crop Water Requirement
DP - Deep Percolation
D_j - Representative grain diameter for sediment size fraction j
D₁₀ - 10% finer particle diameter (m)
D₃₀ - 30% finer particle diameter (m)
D₆₀ - 60% finer particle diameter (m)
DP - Goss Domestic Product
ea - mean actual vapor pressure
es - saturation vapor pressure
es – ea: saturation vapor pressure deficit
ERSWEC - Economic Recovery, Strategy for Wealth and Employment Creation
ET - Evapotranspiration
E_c - Actual Crop Evapotranspiration
E_o - Reference Crop Evapotranspiration
E_{Tp} - Potential Evapotranspiration
E_{Tr} - reference Evapotranspiration
FAO - Food and Agriculture Organization
FC - Field Capacity
f_w - an average fraction of soil surface wetted by irrigation or precipitation
g - Acceleration due to gravity (m/s²)
h - Depth of flow
ID – Irrigation duration

MAD – Maximum Allowable Depletion
NAD – Net application depth
NERICA – New Rice for Africa
NIB - National Irrigation Board
 ν - Kinematic viscosity
 ρ - Water density (kg/m^3)
 P_{eff} - Effective Rainfall
PET - Potential Evapotranspiration
RAW – Readily Available Water
 R_d – Root depth
RO – Surface Runoff
SDG – Sustainable Development Goals
SRA - Strategy for Revitalization of Agriculture
 K_c - crop coefficient
PIS – Perkerra Irrigation Scheme
PM - Penman-Monteith
UN – United Nation
UNFCCC - United Nations Framework Convention on Climate Change
WEC – Water and Environment Centre
WHC - water holding capacity
WP – Water Productivity
Y - yield

CHAPTER 1: INTRODUCTION

1.1 Background information

Water scarcity is a major problem in many African countries at the moment. The scarcity may be due to changing climate, increasing demand for freshwater by the competing users in various sectors like industries and the problems caused by the environment destruction such as desertification and over-exploitation of the water resources.(Adeboye *et al.*, 2009) Kenya has one of the most one-sided distribution of income amongst low-income economies in the world. approximately 56% of the its entire population live below the poverty line out of which 80% are living in the rural areas. More than 75% of the entire population in the rural area depends on agriculture for their livelihoods (FAO, 1996).

Natural precipitation (rainfall) contributes to approximately 65% of global food production while irrigation water provides 35% on 17% of the total land under agricultural. Rainfall has been insufficient to grow crops in most parts of the world as rain-fed food production is affected by rainfall variations (Smith, 2000). Therefore, to increase crop production irrigation is the only option to be adopted. Irrigation infrastructures have increased over the past a quarter a century year by diverting the already limited surface water and exploiting the limited groundwater. The area under irrigation in the world have escalated by 25% over a period of 30 years (FAO, FIDA, and PMA, 2015). The irrigation expansion rate has reduced because of the unreliable surface water and over-exploitation of the groundwater resources (Smith, 2000). There is an agent need to reduce losses of water for irrigation and establishing an effective irrigation strategy and management. This implies that water diverted for irrigation are not efficiently used for crop growth due to losses. on average, only 45% of the water supplied to crops is taken up by the crop, with an estimated 15, 15 and 25% being lost in the water conveyance, water field channels and inefficient applications in the fields respectively (FAO, 2012).

Water Use Efficiency

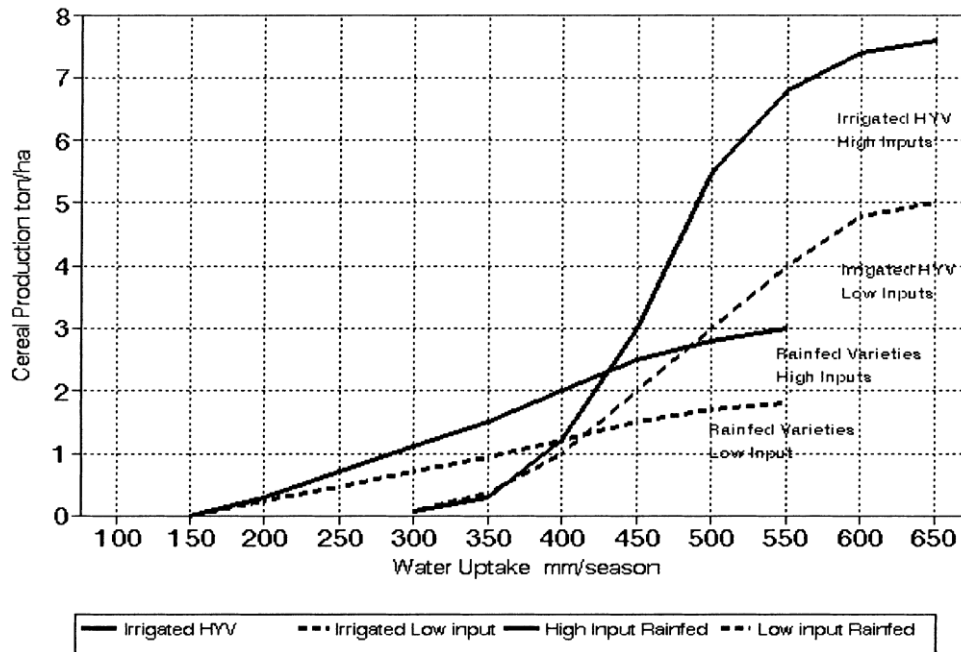


Figure 1.1: Efficiency of water used in rainfed and irrigated crops (Smith, 2000)

Poverty is drastically increasing in many parts of Kenya as water becomes scarce due to the population increase. This calls for urgent solutions in the agricultural sector. There is a need to formulate an irrigation technique so as to ensure that it has both a positive impact on reducing poverty by maximizing on the limited water under climate change situation (Ngigi, 2002).

Climate change has resulted into droughts and floods in many regions. This has resulted into many rivers having very low water levels or running dry during the dry season which makes irrigation during this time impossible. The compilation and scrutiny of data obtained from the nearby meteorological station for crop water requirement and crop productivity have a major factor in establishing irrigation schedule strategies which maximize use of water for crop production and the most appropriate strategies for water management. Therefore, adapting techniques that can minimize the use of water or planting crops that require a minimal amount of water when river levels are low is necessary (Kamble *et al*, 2013). Farmers tend to over-irrigate when there is enough water believing that applying excess water will improve crop yields. Instead, excess irrigation reduce yields and quality of the crop because the excess soil moisture usually results in diseases to crops, leaching of useful nutrients, reduce effectiveness of pesticide, and wastage of water and energy in case water is being pumped (Ngigi, 2002).

The surplus water can then be used to expand the area under irrigation or increase the river flow downstream for other purposes thus increasing both production and the income to the farmers. In deriving irrigation schedule strategies, an adequate relationship between water required for irrigation purposes and for river environmental flows is paramount.

For the sustainable development goals one (Zero poverty) and two (Zero hunger) to be accomplished, action should be taken to ensure sustainable growth in the agricultural section. Water is required by crops for growth and yield production. When crops are water stressed, their stomata close and they no longer photosynthesize to the required level. Best growth can be achieved when crops have an equilibrium of soil moisture and air in the root zones in which the soil moisture requirement in any crop depends on the growth stage of crops (initial, development, mid-season, and late stage) (Kamble *et al.*, 2013) .

Irrigation is the artificial application of water to the soil for the purpose of supplying water required for plant growth (FAO, 1996). Scheduling refers to the sequence of events in a chronological order in which such things are intended to take place. Therefore, Irrigation scheduling refers to the process of defining the most desirable irrigation frequencies and depths. It is meant to avoid negative effects of under or over-irrigation. Irrigation scheduling entails determination of the right amount of water required by crops and estimation of the sequence to apply the water to crops.

The major problem irrigated agriculture is facing is inefficiency in which water resources are being utilized for irrigation purposes. An estimation of about 40% of the water diverted from the source to be used for irrigation is mismanaged in the farm by surface runoff or deep percolation (Adeboye *et al.*, 2009). Improper irrigation activities can lead to irrigation water loss by percolation and surface runoff, soil erosion due to surface runoff, leaching of the useful minerals by percolation, high consumption of energy and increase in operation and maintenance cost. Irrigation scheduling can help in reducing such problems and boost productivity. Irrigation scheduling increases water use efficiency and profitability by; minimizing water lost through deep percolation and runoff, maximizing the quality and crop yield, saves on the energy required by optimizing pumping costs and reduction in the operation and maintenance cost. (ICDC, 2008)

Silts washed by surface run-off are usually deposited on the low areas in the field. This calls for frequent de-silting of these regions which is an extra task for the farm operators and a loss in terms of energy, cost, and time. These de-silted sediments though they are fertile, they are heaped in one area which becomes unbearable as they retard crops growth since they cover up crops and forcing them to fall down. Very little air remains in the soil because most of the soil pores are filled with water. The soil becomes waterlogged with no air in the soil if the internal drainage of the soil is blocked that results to the drying of the roots and eventually crops die due to lack of oxygen (ICDC, 2008). De-silting is being done more often so as to curb crops being swept or covered by silts. This reduces the time farm operators have for other farm activities such as herbicide application, weeding, and other irrigation management activities in the farm. This phenomenon has been observed in Perkerra Irrigation Scheme. PIS is a good representative of schemes with less supply of water for irrigation and rampant surface runoff which erodes top layer of the soil in Kenya.

Application of too much water has a less visual effect though it wastes fertilizer, soil, and water. Irrigating at a required proportion help in holding water and available useful nutrients in the root zone where crops can utilize them (Shock *et al.*, 2013).

1.2 Problem statement

Irrigation scheduling strategies have been and are still a problem in agricultural production in many countries where irrigation is practiced. Poor irrigation strategies/timing affect the operation of irrigation schemes by losing a lot of irrigation water through surface runoff and deep percolation, loss of rich silty soil carried by surface runoff, loss of beneficial nutrients through leaching and loss of energy through excessive pumping of irrigation water. Perkerra Irrigation Scheme (PIS) is one of the irrigation schemes which require proper irrigation scheduling. It is of high importance to march the site specific and the exact crop for the best irrigation scheduling strategy.

Problems experienced in the PIS include;

- Water logging that results to the reduced uptake of water by crops
- Blockage of soil pores by soil particles along the furrows resulting in reduced infiltration
- Loss of the essential nutrients and fertilizer by percolation
- Loss of water by percolation
- Erosion of the important top soil that results to siltation in the downstream

This has led to a lot of rich silt soil being lost through surface runoff that is so rampant in the scheme. Likewise, it has led to a lot of siltation being formed in downstream and in irrigation canals. The silt deposits have to be removed frequently, thus giving farm operators a heavy burden of removing or de-silting the downstream or low lying areas which are very costly in irrigation schemes. The funds and energy that are to be used in other farm operations are directed into curbing siltation in the low-lying areas. Uneven deposition of the silt also results in problems of unequal water distribution which at times reduces the growth rate of crops because silts cover the crops. Settling basins to extract sediment from the plots has been developed which fills up fast and frequent emptying required which is costly. Many irrigation canals are filled with silts and are at times not operational.

There is a problem of excess irrigation where farmers do not know when to cut off the water supply when water in the applied field has reached saturation. Knowing this is very important in this study as it will minimize losses due to percolation and surface runoff.

The purpose of undertaking this research is to investigate and develop an optimal irrigation scheduling strategy that will determine and manage irrigation water application and ensure exact quantity of water is applied to crops in the field at the right time. This will help improve the irrigation efficiency, reduce the excessive use of water and enhance crop production. Improving water productivity in agriculture sector as the main water user plays an important role in resolving water shortage problems. Increasing irrigation efficiency by developing a precise irrigation scheduling is the main strategy for this study.

1.3 Objectives of the study

Main objective

The main objective of this study is to evaluate the optimum irrigation scheduling strategy that will help in improving irrigation efficiency and/or water conservation in Perkerra irrigation scheme in Kenya.

Specific objective

The specific objectives are to: -

- (i) Evaluate the effectiveness of the current irrigation scheduling strategies
- (ii) Develop an irrigation schedule that will ensure precise quantity of water is applied to crops in the field at the right time
- (iii) Simulate irrigation water application using CROPWAT model for maize crop (November – March)

1.4 Research Questions

- (i) How effective is the current irrigation scheduling strategy in Perkerra irrigation scheme?
- (ii) Does the predicted application interval help in reducing percolation and surface runoff?
- (iii) Does the predicted application rate help in reducing water use and enhance crop production?

1.5 Justification

Irrigation is the main cause of water scarcity since large quantity of water is used in irrigation requirements in Africa and the world as a whole. Kenya is water scarce and irrigation plays a relatively important role in national development. As climate keeps on changing, many countries are moving from rain-fed agriculture to irrigation agriculture as it enables farmers to grow their crops throughout the year as long as there is a source of water. Crop water requirement for many crops increases with the rising temperature which in turn increases the simulated irrigation water demand. Due to this climatic changes that have been and is being experienced, if necessary measurements are not taken into consideration, food and livelihood may be at stake.

Population increase which has also resulted to food insecurity in many parts of Africa, the area under irrigation should be increased and the already existing irrigation schemes should be well

managed with high precision so as to maximize the productivity or output per unit area. This will help in meeting the Sustainable Development Goals (SDGs) of End poverty everywhere and zero hunger, attain food security and improve sustainable agriculture that was adopted on September 25th, 2015 by United nations (UN) as part of a new sustainable development agenda by 2030 (UN website).

In order to increase crop production, adequate, efficient and effective water should be applied to the irrigation schemes. For efficient and effective use of water in irrigation, surface runoff need to be reduced to as low as possible so as to eliminate sediment deposition in low-lying areas. This will ensure sediments are controlled and effectively managed, adequate water flows into the irrigation schemes and crop water requirement is met throughout the scheme hence increasing crop production.

This study will provide an in-depth knowledge of irrigation strategies and irrigation scheduling which will help other irrigation schemes with the same problem anywhere in the world. This is envisaged to determine how much and at what time the water should be applied to the crops.

1.6 Scope and Limitations

Perkerra Irrigation Scheme was chosen as a study area because it is a representative of schemes in Kenya which is facing water shortage and the problem may escalate in the near future if various measures to use water adequately is not adopted. It is not also used effectively even though it has irrigation potential. It is also faced with a surface runoff that erodes the top layer of the soil. This study majorly focuses on the irrigation strategies and irrigation scheduling that will in turn help in minimizing the amount of water required for irrigation and reducing surface runoff that is so rampant in Perkerra Irrigation Scheme. Empirical methods will be used to predict and also compare predicted values with measured values of various parameters including evapotranspiration, soil water monitoring, soil type and characteristics, water flow, meteorological data among others.

CHAPTER 2: LITERATURE REVIEW

2.1 Irrigation

Irrigation is the artificial application of water in the soil to be used for plant growth (FAO, 1996). It is used in farming to supply enough water that cannot be achieved from rainfall or in arid areas where there is minimal rainfall. One of the main challenges in Africa and the entire world currently is water and food security. Demand for food increases as water allocation deteriorates which suggest that water productivity for producing more food with less water should be increased in the agricultural sector (Cai *et al.*, 2010).

Water is a precious input in crop production. In arid areas, crop growth is impossible without irrigation. Therefore, irrigation management and irrigation systems upgrading are essential in water productivity. Irrigation systems evaluation is done based on irrigation efficiency indices such as application efficiency, distribution uniformity and uniformity coefficient which determines the success of irrigation projects. In many new studies, water productivity (WP) has been introduced as a more comprehensive index for evaluation of irrigation water management and study of efficient use of water in agriculture (Nazari *et al.*, 2013).

Both irrigation efficiency and water productivity indices have useful applications in irrigation and water management systems evaluations (Levidow *et al.*, 2014). Some of manager and experts prefer water productivity and some of them prefer irrigation efficiency indices in their decisions and studies (Nazari *et al.*, 2013). Therefore, determination of irrigation efficiency indices and water productivity index relationships can enhance agreement between decision makers, engineers, researchers and water users in planning and developing strategies adoption. Irrigation adequacy also defined as the proportion of the farm receiving the desired quantity of water affects the water productivity (Playán and Mateos, 2006).

Various studies have been carried out on water distribution and irrigation system effects on crops yield. In the study of set sprinkler irrigation system, there is an additional water loss through air losses that include drift and droplet evaporation. Loss of water for irrigation include deep percolation, runoff, surface and ground water evaporation (Rogers *et al.*, 1997).

Research done on the water use efficiency of sprinkler and drip irrigation systems on maize yield showed drip irrigation being the best system. It reported that applied irrigation water was 41% and 20% less under pivot and conservation tillage respectively than under surface irrigation and conventional tillage (Rogers *et al.*, 1997). The results showed that up to 32% of the volume of water allocated to the irrigated maize in the region annually could be saved with little reduction in yield, by changing/shifting to pivot irrigation system from the current surface systems (Rogers *et al.*, 1997).

Many studies had shown that main changes in irrigation management are essential to access optimize water use. For example, deficit irrigation as an effective water planning a strategy for water use efficiency improve is introduced (Geerts and Raes, 2009). This strategy can be applied with decreasing of adequacy level in irrigation design and management. Irrigation scheduling requires a well understanding of crop water requirement, the soil water content and soil moisture stress sensitivity by crops at different stages of their growth. Irrigation scheduling help to avoid several problems that include; water loss by percolation, water availability for irrigation, reduction in yield, soil erosion, socio-economic, diseases and soil salination (Gulla *et al.*, 2015).

Kenya aims to promote an innovative, commercially-oriented, and modern agricultural sector. In order to achieve these, key institutions in agriculture should be transformed to enhance agricultural growth, crop productivity should be improved, land use policies should be introduced for better utilization of potential lands for agriculture, arid and semi-arid areas should be developed for agriculture and market access improved through better supply chain management (Ministry of Agriculture). Farmers have been using their own experience and indicators that entail wilting of the growing crops and soil moisture status (dryness) to determine the time for irrigation (Melvin *et al.*, 2002). Farmers complain that the methods mentioned above have proved to be not accurate and a professional advice for them on the exact time and the amount to irrigate can save sufficient water. Irrigation system provides the irrigation water required in the farm for agricultural production. Therefore, for effective irrigation system planning and development, the objectives of irrigation systems are usually suited to best meet the following water requirements.

2.1.1 Irrigation adequacy

Adequate as well as well-timed water supplies corresponding to crop water requirement of a crop during its life span is central to the normal growth of a crop. This also means that there is no reduction in crop produce ignoring other factors that may influence crop yield. The irrigation system should ensure an adequate quantity of water is delivered to the farm for crop growth. The required water depends on the area of irrigated field, crop consumption, cultural practices, application losses, and crop water production. Adequacy of water delivery is determined by the water supply, irrigation schedule, the capacity of water delivery and the operation and maintenance of the systems (Playán and Mateos, 2006).

2.1.2 Irrigation efficiency

This is the application of irrigation water to crops more accurately. Conservation of water is essential in water delivery because water conserved can be used in irrigating more irrigation field or expanding the area under irrigation. Conveyance efficiency is mostly used to determine the efficiency in irrigation systems. Excess water deliveries to the field can lead to waterlogging and salinity but if water is efficiently applied in the field, such problems will be prevented. This part majorly comprises conveyance and application efficiency (Keller and Keller, 1995).

2.1.3 Irrigation dependability

This alludes to the spatial consistency of the proportion of the conveyed water to the planned measure of water. The irrigation system should be consistent for it to be considered dependable. Dependability of water conveyance framework is critical to agriculturists for planning and improvement. Reliability can be enhanced by planting less or modifying farm inputs and upkeep of the watering system framework (Molden *et al.*, 1991).

2.1.4 Irrigation equity

This refers to the supply of a fair portion of a specified amount of water to farmers throughout the irrigation system (Smout & Gorantiwar, 2005). The amount of water can be due to a legitimate ideal for water which can be set as a constant amount of a water supply to different preoccupations in the field like in numerous rotational watering system. Equity is extremely crucial in picking the

best option for the watering system strategies and in designing the watering system framework (Molden *et al.*, 1991).

2.1.5 Irrigation sustainability

This is the performance measure related to upgrading, maintaining, and degrading the environment in the irrigation scheme. Irrigation system should not in any way degrade the environment in which it is located (Smout and Gorantiwar, 2005)

2.2 Model description

CROPWAT is a computer software that was designed to help meteorologists, agronomists, and irrigation engineers in carrying out standard calculations for crop evapotranspiration and water use by various crops under different environment. CROPWAT is especially used in the design and management of irrigation schemes. It can be used to develop and improve irrigation activities, planning of irrigation schedules under different water supply, and the yield assessment under rainfed or deficit irrigation (UNFCCC, 2014). CROPWAT was developed by the Land and Water Development Division of FAO for planning and management of irrigation (Marica and General, 2001).

2.2.1 CROPWAT Input

Climatic variables, crop and soil data are entered into the CROPWAT software in order to calculate the crop water requirements and irrigation requirements. The entered values for the estimation of crop water requirements (CWR) include reference crop evapotranspiration (E_{to}) which is calculated using penman Monteith formula from climatic data such as minimum and maximum air temperature, relative humidity, sunshine hours, wind speed and rainfall data. A cropping pattern such as the planting and harvesting date, crop coefficient data files (including crop coefficient values, growth stages, root depth and depletion fraction) are entered to determine the irrigation requirement (Clarke *et al.*, 2000). Input requirement for the estimation of Irrigation Scheduling includes the type of soil, total available soil moisture, maximum rooting depth and initial soil moisture depletion (Marica and General, 2001).

2.2.2 CROPWAT Output

When all the data required has been entered, CROPWAT software automatically calculates the results and present them in tables or graphs. The results can be presented as daily, decade or monthly. The output obtained for each crop include reference crop evapotranspiration, average values of crop coefficient for each stage, actual crop evapotranspiration, effective rain, readily available moisture, total available moisture, crop water requirements, irrigation requirements, daily soil moisture deficit, irrigation depth applied, irrigation interval, lost irrigation, ratio of actual crop evapotranspiration to the maximum crop evapotranspiration and estimated yields reduction due to crop stress (Marica and General, 2001).

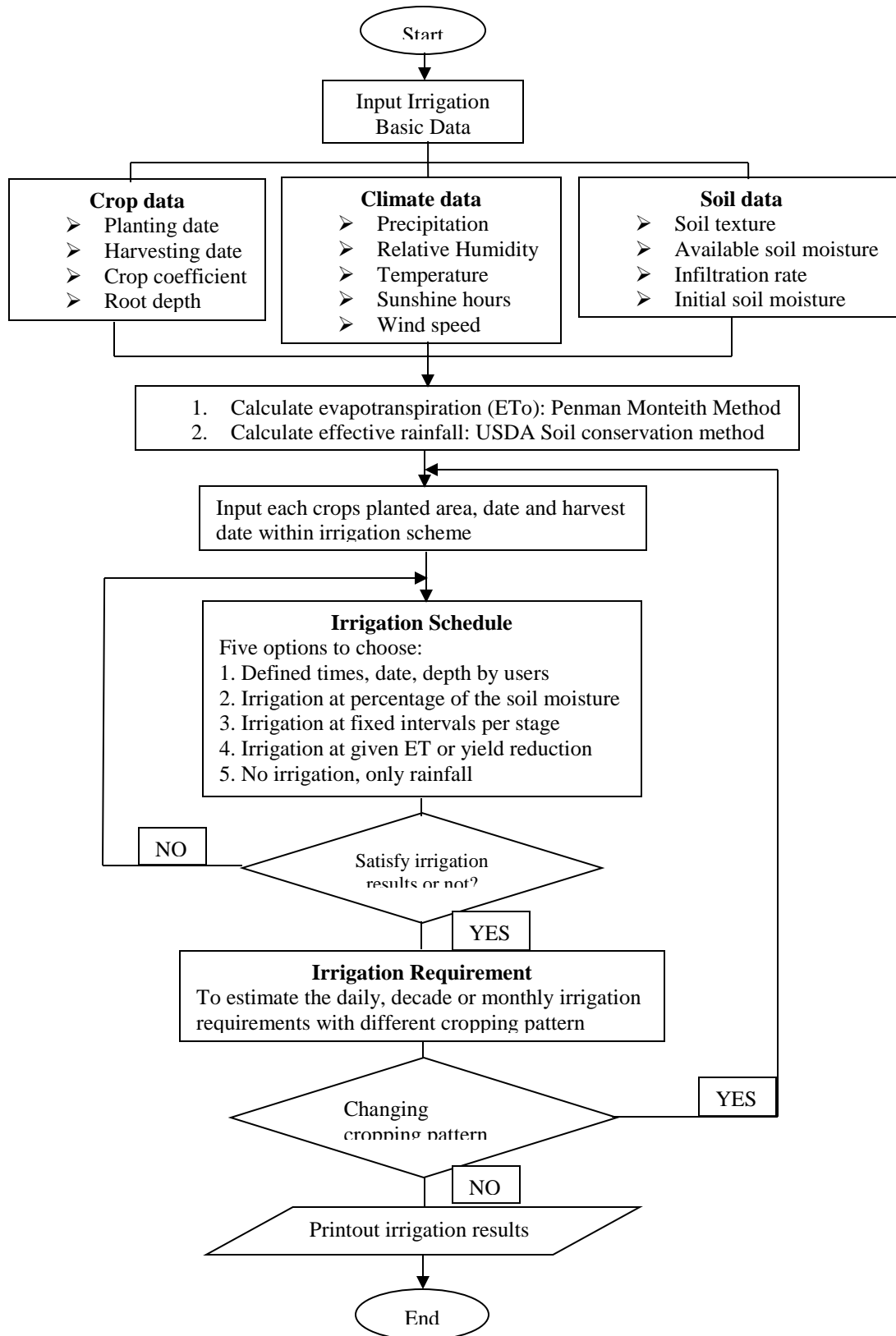


Figure 2.1: Schematic diagram of CROPWAT (Rao *et al.*, 2010)

2.3 Irrigation management strategies to conserve water

2.3.1 Fully watered

This management strategy prevents moisture stress to the crop from planting to maturity by making sure the available soil water in the active root zone between field capacity and 50% depletion is balanced. The soil in the root zone is maintained one inch below field capacity(FC) so as to store the effective rain water just in case it rains (Melvin *et al.*, 2002).

2.3.2 Water miser BMP

This irrigation management strategy saves water in less sensitive growth stages like initial and late stages and fully watering in critical flowering/reproductive growth stages. When the crop attains the reproductive growth stage, the crop available soil water is maintained between field capacity and 50% depletion (Melvin *et al.*, 2002). There is no significant yield reduction when the crop is slightly stressed during the vegetative stage. But, severe yield reductions are found when the corn is stressed during the pollination period (Melvin *et al.*, 2002).

2.3.3 Deficit irrigation

This is irrigation that applies less water than the crop needs for its full development i.e. the crop is stressed for some time before water is supplied. Some crops lose little yield and quality with deficit irrigation by saving water. It works best with deep rooted crops (Shock *et al.*, 2013).

Drought stress handling of various crops varies as some crops resist drought stress than others. Knowing every harvest's resilience of dry season anxiety is vital as it helps the farmer to plan water application to the crops as needed. The deficit irrigation management strategy ought to be utilized if and just if the water supply is negligible, in light of the fact that it results in the lessening of yield. This technique points on precisely timing the utilization of a deliberate measure of water within the crop growth with the point of balancing out yield by applying water on the soil water depletion basis (Geerts and Raes, 2009).

The idea of deficit irrigation is to keep the soil dry enough to reduce evapotranspiration rate, but not keeping it dry to significantly lower the yield potential. In this strategy, little amount of water will be applied in wet season and slightly more water in dry season. When the crop finishes the flowering stage the crop available soil water in the active root zone is adjusted to approximately 30% and 60% depletion. It is from that point it is permitted to dry down to 70% depletion after the hard dough stage (Geerts and Raes, 2009).

2.3.4 Plan your acreage under irrigation

Knowing the water use prerequisites of the harvests expected to be developed and ensuring there is sufficient water to get a financial yield. Crops that require an insignificant measure of water ought to be developed where there is a scarcity of water supply. This will help in capitalizing on the available water into an economic gain which in turn will reduce food shortage (Shock *et al.*, 2013).

2.3.5 Conservation tillage and crop residue management

Conservation tillage help in conserving the soil water. Tillage is diminished or kept to zero and crop residue from the previously harvested crop is retained on the soil surface which goes about as a mulch. These retained crop residues help in enhancing the soil capability to hold moisture and decreasing loss of moisture from the soil to the atmosphere which then helps in cooling the soil. The soil is usually exposed to drying by the sun every time it is plowed. In the event that the strategies are correctly executed, water application might be decreased by one or more applications (Shock *et al.*, 2013).

2.3.6 Careful management of surface irrigation

Surface irrigation systems dislodges soil particles because of the constant direct contact with the soil. There is a tendency in surface irrigation systems where the upper irrigated field is over-flooded and the bottom is under-watered. Therefore, for water saving with furrow irrigation, change irrigation sets soon after the water reaches the end of the furrow as opposed to at a predefined time of day. Excess irrigation at the upper part of the field cause stress to crops and causes nitrogen deficiency as nitrogen leach beneath the root zone through percolation (Shock *et al.*, 2013).

2.3.7 Irrigation Scheduling

Irrigation scheduling refers to the method of defining the most desirable irrigation frequencies and depths. It is meant to avoid negative effects of under or over-irrigation (ICDC, 2008). The effective irrigation scheduling requires great comprehension to the know-how of soil water holding capacity, water used by crop, and crop sensitivity to water stress at different growth stages (Levidow *et al.*, 2014). The irrigation scheduling can help prevent a lot of problems such as soil salinity, reduced yield, loss of water by percolation, soil erosion and sedimentation, socio-economic and institutional issues, human health and water availability for irrigation (Simonne *et al.*, 2012).

Soil moisture and crop water use should be monitored and irrigation carried out only when needed with the exact amount of water. By doing this, it is estimated that 0.3 to 0.5 acre-feet of water per acre may be saved for other purposes depending with the number of farms irrigated and scheduling method. From the already existing research conducted on surface water delivery through a series of canals, laterals, and on-farm distribution systems, irrigation scheduling reduces water delivered to the farm for irrigation by between 10% and 25% depending with the farmer (Martin and Gilley, 1993).

2.3.8 Volumetric Measurement of Irrigation Water

This entails the installation of water measuring gadgets, for example, water meters to quantify water streaming into the farm. This strategy can make farmers use water more responsibly. Data earned may likewise be utilized to actualize other water preserving methodologies.

2.3.9 Irrigation System Maintenance

Irrigation system maintenance strategy is imperative in reducing water and energy losses. Exhausted parts of the irrigation system ought to be replaced as quickly as time permits in order to increase the efficiency and maximize output. For sprinkler irrigators, replacing worn sprinklers, self-levelers, drains, gaskets, and fixing leaks increases the irrigation uniformity which results in more yield per unit of water applied. For surface irrigators, re-leveling is required at a given time period; evaluate if to improve the flow rates and set times in furrow or border irrigation to increase

irrigation efficiencies. In some occasions, it might be economically feasible to update irrigation systems to more proficient systems.

2.3.10 Lining of On-Farm Irrigation Ditches and Replacement of canals with Pipelines

This entails the establishment of a fixed lining impervious material in a current or recently built irrigation field trench. Commonly used liners include concrete, urethane and Ethylene-Propylene-Diene Monomer(EPDM). Water is saved by reducing amount of seepage from the canals. Canals made of concrete are estimated to prevent around 80% of the original seepage. Replacement canals with pipelines involves replacing open ditches with buried pipeline that is less than 24 inches in diameter. The quantity of water lost through evaporation is little compared to the seepage from canals. It is estimated that water savings from minimized evaporation are less than 10 percent of the seepage losses (Keller and Keller, 1995)

2.3.11 Land Management Systems

Land Leveling is majorly used by farmers using surface irrigation (furrow, basin, or boarder irrigation methods). Land leveling is used to increase the effectiveness and efficiency of water supplied to an irrigation field or where crops are growing. Water saved from land management system is difficult to quantify and its cost differs from one field to the other.

2.3.12 Best Management Practices

Best management practices are conservation measures that are useful, cost-effective, and accepted among farmers. Soil moisture conservation can be enhanced by controlling of weeds. Weeds usually take away limited water supplies available for crops. They influence the irrigation scheduling and it can prompt withering of crops if not carefully observed. Proper fertilization can also help to utilize water more effectively. An accurate selection of crop varieties with enormous production for the intended farm conditions ought to be accomplished (Allen, 2014).

2.3.13 Crop Selection and Irrigation Needs

These are very imperative in irrigation management strategies. Crop characteristics such as root depth, crop water requirement, canopy, leaves surface area among other factors should be considered. A good crop pattern can effectively utilize the available irrigation water. For instance,

if the irrigation water supply depends on runoff with high flows in May and June, then sow crops such as small grains that can utilize this water and cut off crops that have high water use in July, August, and September (Allen, 2014).

2.3.14 Crop Rotation and Selection

This increases the efficiency of irrigation. For instance, planting a profoundly rooted crop like wheat in the wake of growing a shallow rooted crop like a potato can help in diminishing the amount of water required for irrigation and fertilizer required for the crop development (Allen, 2014).

2.3.15 Miscellaneous systems

Tailwater recovery and reuse is very essential in irrigation system in where large quantity of water runs through irrigated field. This strategy consists of ditches or pipe network which collect the tail water then channel it to a storage reservoir. Water collected from the tailwater reuse system depends mostly on the water supply and the on-farm water management practices of the farmer. Water that can be saved from this method varies from 5 - 25 percent of the water supplied to the upper segment of the farm (Gilley *et al.*, 2003).

2.4 Factors Affecting Irrigation Planning and Development

2.4.1 Soil

Soil assumes an imperative part in planning and developing of the irrigation system. The land's suitability for irrigation relies on soil features and geological profile, deposits and texture of the surface soil. The soil conditions required for profitable, diversified crop production under sustained irrigation includes adequate moisture holding capacity, infiltration rate, sufficient internal drainage, texture, structure and absence of toxic elements such as acidity and alkalinity (Ali, 2010)

2.4.2 Climate

Crops usually have a level of climatic requirements for sufficient growth. Crops can't become legitimately and produce flowers past the fancied climatic farthest point which results in an impeded development. Climatic elements that affect the type of irrigation system to be erected in

a particular place include maximum temperature, minimum temperature, sunshine intensity, humidity, crop evapotranspiration and the length of the day. Therefore, climatic factors are essential in irrigation planning and development.

2.4.3 Topography

Topography is an important factor to consider when it comes to planning and development of the irrigation system because it helps in choosing the best strategy to apply to increase irrigation efficiency. Topography also determines work necessity requirement, erosion, drainage, land advancement and scope of crops to be grown. Some irrigation systems perform better in steep slope and vice versa.

2.4.4 Water Source

It is necessary to identify water source to ensure there is constant water supply to the field. The source of water likewise helps in determining the amount of energy that can be utilized in pumping to ensure water is readily available for irrigation. The energy utilized for any irrigation system where pumping is required should be as low as possible so as to ensure that the farmer gains enough benefit from the farming activities.

2.4.5 Crops

Crop to be grown dictates majorly the type of irrigation system to be selected. Crop elements to be considered include rooting depth, growth stages, crop water use, ground cover, available market and consumer demands. The water requirement shifts in every crop consequently, water. Planning and selection of cropping pattern are necessary for the protection of the soil against nutrient depletion, salinity, alkalinity, acidity and providing enough quantity of water to irrigation network.

2.4.6 Energy

How water will be conveyed to the irrigation field is very vital as it determines when water is to be pumped from the source to the crop field in case it cannot flow via gravity. The source of water (distance and elevation) helps to determine the amount of energy that can be used for supplying the water to ensure it is readily available for irrigation. The energy used for supplying water to any

irrigation system should be as low as possible so as to ensure the farmers gain stipulated profit from the farming activities (Simonne *et al.*, 2012)

2.4.7 Economic Factor

The escalated cost of construction that yields low returns from agricultural production is the primary challenge influencing irrigation development projects. Numerous irrigation systems collapse a few months after establishment or commissioning in Kenya. To achieve efficiency, cost for setting up an irrigation project must be fully recovered. The value of revenues to be generated from the irrigation project must be equal to the value of cost. Farmers benefiting from the irrigation project ought to pay for the expense depending on the distribution of returns from the irrigation. The outcome of an irrigation project is affected by the low price of the crops in the market, low yields from poor irrigation scheduling, high input costs and the management level which are different from one region to the other (Ali, 2010)

2.4.8 Environmental Aspect

These aspects which influence the planning and development of the irrigation system includes siltation and sedimentation, water logging, less or no water downstream, distortion of natural habitat, drainage effluents, emission of methane gas from agricultural fields and biodiversity. Diversion of the existing river flow for the purposes of irrigation may influence the downstream water users in terms of quantity and quality. For this situation, development of the large water retention structures or setting up an irrigation scheme would lead to human being displacement and properties, which is unacceptable both socially and politically (Savva and Fenken, 2002).

2.4.9 Socio-Cultural Aspects

The implementation of irrigation projects changes the land use pattern, household resource requirements and tenure issues. These socio-economic factors affect irrigation development.

2.4.10 Institutional Infrastructure

Numerous recently commissioned irrigation systems breakdown a couple of months after due to the poor institutional infrastructures. Irrigation system construction requires planned operation and

maintenance, financing and cost recovery. Infrastructure is required in the policy decisions with respect to the project design, construction, operation and maintenance and cost recovery

2.5 Determining the time of irrigation

Time of irrigation refers to the estimated time in which water should be applied to the crops. It is paramount for crop yield and water use efficiency. The duration in which water is to be applied depends on the crop water requirement, depth of application, type of soil and the field capacity (Ingvaldsen *et al.*, 2015).

The quantity of water to be pumped to irrigate any irrigation field should be higher than the irrigation requirement so as to enable some water to be held in the root zone since some water always get lost during application to evaporation and non-uniform application of water caused by wind drift. This is the main reason why application efficiencies are usually less than 100%.

2.5.1 Crop water requirement

Crop water requirements can be carried out from the crop's information selected such as K_c , rooting depth, depletion level and length of individual growth stages (FAO, 1996). The water requirements are different and depends with the crop. The quantity of water used by crops depends on a number of factors such as the degree of crop growth, type of crop and climatic factors.

In initial stage of growth, the water needs are usually low but increases as the crop grows towards flowering stage which then decreases at the later stages as the crop matures (Ingvaldsen *et al.*, 2015).

The crop water requirement can be calculated from the equations (2.1) shown below;

$$CWR = IR + P_{eff} \tag{2.1}$$

Where;

CWR – crop water requirement including inefficiencies of the application system and leaching requirement, mm

IR – irrigation requirement, mm

Pe_{ff} – effective precipitation, mm

2.5.2 Application depth

This alludes to the amount of water used to irrigate a given irrigation field which is normally measured in millimeters (mm). It is essential to take into consideration the root depth at every crop growth stage since the application depth varies proportionally with the crop growth and different crops have distinctive root depth (Allen *et al.*, 1998).

The depth of application is also depending on the type of irrigation system being used because some systems apply more water per unit time when contrasted with others. For example, furrow irrigation applies more water as compared to trickle irrigation. Different types of soil have different water holding capabilities. Irrigation is scheduled after a fraction of the soil water in the plant root zone has been depleted (Clarke *et al.*, 2000).

Table 2.1: Available water holding capacities based on soil texture and depth (Broner, 2005)

Textural class	Available water mm/dm of depth
Coarse sands	5 – 7
Fine sands	7 – 8
Loamy sands	9 – 10
Sandy loams	10– 11
Fine sandy loams	12 – 16
Silt loams	16 - 20
Silty clay loams	15- 16
Silty clay	12- 14
Clay	10- 12

2.5.3 Field capacity (FC)

This is the quantity of water that remains in the soil volume after drainage of gravitational water. Available water (AW) is the part of the water content that can be possibly removed from the volume of the soil by the crop. Soil moisture reservoir refers to the quantity of available water within the crop root zone at a given time. Shockingly, just a small amount of the reservoir is readily

available for the crop without water stress. Soil texture normally influences the water holding capacity of soil. Heavy soils like clay with low infiltration rate are liable to water logging (Shock *et al.*, 2013). Sandy soil have a low water holding capacity because of their large grain size while clay soil have a higher water holding capacity (Shock *et al.*, 2013).

Table 2.2: Values for available water holding capacity of different soil (Jensen *et al.*, 1990a)

Texture class	Field capacity mm/dm	Wilting point mm/dm	Available capacity mm/dm
Sand	12	4	8
Loamy Sand	14	6	8
Sandy Loam	23	10	13
Loam	26	12	15
Silt Loam	30	15	15
Silt	32	15	17
Silty Clay Loam	34	19	15
Silty clay	36	21	15
Clay	36	21	15

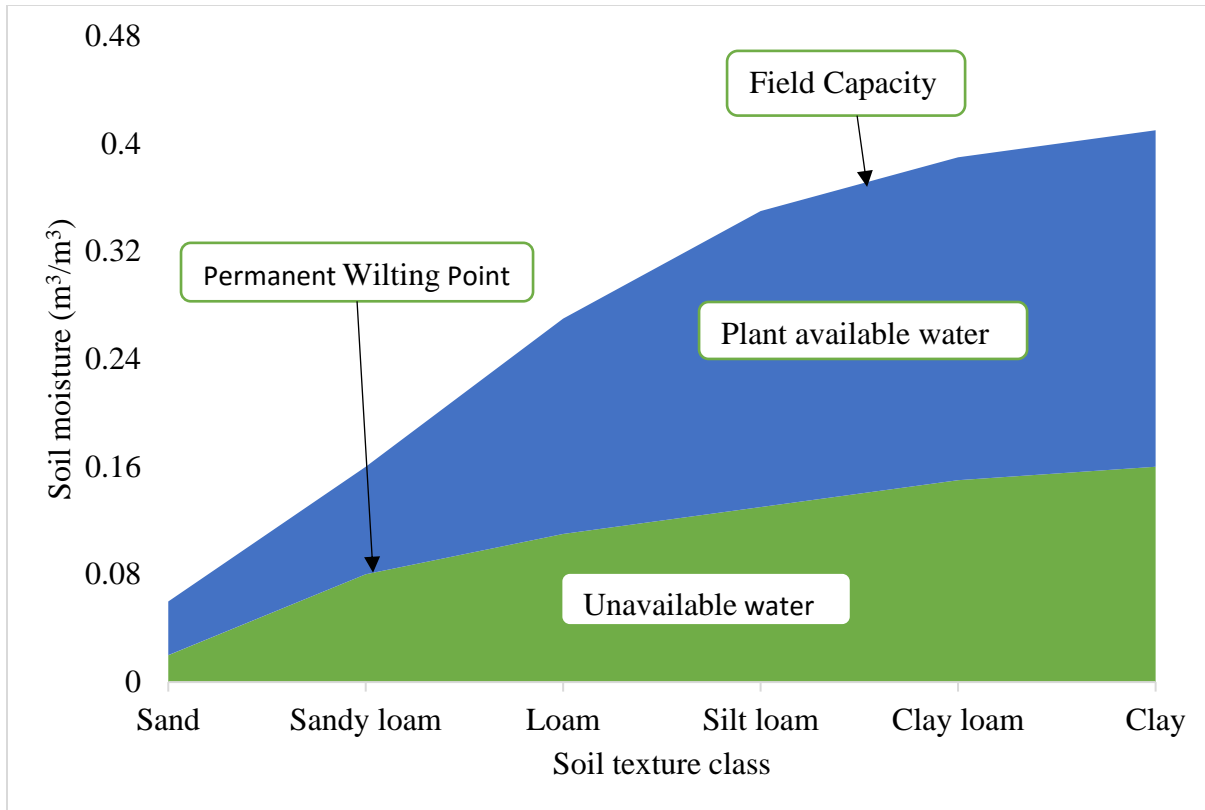


Figure 2.2: General relationship between plant available water, field capacity, permanent wilting point and soil unavailable water in different soil texture class (Zotarelli and Dukes, n.d.)

2.6 Establishing irrigation scheduling

Irrigation scheduling aims at making the optimum use of water and energy by applying the right quantity of water to crops at the right time and place. Irrigation scheduling requires a lot of data about the soil (root zone depth at different growth stages of each crop), crop (crop types, rotation, date of planting and harvesting, daily water requirements of the different crops (Etc) at different stages of growth) and the meteorological data (on-site rainfall data and long term climatic data). These are important parameters required for effective irrigation scheduling. The information about crop is important to determine the amount of water required for irrigation. Meteorological data helps in determining the irrigation efficiency, effectiveness and the amount of water to be applied. In irrigation scheduling, there are two major factors which are considered:

- a) Determination of the time of irrigation.
- b) Calculation of water requirement.

Many methods have been and are still used to determine when to irrigate and are classified into four broad categories;

- a. Soil indicator methods
- b. Plant indicator methods
- c. Water budget technique
- d. Monitoring the weather

2.6.1 Soil indicator methods

The soil water monitoring is one of the known techniques used to determine the time for irrigation. Soil water status can be measured by determining the soil water content. Soil water potential is the force necessary to remove the next increment of water from the soil (Shock *et al.*, 2013). Various methods are applied to determine the correct quantity of water to be applied by using a criterion that determines the irrigation need and a strategy that estimate how much water to apply in any given time. Methods used in monitoring soil water status include the following:

- (i) Tensiometer measurements
- (ii) Nuclear methods
- (iii) Hand feeling and appearance of soil
- (iv) Gravimetric soil moisture sampling
- (v) Electrical resistance blocks
- (vi) Water budget approach
- (vii) TDR (Time Domain Reflectometers)
- (viii) The monitoring of crop canopy temperature by remote sensing with an infrared radiation thermometer (Keller and Keller, 1995).

We can also monitor the weather elements. This method can give meteorological information which can be used to measure the amount of ETo as it varies from time to time and then schedule irrigation as required (Testa *et al.*, 2011).

Irrigation should always start when soil water content drops below 50 % of the total available soil moisture though it can go up to 40% for some crops. Irrigation scheduling is majorly based on soil moisture measurement, climatic data and monitoring plant stress. Irrigation scheduling methods

are to measure soil moisture content to establish if it has dropped below 50% so as to enable irrigation to be initiated. Gravimetric soil moisture sampling is done in the soil laboratory while the remaining methods are done in the field (Zotarelli and Dukes, 2010).

2.6.1.1 Tensiometer

This is an instrument used to measure the soil water potential. It consists of a manometer and a closed tube connected at the end with special ceramic tip. Immediately after rainfall or irrigation, as soil moisture is depleted by evaporation and/or root extraction, the tensiometers register an increase in tension and proper interpretation is needed in estimating when the plant might begin to suffer from stress so that the irrigation is commenced (Martin, 2009).

The measured value registered by the tensiometer indicates the energy required by the crop to extract water from the soil. Soil water tension increases as the soil moisture content decreases. This means that higher reading for dry soils and low reading for wet soil. The tensiometers are available in various lengths that makes easy monitoring of the soil moisture tension at various depths (Ingvaldsen et al., 2015).

The tip of a tensiometer should be soaked in water for 24 hours with algacide that prevents the development of algae that may cloud the water in the tensiometer column before it is installed in the field. The tip of the tensiometer should make a good contact with the surrounding soil to be sure that the precise reading is registered. Two depths per station are recommended for most crops or soil. Tensiometer should be set with its tip at a depth between a quarter and one half of the root zone which should be used for scheduling the start of the irrigation cycle while the other one at a depth of about three quarter of the active root zone and should be utilized to evaluate if the correct depth of water has been applied (ICDC, 2008).

The soil water tension to the soil moisture content as measured by the tensiometer is shown in the figure 2.3 below

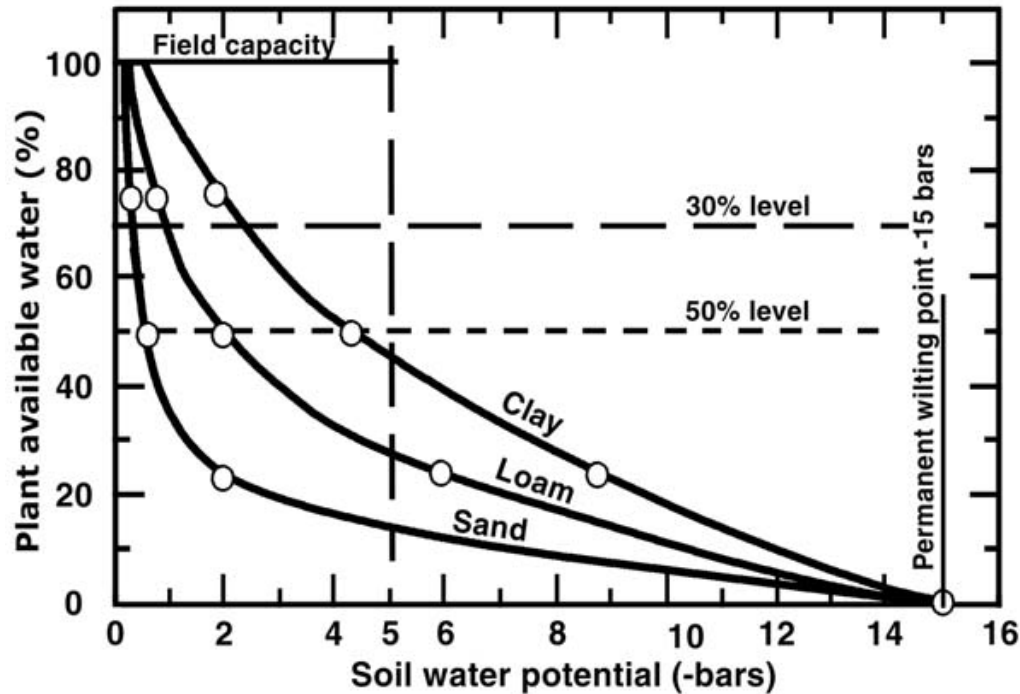


Figure 2.3 A diagram of tension and amount of water for sand, clay and loam soils (USDA, 1997)

The tensiometer should be observed at least once every week. Plotting the reading on the graph helps to allocate the change in the soil water tension, though, it would be better to monitor the tensiometer daily when there is a high soil water tension (ICDC, 2008).

The moisture level can be maintained by modifying the length of time the field is irrigated with different irrigation systems. The amount of time the zone is irrigated to bring the soil moisture to the optimal level should be adjusted depending on whether the soil is usually dry or wet. Tensiometers can be used in all types of the soil if they are not too dry. When heavy clay soils dry, the tension often exceeds maximum reading (80 cb) (Robert Evans, 1996).

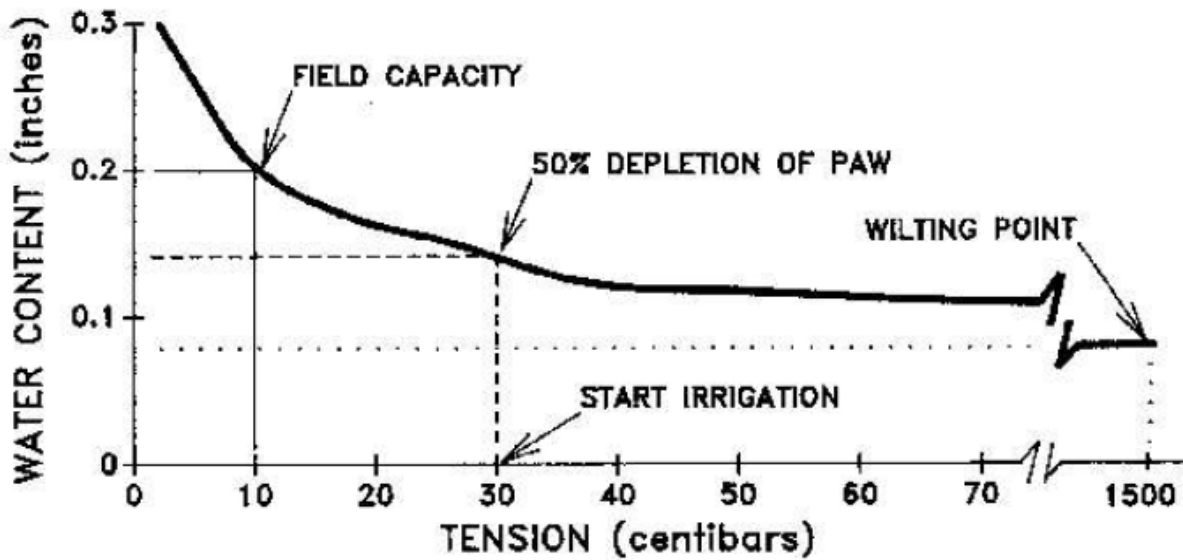


Figure 2.4 A calibration curve of water content versus tensiometer reading (tension) (Robert Evans, 1996)

The range the tensiometer should read to keep the soil moisture at an optimum level when using a drip irrigation system is shown in the table 2.3.

Table 2.3: Soil moisture range for drip/trickle and micro-jet system (Tam, 2006)

Soil type	Soil moisture tension (cb)	
	Low (wet)	High (dry)
Sand	10	15
Loamy sand	10	15
Sandy loam	15	20
Loam	25	30

2.6.1.2 Hand feel and appearance of soil

This method is very cheap and does not require any special skills in order to achieve results as compared to other methods that are expensive and require technical know-how to operate. This method estimates soil moisture by collecting a handful of soil and squeezing tightly between fingers from which various moisture content available in the soil can then be estimated (Maithya, Gibendi, and Asempah, 2010). Though hand feel and appearance of soil is the cheapest and readily available method, its disadvantages include:

- a) It is non-quantitative and subjective,
- b) It does not give any lead time for irrigation,
- c) It only looks at the surface soil in a limited area,

This method is not recommended as the only means of irrigation scheduling, but should still be used to verify other methods.

Table 2.4: Water availability for different soils, numbers in parentheses are available to water content expressed as cm of water per 3 dm of soil depth (Van der Gulik, 2006).

Feel or Appearance				
Available water	Sand	Sandy loam	Loam/Silt Loam	Clay loam/ Clay
>100%	Free water appears when soil is bounced in hand	Free water is released with kneading	Free water can be squeezed out	Puddles; free water forms on the surface
100%	Upon squeezing, no free water appears on soil,	Appears very dark. Upon squeezing, no free water appears on soil, but wet	Appears very dark. Upon squeezing, free water appears on soil, but wet outline of ball	Appears very dark. Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand. Will ribbon about (5 - 7.5 cm)

	but wet outline of the ball is left on hand (2.5 cm)	outline of ball is left on hand. Makes short ribbon. (3.75 cm)	is left on hand. Will ribbon about (2.5 - 5cm)	
75 – 100%	Tends to stick together slightly sometimes forms a weak ball with pressure. (2 - 2.5 cm)	Quite dark. Forms a weak ball, breaks easily. Will not slick. (3 - 3.75 cm)	Dark colored. Forms a ball, is very pliable, slicks readily if high in clay. (3.75 - 5 cm)	Dark colored. Easily ribbons in between fingers have slick feeling (4.75 - 6.25 cm)
50 – 75%	Appears to be dry, will not form a ball with pressure. (1.25 – 2 cm)	Fairly dark. Tends to form a ball with pressure but seldom holds together. (2 – 3 cm)	Fairly dark. Forms a ball somewhat plastic, will sometimes slick slightly with pressure. (2.5 – 3.75 cm)	Fairly dark. Forms a ball, ribbons out between thumb and forefinger. (3 – 4.75 cm)
25 – 50%	Appears to be dry, will not form a ball with	Light colored. Appears to be dry, will not form a ball	Lightly colored. Somewhat crumbly, but holds together with pressure.	Slightly dark. Somehow pliable will ball under pressure (1.5 - 3 cm)

	pressure. (0.5 - 1.25 cm)	(1 - 2 cm)	(1.25 – 2.5 cm)	
0 – 25%	Dry, loose, single- grained, flows through fingers. (0 – 0.5 cm)	Very slightly colored. Dry loose, flows through fingers. (0 – 1 cm)	Slightly colored. Powdery, dry sometimes slightly crusted, but easily broken down into powdery condition (0 – 1.25 cm)	Slightly colored. Hard, baked, cracked, sometimes has loose crumbs on the surface. (0 – 1.5 cm)

2.6.1.3 Gravimetric soil moisture sample

Gravimetric soil moisture sampling entails collecting the samples then weighing both the freshly collected and dried samples. The soil is collected at different depths then computed differently. The weight of the samples is then determined before and after being placed in an oven at 105⁰C for 24 hours using a digital weighing balance. The volumetric water content of the soil is calculated using the formula that follows:

$$\theta = \frac{W_w - W_d}{W_d} \times \frac{\rho_b}{\rho_w} \quad (2.2)$$

Where;

θ – the soil water content (cm³/cm³),

w_w – the weight of the soil sample at field condition (g),

w_d – the weight of the soil sample after drying (g),

ρ_b – the dry bulk density of the soil (g/cm³),

ρ_w – the density of water (1.0 g/cm³).

The size and number of samples affect the final result (ICDC, 2008).

2.6.1.4 Electrical resistance blocks

This is a technique used to determine soil water content that can help in deciding the time when irrigation is needed. Electrical resistance block can help to stop irrigation when soil water has reached the field capacity (Rogers *et al.*, 1997).

The resistance blocks are installed during the growing season at different soil depths which determines the amount of water at each depth. They are installed during the growing season to avoid disturbing the root zones later when crops have grown. The readings obtained can then be used to schedule irrigation. The electrical resistance varies between the two electrodes of the block depending with the water content. The higher the soil water content the lower the resistance and vice versa.

Care should be taken to ensure the blocks are placed at the effective root zone and do not interfere with the roots of the crops growing. The electrical resistance block should have a good contact with the soil for the successful installation. The type of irrigation system determines the location of the block in the field as to whether it should be deeper, shallow, at the intake or outlet. Low, high spots and changing slopes should be avoided at all cost during installation of the electrical resistance block, and the area should represent the entire field or crop population.

Two blocks can be installed to manage active root zone. The upper block is placed at about a quarter depth of the root zone and the lower block at three-quarter of the active root zone.

The soil water-holding capacity information is paramount as it will help us to know the exact time for irrigation (USDA, 1997).

2.6.2 Water budget / Water balance approach

In a water budget, the crop root zone is taken as a storage of the available water. Rainfall, and irrigation adds water to the reservoir and removed through absorption by crops, transpiration, and evaporation from the soil surface expressed as millimeters per day (Simonne *et al.*, 2012). Two variations of the water balance method are used where one uses crop curves while the other uses pan evaporation data. Water budget approach method determines how much water is being lost from the soil which in turn helps us in determining how much water is to be topped up to keep the

moisture balance within the required level. An accurate estimate of daily crop water use is a major requirement to ensure a more reliable scheduling for irrigation is obtained (WEC, 2008).

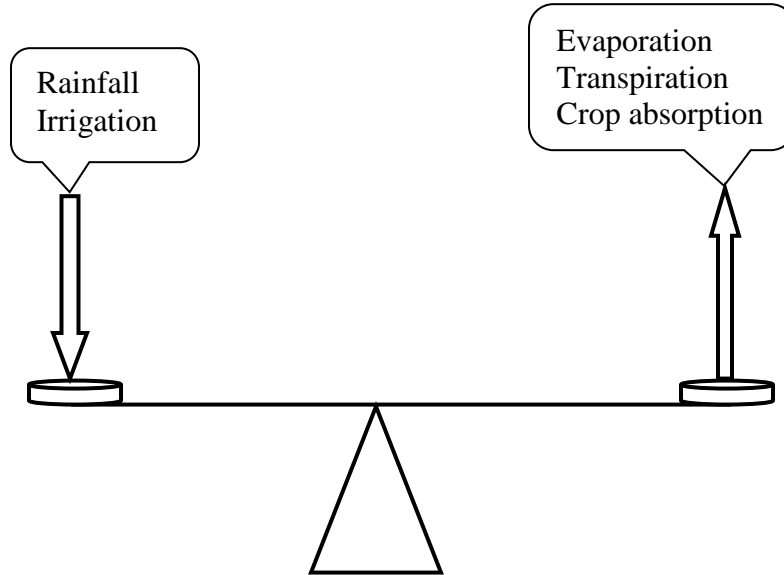


Figure 2.5: water balance (Ingvaldsen *et al.*, 2015)

Table 2.5: Ranges in available water capacity and intake rate for various soil textures (Tan and Layne, 1990)

Soil texture	Available water capacity mm of water/dm of soil	Intake rate mm/hr.
Sands	5 – 8	12 – 20
Loamy sand	7 – 10	7 – 12
Sandy loam	9 – 12	7 – 12
Loam	13 – 17	7 – 12
Silt loam	14 – 17	4 – 7
Silty clay loam	15 – 20	4 – 7
Clay loam	15 – 18	4 – 7
Clay	15 – 17	2 – 5

2.6.2.1 Checkbook scheduling

It is an accounting approach for estimating how much soil water remains in the effective root zone based on water inputs and outputs. Irrigation is initiated when the soil moisture content in the effective root zone nears the allowable depletion volume. This method of scheduling enables farm manager to monitor the field's daily soil water balance which can be used to plan the next irrigation (Wright, 2002). The manager monitors the growth of the crop, the maximum air temperature per day, the daily ET estimation, and the rainfall or irrigation applied to the field then used to calculate the new soil water deficit balance. The data is entered into the soil water balance sheet. The daily update should be done in the early morning after the in-field rain gauges have been measured (Wright, 2002). The equation below is used in determining when to irrigate;

$$RAM = RAM_{(i-1)} + ETc_{(i)} + AD_{(i)} + Pe_{(i)} \quad (2.3)$$

Where;

$RAM_{(i)}$ – readily available moisture in the soil in day (i), (mm)

$RAM_{(i-1)}$ – readily available moisture in the previous day to day (i), (mm)

$ETc_{(i)}$ – evapotranspiration during day (i), (mm)

$AD_{(i)}$ – irrigation application depth in a day (i), (mm)

$Pe_{(i)}$ – precipitation in day (i), (mm)

When the soil water level is at field capacity and the readily available moisture has been determined, then irrigation is withheld until all the readily available moisture has been depleted. The required application depth is then applied to raise the soil water level back to field capacity. These methods only predict the time to irrigate but do not indicate how much to apply.

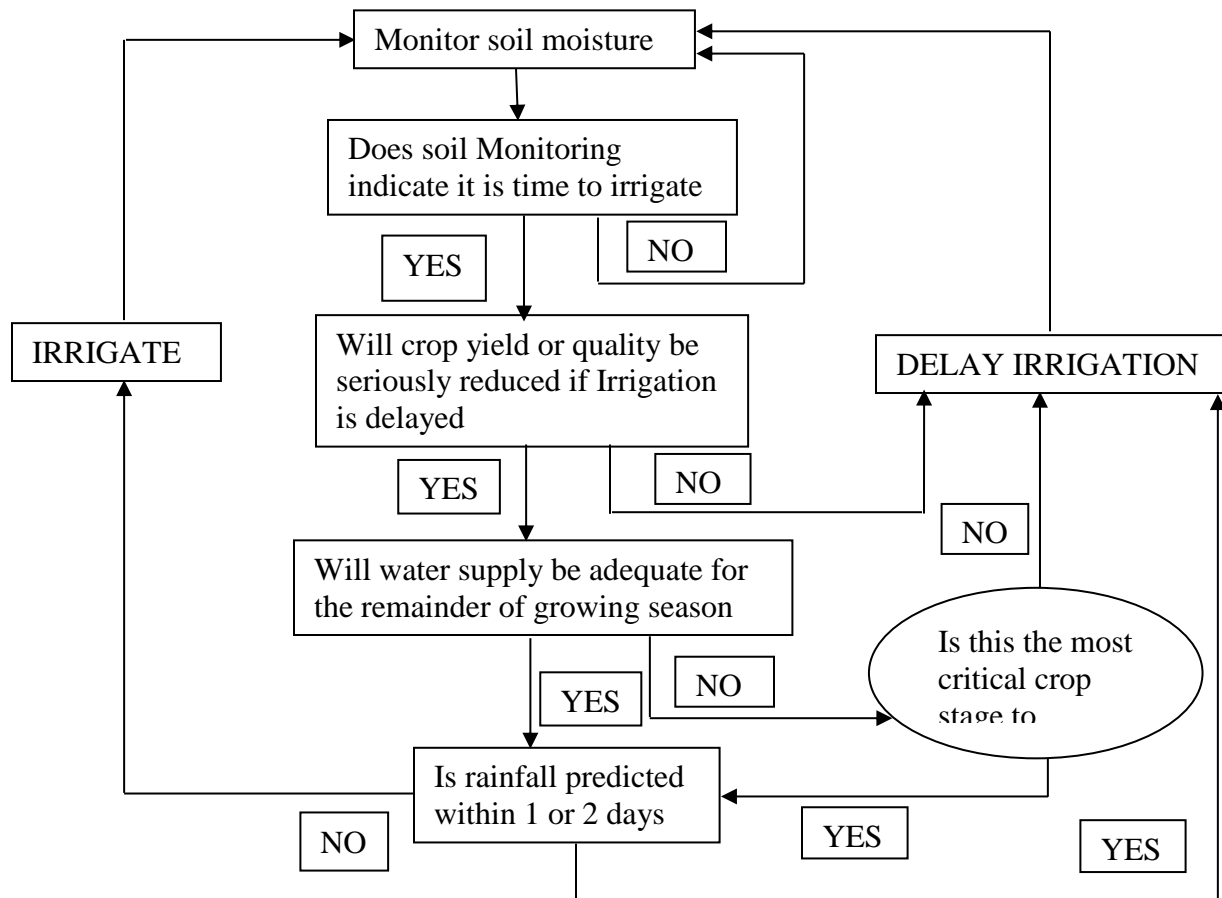


Figure 2.6: Daily decision process required to schedule irrigation effectively (Robert Evans, 1996)

2.6.3 Monitoring the crop

Leaf water potential is used for scheduling irrigation. Irrigation should commence when the crop is water stressed that can reduce crop yield or quality. The level of stress that causes a reduction in crop yield or quality depends on the type of crop and its growth stage. A number of methods have been put in place to monitor the state of water in the plant which includes techniques to estimate transpiration using excised leaves, observations of stomatal aperture, monitoring stem diameter, pressure cell and psychrometric measurements of leaf water potential among others. They are the most direct methods of determining when to irrigate (Gulma *et al.*, 2005). The methods used mostly by farmers in this category include;

2.6.2.1 Appearance and growth

A keen farmer who knows his crop growth can detect signs of water stress by the appearance of the leaves, stems and branches during the period of peak transpiration demand which is usually at midday. This method entails the monitoring of the crop growth characteristics like wilting when other factors such as fertilizer, pest, and diseases have been met. It involves visual interpretation of the leaf and shoots wilting, leaf color and measurement of the stem diameter and height at a given interval. It is the simplest method that has been used by farmers in remote areas.

2.6.2.2 Leaf temperature

The monitoring of crop canopy temperature by remote sensing with an infrared radiation thermometer can be used in monitoring soil moisture content (Jackson, 1982). When the leaf temperature rises, it indicates that there is a reduced rate of transpiration since the plant temperature is controlled by transpiration. The handheld infrared thermometer is used to indicate the canopy area that its temperature exceeds air temperature for each day. Irrigation can then be initiated when a certain level has been reached.

2.6.2.3 Leaf water potential

This method involves removing the leaf and placing it in a pressurized chamber where measurements are done for pressure required to force the fluid from the leaf stem. This is a measure of the leaf's moisture potential where the lower potential indicates a greater need for water.

2.6.2.4 Stomatal Resistance

This is related to the degree of stomatal opening and the rate of transpiration. It acts as an index to the need for water by the plant. Commercial leaf is used in this method to determine stomatal resistance. This method requires a high level of skills.

2.6.4 Monitoring the weather

This method gives meteorological information that can be used to measure the amount of evapotranspiration and to set the amount of water needed for irrigation. The timing of irrigation can then be determined with reference to the wetness of the soil or in reference to the status of the crop (Hillel, 1990).

2.7 Determining evapotranspiration (ET)

Evapotranspiration (ET) refers to a combined process of evaporation and transpiration from plants. Evaporation accounts for the loss of water to the atmosphere from the soil, plants and water bodies while transpiration, on the other hand, refers to the loss of water within a plant and the subsequent loss of water as vapor through the stomata in the leaves (Allen *et al.*, 1998).

The sun provides the energy necessary for the evaporation to take place. Wind speed, air humidity, water available, solar radiation, air temperature and the degree of shading of the crop are some of the factors affecting evaporation. On the other hand, the difference between the water vapor inside the leaf and the atmosphere is the driving force that enables transpiration to occur. (Allen *et al.*, 1998).

Evaporation is the major process causing loss of water from the soil to the atmosphere at the early stages of plant growth which changes to transpiration as the crops develops. The technique chosen for calculating evapotranspiration relies on the availability of data. Some of the methods for calculating ET are discussed below:

2.7.1 Soil water balance

Evapotranspiration can be determined by using the soil water balance method by measuring the various components of the soil water balance (Heermann, 1985). The equation is given as shown below;

$$ET = I + P - RO + DP + CR \pm \Delta SF \pm \Delta SW \quad (2.4)$$

Where;

I – the irrigation water supplied (mm),

P – the rainfall,

RO – the surface runoff,

DP – the deep percolation which recharges the water table.

CR – the capillary rise.

ΔSF – subsurface flow in (SF_{in}) or outflow (SF_{out}) of the root zone.

ΔSW – change in the soil water content.

All the components given in the above equation are measured or estimated. This method has an acceptable degree of error in evapotranspiration estimation if performed on longer periods of 10 days or a month (Djaman *et al.*, 2013).

2.7.2 Reference evapotranspiration (ET_o)

This is the expected water use from a uniform green cover crop surface such as grass or alfalfa. Alfalfa has been preferred as reference crop because alfalfa has aerodynamic roughness closer to most field crops. Actual crop water use is usually less and is obtained by using a crop coefficient which is almost the same to actual evapotranspiration. The calculation of reference evapotranspiration is a common method used to calculate the crop water requirement, which is required for irrigation scheduling design (Zotarelli and Dukes, 2010).

Clipped grass provides a better representation of reference evapotranspiration than alfalfa because the characteristics of the grass are better known and defined, and the grass crop has more planting areas than alfalfa throughout the world and measured evapotranspiration rates of grass are more

readily available and accessible as compared to the measured alfalfa evapotranspiration (Zotarelli and Dukes, 2010).

Evapotranspiration mostly depends on the soil ground cover, soil fertility, organic matter, amount of moisture stored in the soil, crop type, weather condition and stage of crop growth. Evaporation is most likely to be higher in bright, sunny, hot and windy weather and low in cloudy calm weather. Poor health of the crop due to low soil fertility, low water availability, attack by pest and diseases will all reduce transpiration.

2.7.2.1 Calculation of actual evapotranspiration

Reference evapotranspiration is first calculated from the climatic data and geographic information then the actual evapotranspiration E_{Tc} for different crops is then calculated by multiplying reference evapotranspiration by crop coefficient K_c as shown below (Zotarelli and Dukes, 2010).

$$E_{Tc} = E_{To} \times K_c \quad (2.5)$$

Where;

E_{Tc} – actual evapotranspiration [mm]

E_{To} – reference evapotranspiration [mm]

K_c – crop coefficient (Varies with different growth stage)

2.7.2.1.1 FAO-Penman-Monteith method

It is made up of equation that has generally been accepted as a scientifically proven formula for determining reference evapotranspiration. The equation contains climatic variables such as radiation, maximum temperature, minimum temperature, vapor pressure, and wind speed (Savva and Fenken, 2002). This method is believed to offer the best results with a minimum error in relation to a grass reference crop. Penman-Monteith entails calculation of various parameters contained in the equation (Testa *et al.*, 2011).

There are two resistance factors; aerodynamic and surface resistance. The aerodynamic resistance involves friction from the air blowing over the vegetative surfaces while the surface resistance is the resistance of vapor flow through stomata opening, total leaf area, and soil surface (Testa *et al.*, 2011).

Penman-Monteith equation is derived from combination equation which is shown below;

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2.6)$$

Where;

ET_o – Reference evapotranspiration [mm day^{-1}]

R_n – Net radiation at the crop surface [$\text{MJ m}^{-2} \text{day}^{-1}$]

G – Soil heat flux density [$\text{MJ m}^{-2} \text{day}^{-1}$]

T – Daily air temperature at 2 m height [$^{\circ}\text{C}$]

u_2 – Wind speed at 2 m height [m s^{-1}]

e_s – Saturation vapour pressure [KPa]

e_a – Actual vapour pressure [KPa]

$(e_s - e_a)$ – Saturation vapour pressure deficit [KPa]

Δ – Slope vapour pressure curve [$\text{KPa } ^{\circ}\text{C}^{-1}$]

γ – Psychometric constant [$\text{KPa } ^{\circ}\text{C}^{-1}$] (Shen et al., 2013)

The Penman Monteith equation is combined with various equations where each equation has an expression of some factors that are used to determine reference evapotranspiration. Each component has been discussed as shown in the following equations;

The soil heat flux density (G) is usually ignored or taken to be zero in the Penman-Monteith equation ET_o calculation because its size beneath the grass reference surface for one-day and ten-day periods is relatively negligible (Savva and Fenken, 2002).

The net radiation

$$R_n = R_{ns} - R_{nl} \quad (2.7)$$

Where;

R_n – Net radiation (MJ/m^2 per day)

R_{ns} – Net incoming shortwave radiation (MJ/m² per day)

R_{nl} – Net outgoing longwave radiation (MJ/m² per day)

Solar or shortwave radiation

$$R_s = \left[0.25 + 0.5 \frac{n}{N} \right] R_a \quad (2.8)$$

Where;

R_s – Solar or shortwave radiation (MJ/m² per day)

n – Actual sunshine hours (hour)

N – Maximum possible duration of sunshine hours or daylight hours (hours)

n/N – Relative sunshine duration

R_a – Extraterrestrial radiation (MJ/m² per day)

Latent heat vaporization

$$\gamma = \frac{C_p P}{\varepsilon \lambda} = 0.665 \times 10^{-3} P \quad (2.9)$$

Where;

C_p – Specific heat at constant pressure = 1.013×10^{-3} MJ/Kg⁰C

P – Atmospheric pressure (kPa)

ε – Ratio molecular weight of water vapour/dry air = 0.622

λ – Latent heat vaporization = 2.45 MJ/kg (at 20⁰C)

Mean daily temperature

$$T_{mean} = \frac{T_{max} + T_{min}}{2} \quad (2.10)$$

Where;

T_{mean} – Mean daily temperature (⁰C)

T_{max} – Mean daily maximum temperature (⁰C)

T_{min} – Mean daily minimum temperature (⁰C)

Wind speed at 2m above ground surface

$$u_2 = u_z \times \frac{4.87}{\ln(67.8z - 5.42)} \quad (2.11)$$

Where;

u_2 – Wind speed at 2m above ground surface (m/sec)

u_z – Measured wind speed at z m above ground surface (m/sec)

Z – Height of measurement above ground surface (m)

Mean saturation vapour pressure

$$e_s = \frac{e^0(T_{\max}) + e^0(T_{\min})}{2} \quad (2.12)$$

Where;

e_s – Mean saturation vapour pressure (kPa)

$e^0(T_{\max})$ – saturation vapour pressure at the maximum air temperature (kPa)

$e^0(T_{\min})$ – Saturation vapour pressure at the minimum air temperature (kPa)

Saturation vapour pressure

$$e^0(T) = 0.6108 \exp\left[\frac{17.27T}{T + 237.3}\right] \quad (2.13)$$

Where;

T – Mean air temperature ($^{\circ}\text{C}$)

Exp[.] – 2.7183(base of natural logarithm) raised to the power [..]

Actual vapour pressure

$$e_a = \frac{\left[e^0(T_{\min}) \times \frac{RH_{\max}}{100} \right] + \left[e^0(T_{\max}) \times \frac{RH_{\min}}{100} \right]}{2} \quad (2.14)$$

Where;

e_a – Actual vapour pressure (kPa)

$e^0(T_{\min})$ – saturation vapour pressure at daily minimum temperature (kPa)

$e^{\circ}(T_{max})$ – saturation vapour pressure at daily maximum temperature (kPa)

RH_{max} – Maximum relative humidity (%)

RH_{min} – Minimum relative humidity (%)

Slope vapour pressure curve

$$\Delta = \frac{4098 \left[0.6108 \exp\left(\frac{17.27T}{T + 237.3}\right) \right]}{(T + 237.3)^2} \quad (2.15)$$

The equation uses standard climatological records. The measurements should be taken at 2m above an extensive surface of green grass and not short of water to guarantee that the computational results are accurate. The Penman Monteith method for determining reference evapotranspiration is that it is accurate and data are readily available from meteorological stations though some data needed may not be available. Estimated potential ET for reference crop, actual ET for various crops estimated with crop coefficients and Kc varies with local conditions which is disadvantageous (Zotarelli and Dukes, 2010).

2.7.2.1.2 Pan evaporation method

This is the most practical technique for determining reference evapotranspiration. It entails the effects of temperature, solar radiation, humidity and wind speed. The evaporation from the pan is near to the evapotranspiration of grass that is taken as a reference point for the reference evapotranspiration for calculating actual evapotranspiration. The readings (Span) from the pan are related to the reference evapotranspiration with the help of the pan coefficient (K_{pan}), which depends on the pan, its location (vegetation cover) and the climate.

$$ET_o = E_{pan} \times K_{pan} \quad (2.16)$$

ET_o – Reference evapotranspiration

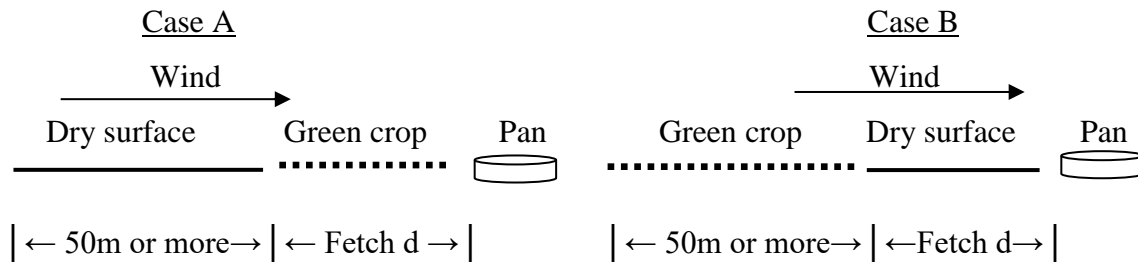
E_{pan} – Pan evaporation

K_{pan} – Pan coefficient

Crop water requirement can then be calculated from reference evapotranspiration by determining specific pan crop coefficient (Kc). There are specific types of pans (circular or square pan) used in estimating the evaporation rate (pan evaporation) (Allen *et al.*, 1998).

We can then calculate crop water requirement from reference evapotranspiration by determining specific pan crop coefficient (Kc). There are specific types of pans (circular or square pan) used in estimating the evaporation rate (pan evaporation) (Allen *et al.*, 1998).

There are two cases of pan siting which vary depending on the ground surface in the upwind direction as illustrated below;



Case A: defines the situation when air moves across at least 50m of dry surface and then across from 1-1000m of green crop

Case B: defines the reverse situation when air moves across at least 50m of green vegetation and then across from 1-1000m of a dry surface.

$$K_p = 0.475 - 0.24^{10^{-3}} (U_{2m}) + 0.00516 (RH_{mean}) + 0.00118 (d) - 0.16^{10^{-4}} (RH_{mean})^2 - 0.101^{10^{-5}} (d)^2 - 0.8^{10^{-8}} (RH_{mean})^2 (U_{2m}) - 1.0^{10^{-8}} (RH_{mean})^2 (d) \quad (2.17)$$

Where;

U_{2m} – Wind run at 2m height, km/day

RH_{mean} – Mean relative humidity, percent

d – fetch distance of green crop, m

When the wind speed is measured at a height other than 2m, the equation above is modified to the equivalent 2m wind speed by application of the log wind law as shown;

$$U_{2m} = U_x \left[\frac{2.0}{z} \right]^{0.2} \quad (2.18)$$

Where;

U_{2m} – equivalent wind speed at 2m

U_x – wind speed measured at height z

z – height of wind measurement

2.8 Crop coefficient, K_c

A crop coefficient is always applied to adjust reference evapotranspiration value for local conditions and the crop type being irrigated from the determined reference evapotranspiration to obtain the actual evapotranspiration. The crop coefficient takes into account crop type and the growth stages to adjust the E_{to} for that specific crop. The crop coefficient value is different for every crop which depends on their properties that result to different water use. Crops cannot utilize the same amount of water as grass in the event that it is utilized as a reference crop because different crops have varying rooting depth, length of growth stages, and physiology. It is necessary to distinguish the crop growth stages, lengths and selecting the corresponding crop coefficient for every stage before calculating the crop coefficient for any crop (Allen *et al.*, 1998).

The growing season is divided into four stages (initial, crop development stage, mid-season stage, and late stage). The length of every stage depends on the climate, latitude, elevation and planting date.

Initial stage: At this stage, the crop cover is less than 10%, the soil surface is mostly bare and the length is different for different crops.

Crop development stage: In this stage, the crop cover ranges from 10% to effective full cover (80%) which occurs at the beginning of flowering.

Mid-season stage: This stage starts from effective full cover to the start of maturity. The crop coefficient reaches its optimum value at this stage.

Late stage: It starts from the beginning of maturation to full maturity or harvest. The rate of evapotranspiration (ET) depends on the range of crop canopy cover. The maximum evapotranspiration occurs when the canopy cover is approximately 60% for tree crops and 70% for field and row crops. The extreme shade cover occurs at a time of the year when sun radiation and air temperature are at the peak which implies that the maximum ET occurs during mid-season. (Smesrud and Selker, 2001)

2.8.1 Estimating Kc for different stages

The crop coefficient values can be obtained from (FAO,1998) for the climates that suits a specific area. The expected average Kc value under climatic condition of a specific area is defined as a sub-humid climate with average daytime minimum relative humidity of 45 % and having calm to moderate wind speeds averaging 2 m/s. When we have a typical climate which has more or less relative humidity than 45 % or wind speed more or less than 2 m/s, the Kc must be modified. (Allen *et al.*, 1998)

2.8.2 Crop coefficient curve

This allows for the determination of Kc values for any period of the growing season. The crop coefficient curve is constructed by separating the growing period into four growth stages (initial, development, mid and late season stage). The length of the growth stages and the crop coefficient for each stage is then determined. The initial stage value must be adjusted by multiply it with a fraction of soil surface wetted (fw) depending on the precipitation or irrigation method.

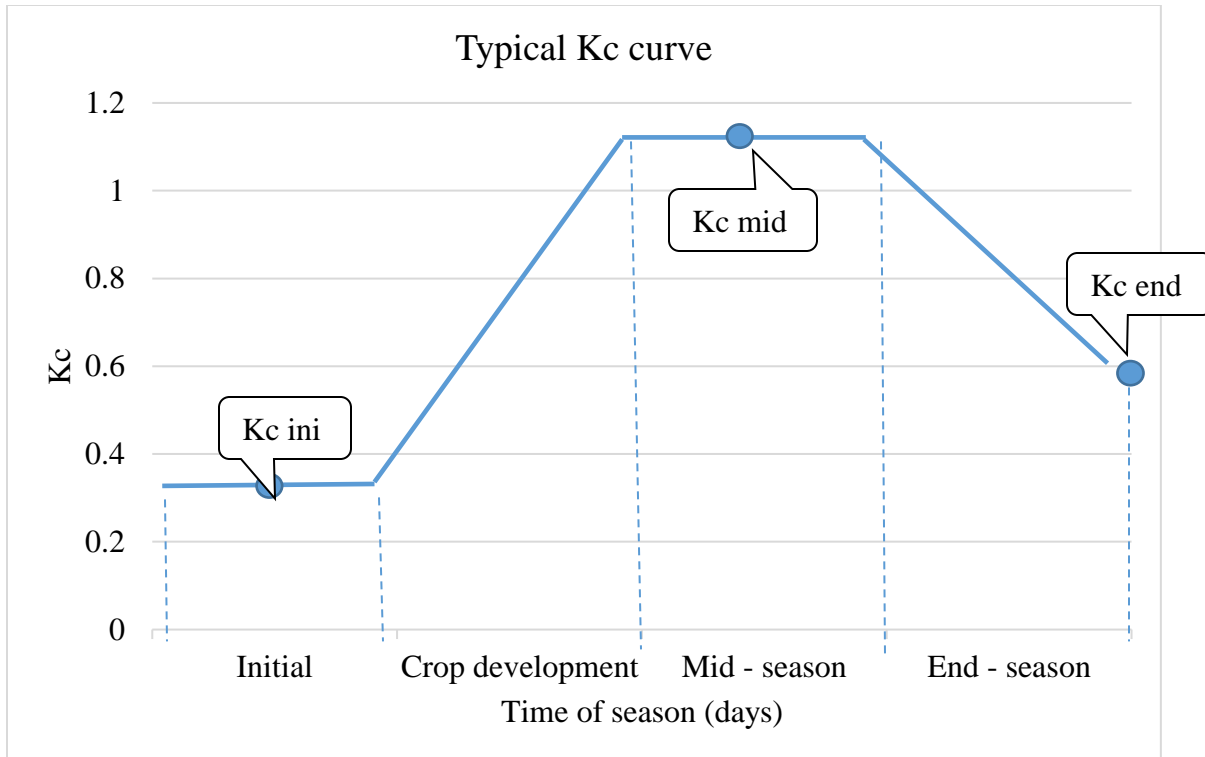


Figure 2.7: An example of Kc curve showing Kc ini, Kc mid and Kc end (Allen *et al.*, 1998)

Table 2.6: Common values of fraction (fw) of soil surface wetted by precipitation or irrigation (Allen *et al.*, 1998)

Wetting event	fw
Precipitation	1.0
Sprinkler irrigation	1.0
Basin irrigation	1.0
Border irrigation	1.0
Furrow irrigation (every furrow), narrow bed	0.6-1.0
Furrow irrigation (every furrow), wide bed	0.4-0.6
Furrow irrigation (alternated furrows)	0.3-0.5

2.8.3 Crop water use

This is also known as evapotranspiration. It refers to the actual amount of water absorbed by the crop from the soil by the roots. The crop water use can be determined by multiplying the reference evapotranspiration by a crop coefficient.

2.9 Effect of irrigation systems on irrigation scheduling efficiency

As we have examined before, irrigation scheduling is a decent strategy to decide the quantity of water and the ideal time for irrigation. Irrigation scheduling is more efficient when we consider the type of the irrigation system to be applied. The effectiveness of the irrigation scheduling optimises by picking the correct irrigation system. Drip irrigation system has a higher efficiency water use when contrasted with furrow irrigation (LeBoeuf, 2008).

Table 2.7: Irrigation system efficiencies (Rogers *et al.*, 1997)

Type of irrigation system	System	Application Efficiency (%)
Surface Irrigation	Basin	60 – 95
	Border	60 – 90
	Furrow	50 – 90
	Surge	60 – 90
Sprinkler Irrigation	Hand move	65 – 80
	Traveling Gun	60 – 70
	Center Pivot & Linear	70 – 95
	Solid Set	70 – 85
Trickle irrigation	Point source emitters	75 – 95
	Line source emitter	70 – 95

CHAPTER 3: MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location

The Project was implemented in Marigat in the Western part of Baringo county located between latitudes 00° 28' S and longitudes 36° 01' E. Marigat District covers an area of 1,677.5 sq. km which lies between Latitudes 00° 13" North and 10 40" North and Longitudes 35° 36" and 36° 30" East. The altitude varies from 1,000m to 2,600m above sea level.

Perkerra Irrigation Scheme is found about 100km from Nakuru town along the famous river Perkerra that is the main source of water in the region. The name came from the River Perkerra which is the only source of water for irrigation and the only permanent river in the Margat district. The District borders East Pokot to the North, Baringo Central District to the West, Koibatek District to the South, and Nyahururu District to the East. The total area covered by the District is 1677.5km² as shown in the table below.

Table 3.1: Area and administrative units by division (KNBS, 2009)

County	District	Division	Locations	Sub-Locations	Area (km ²)
Baringo	Marigat	Marigat	11	18	788.9
		Mukutani	3	6	404.0
		Mochongoi	4	7	484.6
	Total	18	31	1677.5	

Total potential irrigation area is 2,000 acres out of which only 1200 acres has been developed for gravity furrow irrigation and is being cropped due to the water shortage. The main crops that used to be grown include onions, chilies, watermelons and tree crops (paw paws, mangoes, oranges, and bananas). Maize was then introduced in 1996 as a result of the contract with Kenya seed company. It is grown in the main season.

3.1.2 History of establishment

Perkerra Irrigation Scheme is one of the seven public irrigation schemes under National Irrigation Board (NIB). Others include Bura, Ahero, South West Kano, Mwea, Bunyala and Tana Irrigation Scheme. It is in Baringo County in the western part of Kenya that was set up and funded by the Government with the overall aim of improving the livelihoods of farmers by enhancing their incomes through the practice of sustainable irrigated agriculture.

The Perkerra irrigation scheme was launched in 1952 and construction began in 1954 by the Mau laborers because Margat town was one of the camps used for detaining colonial prisoners in the country at that time. (Roll-out, 2011)

The project was initiated in a region with a backdrop of extreme poverty of about 66% amongst its sparse population who experienced unreliable rainfall and frequent crop failures where agriculture (farming and pastoralism) is the mainstay of the people (Poverty Mapping exercise, 2003/2004).

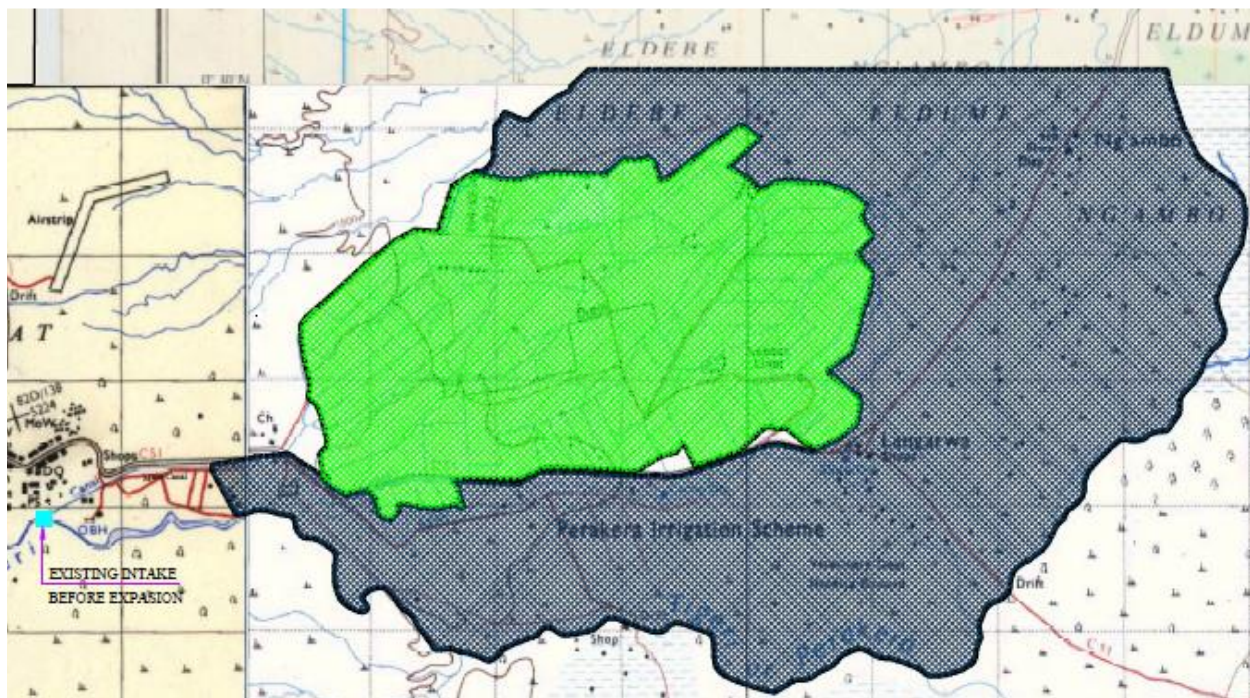


Figure 3.1: A map showing an area covered by Perkerra Irrigation Scheme

3.1.3 Beneficiaries

Beneficiaries are grouped into two broad categories; direct beneficiaries of about 13000 people and indirectly benefits the larger Baringo and part of Nakuru counties by the marketing of the farm produce. The Perkerra irrigation scheme supports about 750 farm households with the majority having 3 to 4 acres of farmland.

3.1.4 Climate

Climatic patterns in Perkerra Irrigation Scheme range from humid subtropical in the highlands to semi-arid in the lowlands. Agro-ecologically, the area is sub-humid with mean annual rainfall ranging from 600mm in the lowlands of Njemps Flats to 1000-1500 mm in the highlands. The rainfall has a high variability in duration and amount making up two fairly distinct seasons. It receives one rainy season between April and August and the rest are prolonged the dry season. It is receiving low to average annual rainfall. Though in the Neighboring Kabarnet District there are high potential areas neighboring the highlands that receive high rainfall (GoK, 2010). There is high rainfall variability in Marigat District. It has a high evaporation rate of up to 6mm. The mean annual maximum temperature is 32.4 °C, the mean annual minimum temperature is 16.8 °C and the mean annual temperature in the highlands is 14°C and in the lowlands 24°C.

3.1.5 Topography, Soil, and Vegetation

The area has a varying textures and drainage conditions. Generally, the land slopes gently in the direction of Lake Baringo. The topography of the irrigable land earmarked for the scheme is fairly gentle slopes of approximately 5%.

Soils within the plains are well drained, deep, friable silty loams or heavy cracking clays. Soils are light silt to clay loam and are modestly alkaline with an average PH of 7.5 and little organic matter. It is well rich in calcium phosphate. The original Acacia woodland has been degraded over time due to human settlement and agriculture. Eucalyptus Euphorbia, Aloe vera, indigenous and exotic tree species are also present (GoK, 2010).

The major topographical features in Marigat are river valleys and plains, the floor of the Rift Valley and the northern plateau. In the eastern part near lake Baringo is the Lobo plain covered mainly

by the lacustrine salt-impregnated silt deposits, which are fertile enhancing the growth of the weed. (GoK, 2010).

3.1.6 Water Resources:

The sources of water in the area include; Lakes, boreholes, springs and rivers. The district has two lakes which are Lake Baringo and Bogoria. The main rivers are Perkerra, Molo, Kerio, Lobo and Sugutaol Arabal. Due to technical and financial consideration, Perkerra river is the major source of water for the Irrigation Scheme. It allows water to flow via gravity through the scheme. The Perkerra River is the only perennial river in Baringo county that feeds the freshwater Lake Baringo. The Perkerra river supplies water to the Perkerra Irrigation Scheme in the Njemps flats near Marigat town. The river runs through a catchment area of 1,207 square kilometers. It rises in the Mau Forest on the western part of the Rift valley at 2,400 m, dropping down to 980 m at its mouth on the lake. The variation in elevation is associated with corresponding changes in climate, soil, and vegetation. Most of the water comes from the hill slopes, where annual rainfall is from 1,100 - 2,700 mm. The region around the lake is semi-arid, with an annual rainfall of 450 mm and annual evaporation rates of 1,650 - 2,300 mm.

3.1.7 Economic activities

Population in the area is predominantly of the three ethnic groups; the Tugen, the Keiyo, and the Il-Chamus. The Tugen and the Keiyo practice a mixed subsistence agriculture, the Tugen in the Tugen Hills and the Keiyo on the Elgeyo escarpment. The Il-Chamus are pastoralists in the lowlands of Njemps Flats adjacent to Lake Baringo. The majority of the farm households have cattle.

3.1.8 Population

The average population density is 120 people per square kilometer. There is an average growth rate of 3.6% compared to 2.4% for the country.

Table 3.2: Population per division (KNBS, 2009)

Division	Population		Households	Density
	2009	2011		
Marigat	41,780	44,843	9,160	53
Mukutani	5,660	6,075	1,065	14
Mochongoi	25,737	27,624	5,320	53
Total	73,177	78,542	15,545	120

A considerable number of the local population practice mixed farming, pastoralism, bee keeping and charcoal burning.

3.2 Evaluation of the existing irrigation scheduling strategies

First, a literature review was conducted on irrigation scheduling techniques and crop evapotranspiration with the aim of investigating the technologies in Perkerra Irrigation Scheme and later refine these methods to develop an improved irrigation scheduling model.

3.2.1 Primary field data collection

- Primary field data collection commenced with a reconnaissance survey of various sites and discussions with relevant government agencies.
- The collection was from frequent field observations, informant interviews, semi-structured interviews and focus group discussions.
- The data collected include irrigation scheduling in use, crops cultivated, the size of the field, the problem facing farmers, farm management practices, local food security, water application and practices related to water management techniques carried out by the farmers.
- Canal water flow at the diversions discharge was taken at an interval which helped us in estimating the total volume of water that is being diverted by the irrigation scheme.

- Moisture contents of the soil of the selected irrigation fields before and after irrigation was determined by using the digital soil moisture meter and by taking soil samples at different depths of the soil profile.

3.2.2 Secondary data collection

- Secondary sources of data from Irrigation Offices at Regional and sub-region levels was collected as required.
- The Secondary data included best irrigation scheduling strategies, crop types, farm gate prices of irrigated crops, area irrigated per crop per season, production cost per season and cropping pattern.
- Meteorological data for each irrigation projects was obtained from the library, the internet, and the nearby weather station.
- The design documents of the irrigation project was obtained from the National Irrigation offices (Mark *et al.*, 1992).

3.3 Development/calibration of the CROPWAT for irrigation scheduling

The data collected in part 3.2 above was used in the development of the irrigation scheduling as follows;

3.3.1 Determination of the reference evapotranspiration

The reference evapotranspiration E_{To} was calculated by FAO Penman-Monteith method, using CROPWAT 8.0 developed by FAO. We used the meteorological data from the nearby weather station to estimate E_{To} . The Penman–Monteith equation integrated in the CROPWAT program is expressed as:

$$E_{To} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (3.1)$$

Where;

E_{To} – Reference evapotranspiration [mm/day]

R_n – Net radiation at the crop surface [MJ m⁻² day⁻¹]

G – Soil heat flux density [MJ m⁻² day⁻¹]

- T – Daily air temperature at 2 m height [$^{\circ}\text{C}$]
- u_2 – Wind speed at 2 m height [m s^{-1}]
- e_s – Saturation vapour pressure [KPa]
- e_a – Actual vapour pressure [KPa]
- $(e_s - e_a)$ – Saturation vapour pressure deficit [KPa]
- Δ – Slope vapour pressure curve [KPa $^{\circ}\text{C}^{-1}$]
- γ – Psychometric constant [KPa $^{\circ}\text{C}^{-1}$]

The reference evapotranspiration (ET_o) is the only value that we determined using the meteorological data. Meteorological data used in the determination of ET_o was latitude, longitude and altitude of the station, maximum and minimum relative humidity, wind speed, sunshine hours and maximum and minimum temperature. ET_o was calculated for every decade then expressed in a month.

3.3.2 The effective rainfall

The effective rainfall was calculated by CROPWAT using the United States Department of Agriculture (USDA) soil conservation service method as shown.

$$PE = 124.8P_{tot} \quad (3.2)$$

For $P_{tot} < 250$ mm

$$PE = 125 + 0.1P_{tot} \quad (3.3)$$

For $P_{tot} > 250$ mm

Where;

PE – effective rainfall, mm

P_{tot} – total rainfall, mm

3.3.3 Soil parameters

Soil characteristics required for the determination of crop water requirement include; available water content, total available water, depth of the plant root zone, depletion volume and readily available water which was using the formulas below:

$$AWC = FC - WP \quad (3.4)$$

$$TAW = AWC \times R_d \quad (3.5)$$

$$RAW = p \times TAW \quad (3.6)$$

Where;

TAW – total available water capacity within the plant root zone (mm)

AWC – available water capacity of the soil, (m^3 / m^3)

Rd – depth of the plant root zone, (m)

p – an average fraction of TAW that can be depleted from the root zone before water stress sets in.

The depth of the zone from which water uptake can occur, Rd, is calculated by assuming that maximum rooting depth coincides with the development of full canopy (Adeboye *et al.*, 2009).

3.3.4 Crop data

Crop coefficient, planting date, and harvesting date are some of the crop data that was obtained from the PIS office for this research study. We majorly focused on maize in our study for its importance to the people of Marigat and in the larger population of Africa.

We obtained Crop coefficient values (Kc) for initial, mid and late growth stages from the available published data (FAO 1998) adjust them to the actual climatic condition of the site and then use them in our calculations.

FAO 56 was used in determining the length of each growth stages of the crops studied (Mark *et al.*, 1992). The length of the individual stages and the total growing period for specific climates, locations, and for a wide variety of crops are provided in FAO 56.

Table 3.3: The crop coefficient values for various crops (Allen *et al.*, 1998)

Crop type	Kc Initial	Kc Development	Kc end
Maize	1.20	0.6	0.35
Onions	0.7	1.05	0.8
Watermelon	0.4	1.0	0.75

3.3.5 Crop evapotranspiration (ETc)

Eto obtained was multiplied by an empirical crop coefficient (Kc) to produce an estimate of crop evapotranspiration (ETc) as follows;

$$ETc = Kc \times ETo \quad (3.7)$$

Where;

Etc - Crop evapotranspiration

Kc - Crop coefficient

Eto - Reference crop evapotranspiration.

3.4 Simulation of the irrigation water application using CROPWAT

After obtaining all the required data, they were used to calibrate the CROPWAT model to suit our study site (Perkerra Irrigation scheme). We then ran the model to get the results.

Crop water requirements (CWR) was calculated by CROPWAT from the above parameters (the effect of climate, the effect of the crop characteristics and the effect of local conditions and agricultural practices).

Table 3.4: Summary of the input data

INPUT			
CLIMATE	SOIL	CROP	IRRIGATION
Rainfall	Kc	Type of soil	System type
Maximum Temperature	Rooting depth		
Minimum Temperature	Planting date	Field capacity	efficiency
Wind speed	Harvesting date	Permanent wilting point	
Humidity	Length of each stage	Saturation capacity	
Sunshine hours	Critical depletion factor	Root depth	
	Infiltration rate		

Table 3.5: A summary of the output data

OUTPUT	
Reference crop evapotranspiration (mm/period)	Actual crop evapotranspiration (mm)
Average values of crop coefficient for each stage	Effective rain (mm/period)
Irrigation requirements (mm/period)	Readily available moisture(mm)
Daily soil moisture deficit (mm)	Total available moisture (mm)
Ratio of actual crop evapotranspiration to the maximum crop evapotranspiration (%)	Crop water requirements (mm/period)
	Irrigation depth applied (mm)
Estimated yields reduction due to crop stress (when ETc/ETm falls below 100%)	Irrigation interval (days)
	Lost irrigation (mm)

3.5 Percolation Test

Four test holes 6 inches in diameter and depth distributed evenly over the scheme were dug.

Sides and bottoms of the test holes were roughened to provide a natural surface and all loose material removed from each hole.

The bottoms of the test holes were covered with approximately 2 inches of rock to protect the bottom from scouring action when the water is added.

The holes were then filled with clean water and kept full for at least 4 hours to allow the soil to soak for a sufficiently long period of time to allow the soil to swell for the accurate results to be obtained.

The holes were filled so that the water level is measured from a fixed reference point at the surface level. The test was continued for one hour creating four measured drops at 15 minutes' interval in which the water was readjusted to the fixed reference point.

The 4th measured water level drop is used to calculate the percolation rate.

CHAPTER 4: RESULTS AND ANALYSIS

In this chapter, the findings exposing different outcomes from CROPWAT 8.0, personal observation, formal and informal interviews and laboratory results are described.

4.1 Evaluation of the existing irrigation scheduling strategies

The losses incurred from the current irrigation scheduling used in PIS was estimated. The first one was estimated when irrigation was done by farmers in every two to three days till the maize crop matures.

The moisture content of the maize field was taken before irrigation using the digital soil moisture meter. The inflow into the individual plots as measured from the farm ranges from 2.5l/s to 7.0 l/s.

Table 4.1: Inflow of water in the field

Farmer	Inflow (l/s)
Kibet	5.5
Yegon	2.5
Lekitire	3.0
Charles	7.0
Average	4.5

Irrigation was averagely done 4 hours per day.

$$4.5 \times 4 \times 60 \times 60 = \frac{64800}{1000} = 64.8m^3$$

$$= \frac{64.8}{5000} = 12.96mm$$

Assuming that irrigation was done after 3 days

$$= 47 \times 12.96 \times 2 = 1209.6mm$$

The total number of days needed for maize to fully grow is 140 days (from CROPWAT).

From the digital soil moisture meter, it was noted that many farmers irrigated their farms when the moisture content was still very high. Many farmers irrigated at a moisture content of 70% - 80% which was too high to the maize depletion fraction of 50%.

This amount was found to surpass the irrigation requirement from CROPWAT estimate by more than 100%.

4.1.1 Reference Crop evapotranspiration, ETo

Penman-Monteith method was used to compute ETo in CROPWAT. This method is recommended by FAO, and it offers consistent result as compared to other methods. The figure below holds climatic data related to the project site, PIS Project.

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m ² /day	ETo mm/day
January	16.7	38.7	49	29	10.4	24.6	4.84
February	18.2	39.5	47	36	10.2	25.2	5.24
March	18.0	38.3	50	38	9.6	24.6	5.21
April	17.4	35.3	57	31	8.7	22.5	4.59
May	16.6	37.1	59	36	9.9	23.1	4.70
June	17.0	35.5	56	31	9.9	22.3	4.33
July	17.0	36.4	61	26	8.6	20.7	4.18
August	16.6	35.2	59	31	9.2	22.7	4.51
September	16.5	37.5	53	38	9.8	24.5	5.00
October	17.2	38.0	53	36	9.1	23.4	4.91
November	17.2	35.6	55	26	8.6	22.0	4.41
December	16.0	36.5	55	21	9.1	22.3	4.32
Average	17.0	37.0	54	32	9.4	23.2	4.69

Figure 4.1: Monthly weather variables and ETo for PIS

The mean daily reference evapotranspiration (ETo) for PIS is 4.69 mm. The values are high in January to March and in September and October which are dry months. The values are low in the months of June, July, November, and December. The high ETo was experienced in the months where there was a low relative humidity combined with high temperatures. Inversely the low values of ETo were in the months that experienced some rainfall. This could be due to the high relative humidity and slightly low temperatures that come with the rain.

Perkerra scheme has low wind speed which makes it a light wind region

The mean monthly temperature of Perkerra is 26.3°C and the average ETo is 4.69mm/day. This makes Perkerra an arid and semi-arid region.

4.1.2 Rainfall

Monthly rainfall averages are used in the analysis to determine the fraction of rainfall that contributes toward the building of soil moisture content (effective rainfall). The highest monthly

average is in the months of November and December and the lowest monthly average is in the month of January and March. FAO recommended formula (USDA S.C. Method) is used to determine the effective rainfall as shown in the figure below.

	Rain	Eff rain
	mm	mm
January	1.0	1.0
February	2.3	2.3
March	1.4	1.4
April	3.5	3.5
May	3.4	3.4
June	14.7	14.4
July	28.6	27.3
August	8.0	7.9
September	16.7	16.3
October	21.9	21.1
November	59.5	53.8
December	54.4	49.7
Total	215.4	202.0

Figure 4.2: Monthly rainfall and effective rainfall

From FAO irrigation and drainage paper No 56, compared to the rainfall data of Perkerra as shown above, it is clear that in the first quarter of the year the rain is less than 3 mm which implies that it is a very light shower (drizzle). The rainfall is more than 10 mm (medium shower) from June to October excluding the month of August which is a light shower. November and December have a rainfall more than 40 mm which is a heavy rainfall (rainstorms). Rainfall is insufficient in the better part of the year which implies that irrigation is required throughout the growth season.

4.1.3 Actual crop evapotranspiration, ETc

The crop evapotranspiration of maize was found to be **558.2 mm** in the whole season. Etc was more during the dry months than the rainy months. This is because crops lose more water in the dry season and therefore need more water to replace the lost ones than those grown during the

rainy season. The Etc is a function of the temperature and rainfall and varies greatly with the crop growth stages.

Crop Water Requirements

ETo station: MARIGAT Crop: MAIZE (Grain)
 Rain station: MARIGAT Planting date: 01/11

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	1	Init	0.30	1.38	13.8	15.4	0.0
Nov	2	Init	0.30	1.33	13.3	19.6	0.0
Nov	3	Deve	0.33	1.46	14.6	18.6	0.0
Dec	1	Deve	0.54	2.34	23.4	18.4	5.0
Dec	2	Deve	0.76	3.30	33.0	18.7	14.3
Dec	3	Deve	1.00	4.50	49.4	12.5	36.9
Jan	1	Mid	1.19	5.55	55.5	1.0	54.5
Jan	2	Mid	1.20	5.82	58.2	0.0	58.2
Jan	3	Mid	1.20	5.98	65.8	0.1	65.7
Feb	1	Mid	1.20	6.14	61.4	0.7	60.7
Feb	2	Late	1.19	6.25	62.5	0.8	61.7
Feb	3	Late	1.02	5.32	42.6	0.7	41.9
Mar	1	Late	0.76	3.98	39.8	0.5	39.3
Mar	2	Late	0.48	2.49	24.9	0.4	24.6
					558.2	107.5	462.8

Figure 4.3: Monthly actual crop evapotranspiration and irrigation requirement

4.1.4 Crop data

Crop coefficient, Kc; rooting depth; length of plant growth stages; planting date; and allowable depletion were keyed in the CROPWAT for the crop. Crop coefficient, Kc for a variety of crops for their various growth stages were obtained from FAO manual 56. Crop characteristics for maize crop were obtained as in the figure below.

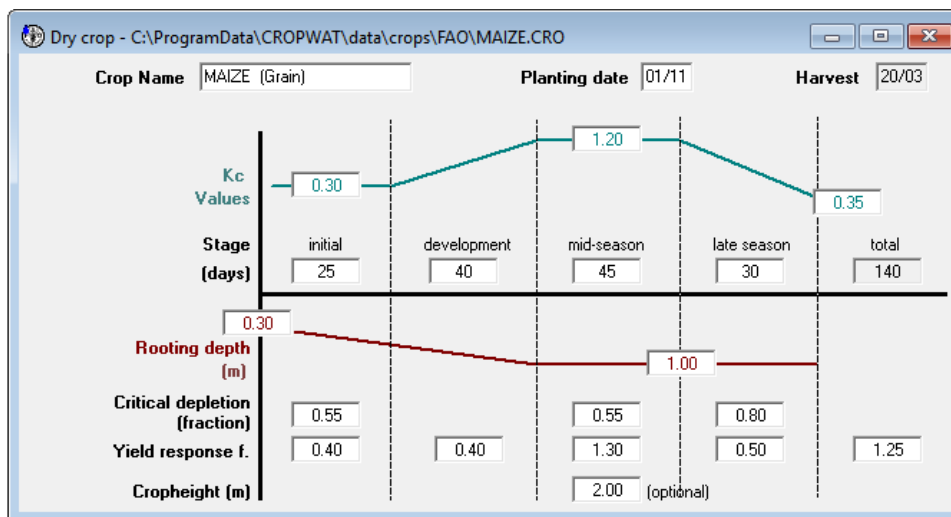


Figure 4.4: Crop data for maize

4.1.5 Soil type

There are two types of soil in the study area. Silt loam and sandy loam but the predominant soil in the scheme is of silt loam. This was obtained from the record books and also done practically in the laboratory. It is assumed that soil moisture at the beginning of crop growth is zero in order to account for initial irrigation required to prepare the soil before seeds are dispersed in the field.

$$AWC = FC - WP$$

Rooting depth of maize from FAO 56 is 0.90m

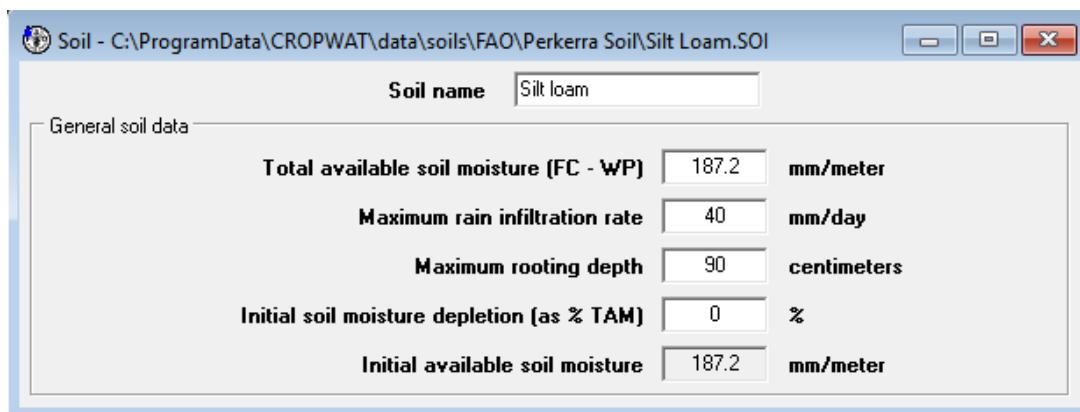
Available moisture content of the silt loam is 208mm/m

$$\begin{aligned} \text{Therefore; TAW} &= AWC * Rd \\ &= 208\text{mm/m} * 0.90\text{m} \\ &= 187.2\text{mm} \end{aligned}$$

Depletion factor of maize is 50%

$$\begin{aligned} RAW &= p \times TAW \\ &= 50/100 * 187.2 \\ &= 93.6\text{mm} \end{aligned}$$

The values calculated above was then fed into CROPWAT 8.0



The screenshot shows a window titled "Soil - C:\ProgramData\CROPWAT\data\soils\FAO\Perkerra Soil\Silt Loam.SOI". The "Soil name" field contains "Silt loam". Below this, a section titled "General soil data" contains the following input fields:

Parameter	Value	Unit
Total available soil moisture (FC - WP)	187.2	mm/meter
Maximum rain infiltration rate	40	mm/day
Maximum rooting depth	90	centimeters
Initial soil moisture depletion (as % TAM)	0	%
Initial available soil moisture	187.2	mm/meter

Figure 4.5: Soil data

4.2 Irrigation Scheduling for Maize crop

Irrigation is scheduled at the wilting point where the soil is irrigated to Field Capacity. Irrigation schedule for maize crop was calculated when initial soil moisture depletion set at 0% in order to obtain a yield reduction of 0% as shown in the figure below.

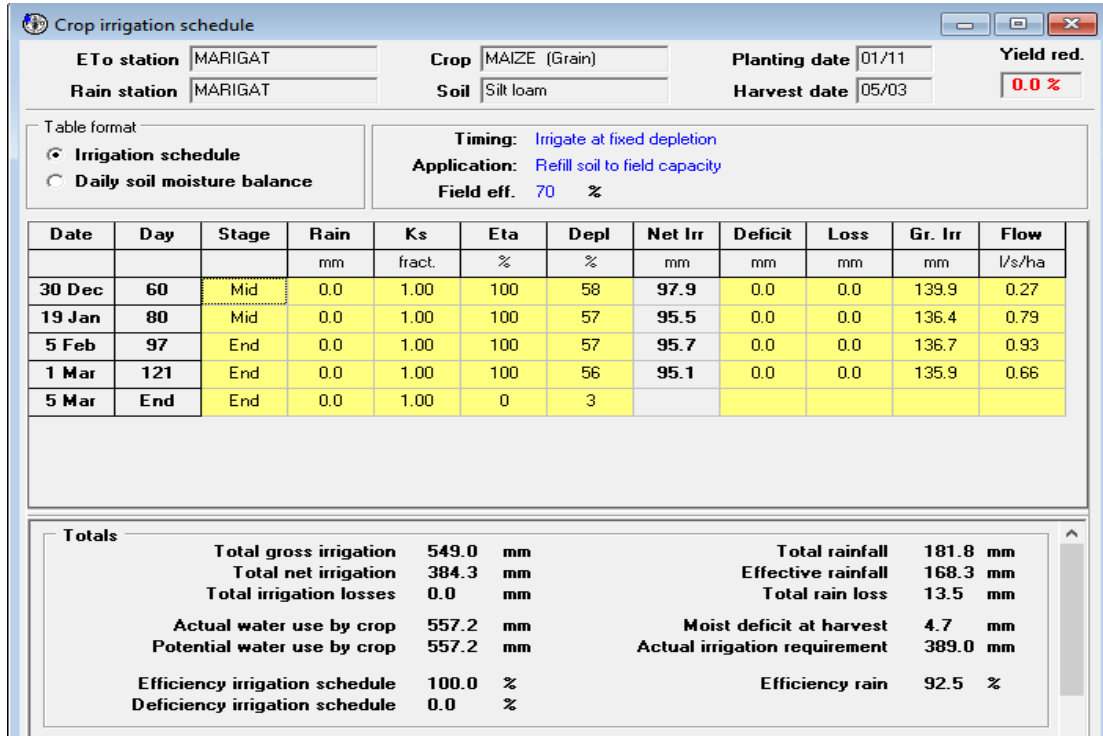


Figure 4.6: Irrigation Scheduling for the maize crop in PIS

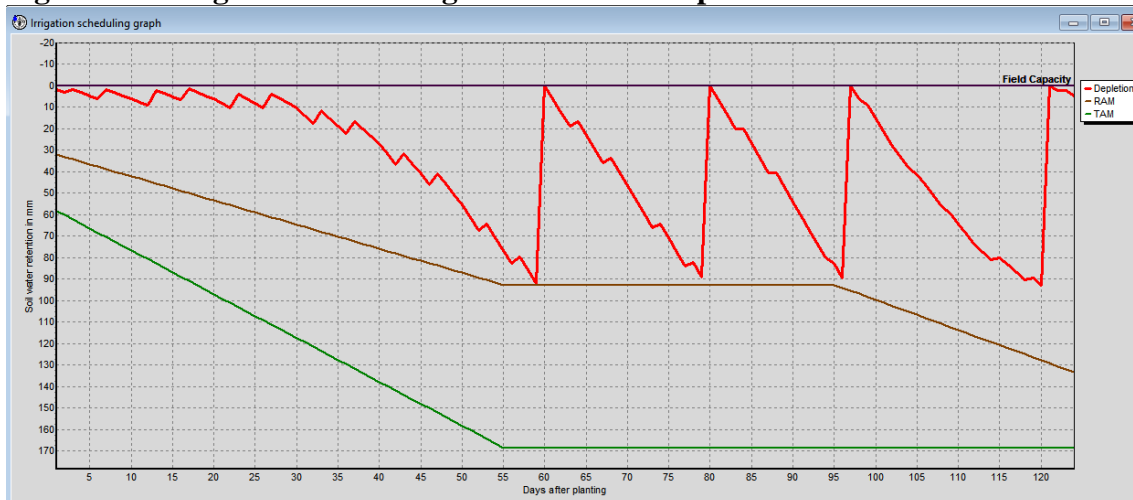


Figure 4.7: Graphical representation of the Irrigation Requirement for maize in PIS

Comparison of the total gross irrigation, actual evapotranspiration and irrigation requirement from CROPWAT with respect to the planting month in PIS is tabulated in the table 4.1 below. This can be used to calibrate the CROPWAT to suit the optimal irrigation schedule for the PIS.

Table 4.2: Comparison of the total gross irrigation, actual evapotranspiration and irrigation requirement from CROPWAT with respect to the planting month in PIS

Planting month	November	October	September
Total gross irrigation (mm)	549	406.7	408.5
Actual evapotranspiration (mm/dec)	558.2	534.8	526.5
Irrigation requirement(mm/dec)	462.8	362.4	356.4

4.3 Water distribution system

PIS has the main canal of 2400 meters' length which carries the water to secondary canals. The secondary canals are categorized into left and right branches. The left branch is 2800 meters and right branch is 7100 meters in length. They distribute the water to the tertiary canals laterally into the farmer's plots. Each farmer has to construct a tertiary canal to divert water from their preferred point that can provide necessary head to irrigate their plots.

4.4 Method of water application

The best irrigation method for PIS is the surface irrigation. Farmers practice mainly furrow irrigation and very few flood irrigation depending on the rainfall season, farmer's interest, irrigation water availability, and land preparation.

4.5 Commercialization of the products

Most farmers grow crops for commercial purposes, especially during the main season. Many farmers interviewed said that they get a lot of income from the companies they are contracted to and it's the only way they can be able to sustain the production cost.

4.6 Downstream-right

The PIS management ensures there is enough water left for the downstream water users of the Perkerra river who are mainly pastoralists and also for domestic uses. This is done by abstraction of not more than 80% of the water flowing in the river. The abstraction is done at night when the

flow in the river is minimal because no one is using the water. Irrigation can also be done in shifts when the water which can be abstracted from the river is less to irrigate the entire scheme.

4.7 Crops that are grown by farmers

Almost all the farmers interviewed were growing maize which is mainly seed maize for Kitale seeds company. Few of the respondents were found to grow other crops such as beans, rice, kales, tomatoes, watermelon, onions and tree plants such as pawpaw during the off peak. Farmers interviewed said they rarely grow cabbage because it takes long to be harvested and it requires a lot of water which may not be available.

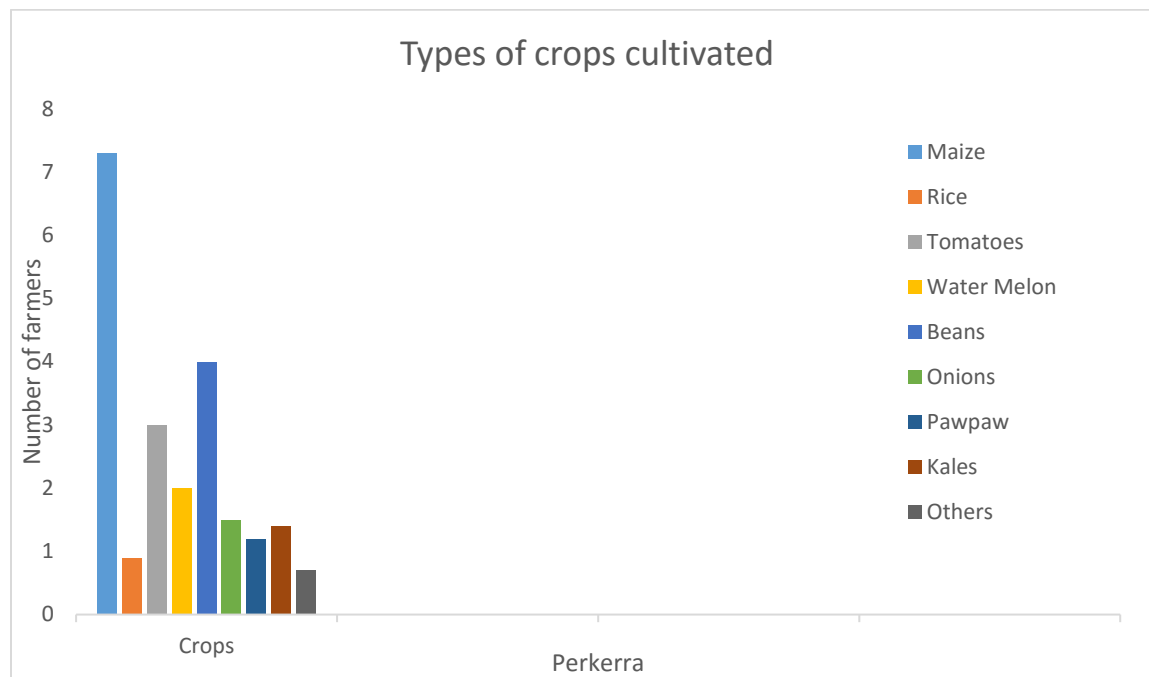


Figure 4.8: Crops grown by farmers in PIS

4.8 Land ownership

97.7% of all the farmers interviewed indicated that they own the land. Less than 2.3% indicated that they rent the land from others for farming or sharecropping so that they may share the profit after the harvest.

4.9 Tillage practices of farmers

Many farmers interviewed said they cultivate using tractors and hand operated implement. The animal-drawn implement is rarely used because of the type of soil. The hand-operated implement

is used after the soil has been broken down by the tractor. It is used mainly in harrowing and weeding purposes.

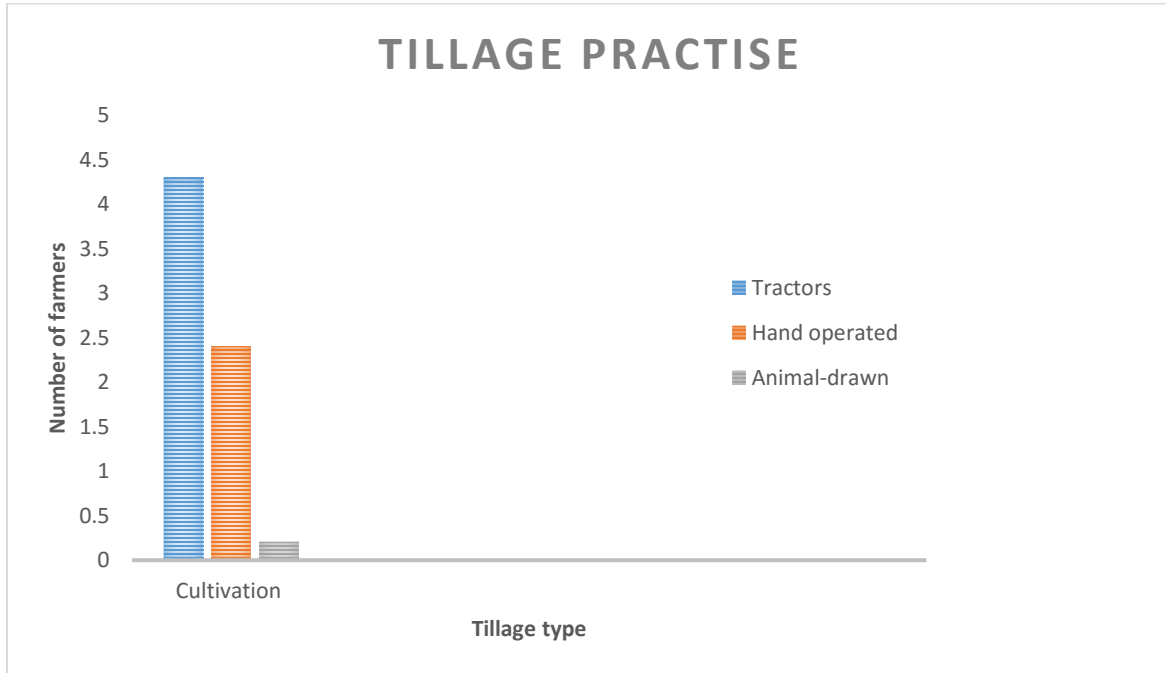


Figure 4.9: Tillage practices of farmers in PIS

4.10 Flow of abstracted

Water being diverted to PIS from river Perkerra ranges from 0.18m³/s to 0.52m³/s depending on the rainfall pattern in the highlands where the source of the river is located.

4.11 Percolation Test Information:

Table 4.3: Percolation rate at different points in PIS

	1st Hole	2nd Hole	3rd Hole	4th Hole
Location where soil sample was taken	Lat: 00° 28.244' N Long: 36° 0.325' E	Lat: 00° 28.202' N Long: 36° 00.378' E	Lat: 00° 8.055' N Long: 36° 00.531' E	Lat: 00° 8.618' S Long: 36° 01' E
1st 15 min. interval	5.0cm	2.0cm	7.0cm	2.0cm
2nd 15 min. interval	4.0cm	2.0cm	4.0cm	1.5cm
3rd 15 min. interval	4.0cm	1.5cm	3.0cm	1.3cm
4th 15 min. interval	3.0cm	1.5cm	3.0cm	1.0cm

Percolation rate = Amount of water (ml)/ Percolation time (min)

From the sieve analysis test done in the laboratory, it was found that the Perkerra scheme soil is a rich gradation type of soil which refers to a sample of aggregate with a high proportion of particles of small sizes.

CHAPTER 5: DISCUSSION

The results of the study are discussed in this chapter.

The justification for irrigation development entails both technical and socio-economic reasons. From the technical point of view, irrigation allows the stabilization of crop production by supplementing irrigation during the rainy season and supplying water to crops throughout the dry season. Socio-economically, it is a mechanism to fight poverty by ensuring that there is enough food and farm produce for the development of agribusiness which relies on the produce from irrigated farms.

5.1 Evaluation and analysis of proposed irrigation strategies for Perkerra Irrigation

Scheme

Interviews and discussions with local farmers, the PIS management, and published documents were all used to evaluate the existing irrigation scheduling strategies and propose the most appropriate for the scheme. This was also based on geologic, hydrologic and institutional conditions with respect to finance. The economic costs and benefits of water savings were analyzed while taking into account current practices. The evaluations were done as follows.

5.2 Volumetric Measurement of Irrigation Water

This entails the installation of water measuring gadgets to quantify water streaming into the farm. In PIS, Parshall flume were initially being used to measure water intake to specific farm blocks from the main irrigation canals. Parshall meters are used in open channels and measure water in cubic meter/second. Individual farms are not metered. Volumetric measurements of irrigation water are not currently adhered to in water delivery. For instance, in India farmers have incentive to apply water efficiently and water saved can be used to irrigate additional area or stored for the next irrigation (Kulkarni, 2007).

The water metering system in PIS can be very effective with high potential for future water savings. As this can make farmers use water more responsibly data earned used to actualize other water preserving methodologies

5.3 Crop residue management and conservation tillage

Conservation tillage like no-till help in conserving the soil water. Tillage is reduced or kept to zero and crop residue from the previously harvested crop is retained on the soil surface as a mulch. These retained crop residues help in enhancing the ability of the soil to hold moisture and decreasing water loss from the soil to the atmosphere which then cools the soil. The soil is exposed to drying each time it is ploughed. In the event that the strategies are correctly executed, water application might be decreased by one or more applications (Shock *et al.*, 2013).

These methods are not currently practiced in PIS and are deemed inapplicable due to soil types and also pastoralism issue as many farmers use the crop residue especially from maize crop to feed livestock. There is currently no water savings to be expected from these two strategies.

5.4 On-farm irrigation audits

An irrigation audit is a procedure used to collect and provide information about the uniformity of application, rate of precipitation, and overall condition of an irrigation system. It helps to identify opportunities to improve water use efficiency in the farm. The irrigation audit will collect information such as type of irrigation system, topography, flood vulnerability, field size, obstructions, previous and current records of crops and water use (Gulma *et al.*, 2005).

On-farm irrigation audits are being conducted in PIS. On-farm irrigation audits are applicable to PIS but the amount of water saved depends on whether or not the farmer chooses to follow recommendations made by the auditors which make quantification of the water savings very difficult.

5.5 Land Management Systems

Land management systems include land leveling which is majorly used in irrigation field to adjust the soil surface and standardize its slope, facilitate the distribution of irrigation water and improve field conditions for other agricultural practices (Maria *et al.*, 2014).

Land Leveling is majorly used by farmers who use furrow, border, or basin irrigation methods. It is used to increase the uniformity, effectiveness, and efficiency of water applied to an irrigation

field or where crops are growing. Water saved from land management system is difficult to quantify and its cost differs from one field to the other (Rapp and Defined, n.d.).

Land leveling has been and continues to be practiced by PIS farmers. The furrows are also made uniform to ensure uniform distribution of water to the farm and eventually crops. Almost all farmers within PIS level their field in an effort to conserve water and make the production of crops more efficient and uniform.

5.6 The lining of on-farm irrigation canals

This entails the establishment of a fixed lining impervious material in a current or recently built irrigation field trench. This conservation strategy has not been practiced in PIS. Currently, all of the on-farm irrigation canals in PIS are not concrete-lined.

Water savings involve reduced amount of seepage from the establishment of a lining material. Concrete liners are estimated to salvage 80 percent of the original seepage (Keller, 1995).

We cannot quantify the exact water that can be conserved by reducing seepage losses in Perkerra Irrigation Scheme but it can be more than enough to double the area under irrigation.

5.7 The use of pipelines

Replacement of On-Farm Irrigation Ditches with Pipelines involves replacing open ditches with buried pipeline that is generally 24 inches in diameter or less. It is also estimated that 80% of the losses from seepage and evaporation could be saved with the use of pipeline (Keller, 1995).

Replacing the on-farm irrigation canals with pipelines has never been practiced in PIS. From the scheme engineer, this is due to high installation cost, the difficulty of maintenance and repairs. Canal lining costs are about 10 percent higher than installing and operating a pipeline for any irrigation scheme because of the difference in operation and maintenance costs. Lower pipeline operation and maintenance costs are attributed to the reduced clean-up costs of trash and other debris in canals. The amount of water lost to evaporation is little compared with drainage misfortunes. It is established that water savings from minimized evaporation are less than 10% of the seepage losses (Keller, 1995).

The use of pipelines on top of seepage loss control, it can also save water by reducing evaporation even though it is negligible compared to seepage losses.

5.8 Regulatory reservoirs.

Irrigation water reservoirs play an important role in areas with limited precipitation where water can be stored and re-distributed later for different purposes (USDA, 1997). PIS has one regulatory reservoir which is not in use due to poor engineering design that resulted in the lower irrigation head than the farms it is supposed to apply water to. One or more reservoirs should be constructed to store water during dry season.

5.9 Irrigation systems

In the study of water use efficiency in sprinkler and trickle irrigation systems reported that trickle irrigation is the best system according to the study of agronomic practices impacts on maize yield reported that applied irrigation water was 41% and 20% less under pivot and conservation tillage than under surface irrigation and conventional tillage, respectively (Rogers *et al.*, 1997). Surface irrigation losses that include runoff, deep percolation, ground evaporation and surface water evaporation in which runoff losses can be significant if tailwater is not controlled and reused (Rogers *et al.*, 1997).

The sprinklers and trickle irrigation systems are currently not used in PIS. This is due to the availability of water, water quality, soil types and costs. A continuous steady flow of water is needed for the pressurized systems to function properly. They are also not economically in terms of cost. Trickle irrigation system requires clean water to avoid clogging of the nozzles yet the water from river Perkerra contains a lot of silt. It also needs regulatory reservoirs to hold the silts and make water available throughout the season.

5.10 Deficit irrigation.

This is the irrigation that applies less water than the crop needs for its full development. Some crops lose little yield and quality with deficit irrigation by saving water. Deficit irrigation normally works with deep rooted crops (Shock *et al.*, 2013). This technique points on precisely timing the

utilization of a deliberate measure of water within the crop growth with the point of balancing out yield by applying water when the water in the soil has been depleted (Geerts and Raes, 2009).

The maximum soil moisture depletion for maize is 50% (Allen *et al.*, 1998). Like in PIS when the irrigation is delayed to a depletion of 70% for instance, the yield reduction will be 3.1% as indicated in CROPWT which will be disadvantageous to the farmers and the Kitale Seeds company who expect good quality maize seeds from the farmers. The volume of water applied to a given field can also be reduced by shifting to crops that require less water but these practices reduce the net income to the farmers. Thus, we will not be considering them in this analysis.

5.11 Irrigation scheduling

An estimated 93 percent of farmers interviewed in Perkerra region confirmed that they use some form of soil moisture monitoring strategies to assist in determining the next irrigation date.

Irrigation scheduling aims at making the most efficient use of water and energy by applying the right amount of water to crops at the right time which then improves irrigation efficiency.

Monitoring the soil water status is one of the available techniques used to establish the time for irrigation. It can be used to adjust the calculated soil water depletion (Shock *et al.*, 2013).

For maize crops, irrigation should start when soil water content drops below 50 % of the total available soil moisture (Allen *et al.*, 1998). Irrigation scheduling methods are to measure soil moisture content to establish if it has dropped below 50% so as to enable irrigation to be initiated (Wright, 2002).

Perkerra farmers use some of the irrigation scheduling methods to determine when the next irrigation is required. Most farmers use hand feel and appearance of the soil and plant monitoring.

Hand feel and appearance of soil method is very cheap and does not require any special skills in order to achieve results as compared to other methods that are expensive and require technical know-how to operate (Martin, 2009). This method estimates soil moisture by obtaining a handful of soil and squeezing tightly between fingers from which various moisture content available in the

soil can then be estimated (Maithya *et al.*, 2010). Though hand feel and appearance of soil is the cheapest and readily available method, *Speer* states that it has disadvantages such as: It is non-quantitative and subjective, does not give any lead time for irrigation and only looks at the surface soil in a limited area.

This method is not recommended as the sole means of irrigation scheduling, but can still be used as verification of other methods. It takes time to become familiar with this method and it requires a lot of experience (*Martin*, 2009). Silvia Lekitirne who grows new rice for Africa (NERICA) in PIS says she usually irrigates after 2-3 days when the soil becomes dry.

Apart from hand feel and appearance of the soil method, many farmers in PIS monitor their crops to help them in scheduling irrigation. As direct measurements of plant water status, leaf water potential can also be used for scheduling irrigation (*Ingvaldsen et al.*, 2015).

Methods to monitor the state of water in the crop include; estimation of transpiration using excised leaves, observations of stomatal aperture, monitoring stem diameter, pressure cell and psychometric measurements of leaf water potential among others. These are the most direct methods used to determine when to irrigate. A keen farmer can detect signs of water stress by the appearance of the foliage (leaves, stems or branches) during the period of peak transpiration demand (*Savva and Fenken*, 2002). The methods used mostly by Perkerra farmers include; Appearance and growth method is a trial and error method of direct visual inspection.

This method entails the monitoring of the crop growth characteristics like wilting when other factors such as fertilizer, pest, and diseases have been met. It involves visual interpretation of the leaf and shoots wilting, leaf color and measurement of the stem diameter and height at a given interval. It is the simplest method that has been used by farmers in remote areas. Douglas Yego a farmer who grows maize and tomatoes says that he normally irrigates when the leaves of the crop start to wilt.

Monitoring the weather method has not been practiced in Perkerra as a way to schedule irrigation.

Monitoring the weather method gives meteorological information that can be used to measure the amount of evapotranspiration as it changes with time and to set the amount of water needed for irrigation. The timing of irrigation can then be determined with reference to the soil's residual wetness (Hillel, 1990).

We used the meteorological data from KALRO and Perkerra weather station to obtain the weather variables that we needed to calibrate the CROPWAT 8.0 to develop an irrigation schedule that will ensure precise quantity of water is applied to the field at the right time.

5.12 Miscellaneous Systems

Tailwater recovery and reuse systems are relevant to any irrigation system where large quantity of water runs through to the end of the fields being irrigated. This strategy consists of ditches or pipe network that gather tail water and conveys it to another field to be used for irrigation purposes or to a storage reservoir. The amount of water collected from the tailwater reuse system depends mostly on the water supply and the current on-farm water management practices of the farmer. Water savings varies between 5 - 25 percent of the water applied to the upper segment of the field (Gilley *et al.*, 2003).

There is little tailwater recovery in PIS because most percentage of the water applied is used for irrigation. Interview with farmers indicates that there is little tailwater with a limited loss from the bottom of the fields but the little available tail water is channeled to the uncultivated farms which then flow via gravity to Lake Baringo. The water is allowed to flow to lake Baringo because there is no water storage facility for the tailwater that may be collected.

5.13 Percolation rate

Percolation refers to the phenomenon of absorption of water by soil into deeper layers. The rate of absorption depends on the types of soil or the composition of the soil. Percolation rate helps in selection of suitable soil for crop growth.

The type of soil in PIS is majorly silt loam and partly sandy loamy. This soil is considered the best for the growth of crops because the percolation rate is between sandy soil and clay soil. This implies that the soil has better water retention capacity for the growth of different crops.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

In this chapter, we will present conclusions that was obtained from the research together with a set of recommendations aiming to improve further researches in the future about the topic.

6.1 Conclusion

Four strategies were found to have water saving potential with respect to Perkerra Irrigation Scheme; Irrigation Scheduling using CROPWAT, Lining of Canals, Replacement of Canals with Pipeline and On-Farm Audits. Regulating reservoirs are paramount for water storage.

Regulatory reservoir cannot guarantee water saving but it ensures availability of water throughout the growing season. There is need to construct regulatory reservoirs which can hold and store water during the rainy season to be used for irrigation when needed in dry season. This reservoir should be built at a strategic point to ensure water can flow via gravity to the directed fields.

Lining of canals and replacement of canals with pipelines can save a lot of water but were found to be expensive for the scheme to implement being that they currently lack funds. They should mobilize for funds and implement either of them in the near future to reduce the water loss through seepage and evaporation.

Irrigation scheduling practice using CROPWAT that incorporates weather variables, crop evapotranspiration, crop coefficient and soil water balance has not been adopted in PIS. From the research study that was conducted in PIS, we found out that a lot of water can be saved when the irrigation scheduling using CROPWAT is adopted. Water can be saved by more than four times.

The reduction in water applied through irrigation scheduling depends on a number of factors. For instance, a lower value of water will be conserved in surface irrigation as compared to other irrigation systems because there are reduced water control opportunities and longer anticipation times required for water delivery to the farm and also because there is no pumping cost that would be reduced.

In some locations where irrigation water supplies are not limited, that is near the diversion that leads to the secondary canals, farmers have a tendency of over irrigating crops to prevent crop yield reduction which is totally not the case. The results of irrigation scheduling project done have demonstrated that water applied to crops can be reduced and in most scenarios enhance crop yields.

From the tabulated results of the total gross irrigation, actual evapotranspiration and irrigation requirement, it is clear that when planting date is shifted from November to September, less water will be required. The water saved will be approximately 140.5mm. This is because maize requires more water during development and middle stage of growth, which can be supplemented by the rain that are available from September all the way to December.

6.2 Recommendation

Irrigation scheduling practice using CROPWAT that incorporates weather variables, crop evapotranspiration, crop coefficient and soil water balance can be incorporated with soil moisture sensors to enhance the performance of the application of water to the crops.

The water conservation achieved in the entire scheme will not be as large as that potential achieved with farmers having direct control of their water supply per plot. Farmers should be helped in developing their individual irrigation scheduling programs.

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