EVALUATION OF EVAPOTRANSPIRATION MODELS USING LYSIMETER MEASUREMENT: CASE OF AWASH MELKASSA, ETHIOPIA

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WATER RESOURCES ENGINEERING PROGRAM

SCHOOL OF CIVIL ENGINEERING AND ARCHITECTURE

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

Dece, 2018

Adama, Ethiopia

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A THESIS SUBMITTED TO THE DEPARTMENT OF WATER RESOURCE ENGINEERING

SCHOOL OF CIVIL ENGINEERING AND ARCHITECTURE

ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

IN PARTIAL FULFILMENT OF THE REQURIMENT FOR THE DEGREE OF MASTER IN WATER RESOURCE PROGRAMME (IRRIGATION ENGINEERING).

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Dec, 2018

Adama, Ethiopia.

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DECLARATIONS

I, Asrat Mulugeta declare that this is my own original work and that it has not been presented and will not presented to any other University for similar or other degree award, and that all sources of materials used for the thesis have been duly acknowledged.

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DEDICATION

This Thesis manuscript is dedicated to my beloved parents, Mrs. Masresha Tekeley and Mr. Mulugeta Kassay, who devoted whole of their life for my success.

BIOGRAPHICAL SKETCH

The author was born in May 10, 1990 G.C in Adama woreda, kebele 13. He attended his elementary education in former name Hailey Chefeke School but now changed the name to Adama No 5 elementary school, and senior secondary school at Adama higher secondary school and Hawas preparatory School, in Adama. In 2010 G.C he completed his high school education and joined Ambo University and graduated with BSc degree in Agricultural and Bioprocess Engineering on July 02, 2014 G.C. The author was immediately started work in Ambo University as assistant lecture.

In October 2016, he was joined to the School of Graduate studies of Adama Science and Technology University for his M.Sc study under Water Resource Engineering program

/Irrigation Engineering/.

ACKNOWLEDGEAMENTS

My First acknowledgment is to God who guides and protects me, and through whose mercy I was able to accomplish my project.

Secondly, I would like to warmly thank my advisors Mekonen Ayana (PhD) and Tilahun Hordofa (PhD) for their immeasurable support and motivation throughout completion of my thesis.

I would like thanks for Adama Science and Technology university specially water resource engineering department for given a chance to study Master of Science degree.

I would like also to thank Melekassa Agricultural Research Center organization and all staffs, which facilitated everything from the first day I arrived to Melekassa until completion of my experiment.

To my family's words would never express how grateful I am for your love and support. You are the reason I strive to become better and to succeed. I would also like to extend my thanks to my fiancée who shared love, inspiration, and patience with me.

I would like also to thank to all my friends project who really helped me to achieve my project goals and provided me with all I needed in order to succeed in my project.

Finally, I would like to thank all the people who helped me during in my experiment.

Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX

ABBREVIATIONS AND ACRONYMS

ΔS	Change in Soil Water
A	Surface Area
BD	Bulk Density
cm	Centimeter
CRM	Coefficient of residual mass
CWR	Crop Water Requirement
d	Depth
D	Drainage
E	Evaporation
ET	Evapotranspiration
ETc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food and Agriculture Organization
FC	Field Capacity
HS	Hargraves-Samani
Kc	Crop Coefficient
S	Daily Soil Moisture
ha	Hectares
hrs	Hours
I	Irrigation
IA	Index of agreement
m	Meter
MARC	Melkassa Agricultural Research Center
mm	Millimeter
MK	Makkink
MoA	Ministry of Agriculture
PM	Penman Montith
PWP	Permanent Wilting Point
R^2	Coefficient of determination
RF	Rainfall
RMSE	Root mean square error
TAW	Total Available Water
TU	Turc
V	Volume
Wd	Weight of Dry Soil
Ww	Weight of Wet Soil

ABSTRACT

Crops require adequate water in the soil to maintain the plant growth, production and productivity. Correct estimation of crop evapotranspiration depends on the correct estimation of reference evapotranspiration. A study was undertaken at research farm of Melkassa agricultural research center of the Ethiopian Institute of Agricultural Research with the objective of determining crop water requirement and crop coefficient for alfalfa and calibrate the most commonly used estimation models under Melkassa climatic condition. Field study was undertaken using two drainage types of lysimeters that involved the various components of the water balance equation in determining crop water requirement of alfalfa. On the basis of measured alfalfa crop evapotranspiration four commonly used ETo estimation model, viz., Penman-Monteith, Hargraves-samani, Turc and Makkink were calibrated and evaluated to obtain best fit model under Melkassa climatic condition. The root mean square error, index of agreement and coefficient of residual mass were used for evaluating prediction models. The result indicated the total crop water requirement of alfalfa under Melkassa climatic condition was 310.29 mm per one cutting period and the maximum alfalfa crop evapotranspiration was 6.92 mm day^{-1} and the mean crop coefficient at the different crop growth stages, viz., initial, development, mid and late season were 0.46, 0.8, 1.24 and 1.12, respectively. Evaluation of the four modeld has indicated that Turc and Makkink models had unsatisfactory and poor performance without calibration and Hargreaves–Samani model proved to be performing better than turc and makkink model. The Makkink model was performed the least among other model with RMSE = 1.94 mm day^{-1}, I = 0.087 and CRM = 30% based on estimation of actual alfalfa ET. The FAO Penman- Monteith had been found to be most precise for estimating ETo with RMSE = 0.9 mm day^{-1}, I = 0.6 and only CRM = 10% based on estimation of actual alfalfa ET.

Key words: Reference evapotranspiration, Alfalfa, Crop water requirement and crop coefficient, Penman-Montith, Hargraves-Samni, Turc, Makkink, Lysimeter.

1. NTRODUCTION

1.1. BACKGROUND

Water in the soil is the most important factor affecting crop growth and production. Crops require adequate water in the soil to maintain the plant growth, production and productivity. Excess water application will retard plant growth thereby affecting crop production and productivity through water logging of roots. Inadequate water also will retard plant growth as a result of soil moisture stress. The estimation of evapotranspiration from crop field is a basic tool to compute water balance and to estimate water availability and requirement.

Evapotranspiration is a combined process evaporation and transpiration. The evaporation is the process by which water transferred from all wet bodies of vegetation and land surfaces to the atmosphere and whereas transpiration is the process by which liquid water transferred through plant tissue to the atmosphere. Water passing through plants contributes directly to crop productivity whereas evaporation from bare soil surface has only an indirect effect in ameliorating the crop microenvironment.

Estimation of crop water requirement is often necessary for efficient planning water resources and management of on farm irrigation water. The correct estimation of crop evapotranspiration depends on the correct estimation of reference evapotranspiration and crop factors referred to as crop coefficient. The reference Evapotranspiration is well known as an expression for the evaporating power of the atmosphere at a specific location and time of a year and reference evapotranspiration (ETref) has been predicted either of two types of reference surface reference crop: grass or alfalfa (Allen et al, 1998).

Different reference evapotranspiration estimation model developed starting from simple empirical equation up to energy equation by different researcher in different area but the performance and effectiveness of the models are vary from place to place, so model evaluation and develop calibration coefficient for local area is necessarily.

Accurate estimation of reference evapotranspiration have immense importance for water sector, hydrology sector and irrigation sector because it represents a considerable amount of water loss from the catchments as a form of both by evaporation and transpiration.

In Ethiopia the availability of fresh water does not meet the potential productivity of the country irrigated land due to improper agriculture water management; Ethiopia has annual fresh water withdrawal in 2013 is 5558 million cubic meters out of this 93.6% used for agriculture purpose, 6% used for domestic purpose and 0.4% used for industry purpose (MoA, 2000). So agriculture sector used a high amount of fresh water of the country and most of the sector water loss as a form of evapotranspiration.

Eastern zone of rift valley in arid and semi-arid area of the country especially Awash Melekassa irrigation area under adama woreda are one of irrigation area in the country so it has been a lot of agricultural activities including farmers cash crop producer up to Wonji sheoa sugar factory large scale irrigation activities. Therefore this study was conducted for evaluate of evapotranspiration estimation models and develop calibration coefficients of the area for accurate crop water estimation and reduce agricultural water loss.

1.2. STATEMENT OF THE PROBLEM

Crops require adequate water in the soil to maintain the plant growth and production; Excess water application will retard plant growth thorough blocking of soil aeration and reduction of soil fertility on the other hand shortage of water can create water stress in the crop root zone and it leads the crop in wilting stage.

The world faces agricultural water crisis as a consequence of irrigation expansion and improper irrigation water management.

Measurement of adequate crop water requirement is not done in Awash Melkassa irrigation area and hence calibration of estimation methods has not been performed for the area. Also local areal of crop water requirement and crop coefficient for alfalfa crop in different growth stage are not done.

For Awash melkassa irrigation area irrigation water application done by traditional manner; it means the farmers can irrigate two or three times within a week based on their own interest and apply irrigation water until the furrow becomes full. So it reduces the potential productivity of the irrigation land area and also decreases the irrigated land productivity of the soil in year to year due to increases the soil salinity of the irrigated land.

Generally underestimation of PET would adversely affect the yield due to plant water stress; whereas overestimation would result in over application of irrigation and the possible salinity and sodicity problem. With regards to design of irrigation structures, underestimation would result in structures too small to store and convey the irrigation water while the overestimation would result in over design of the structures and wastage of resources. Thus, the recalibration of the models enables precise estimation of the plant water requirement and designing of appropriate structures.

So evaluation and calibration of the most commonly used reference evapotranspiration estimation models for Awash Melkassa irrigation area is mandatory for applying adequate water to the crop root zone and water resource management.

1.3. OBJECTIVE OF THE STUDY

1.3.1. General objective

- The general objective of the study is to evaluate and calibrate evapotranspiration estimation models based on lysimeter measurements at Melkasa Agricultural Research Center.

1.3.2. Specific objectives

Specific objectives of this study are:

a) Determine crop evapotranspiration for alfalfa.

b) Determine the crop coefficients for alfalfa crop.

c) Evaluate and calibrate the most commonly used estimation model on the basis of measured alfalfa crop evapotranspiration.

d) Develop the local calibration coefficient for selected reference evapotranspiration estimation models.

1.4. Research Questions

To this end, the research tried to answer the following research questions:

- What is the extent of the evapotranspiration rates of the alfalfa crop?
- What are the crop coefficients of alfalfa crop?
- To what extent the results of evapotranspiration obtained from lysimeter measurement and estimation models differ?
- What are the local calibration coefficients for selected estimation models?

1.5. SIGNIFICANCE OF THE STUDY

As the main objective of this study was to evaluate and calibrate the evapotranspiration estimation models, it serves as a guideline and frame of reference for the future purposes of stakeholders in their endeavor to accurately quantify crop water requirement for Ethiopia in general and for the Awash Melekassa area and its suburbs irrigation areas in particular. It will also contribute a great deal for irrigation system design, regional water balance studies, irrigation scheme, hydrology study, water management (optimum crop water for high production yield) by quantify accurate evapotranspiration for crops, in maximizing the existing irrigation structure performance and also agricultural research center as a guideline.

It also reduces soil salinity effect in irrigation field by removing excess water application; excess water application can create water logging it increases soil salinity.

Overall, the study will have significance importance:

- In determining the best method in estimating potential evapotranspiration in the Awash melekassa among the four models.
- In developing a precise and more accurate method for determining the potential evapotranspiration based on the measured evapotranspiration, which will be used ;
- To increase the quality of water resources planning and management in the area;
- Properly determined irrigation water requirements will lead to develop further and establish improved irrigation water management practices to increase water use efficiency and
- Improved irrigation water and crop management practices will increase crop yields and ultimately this will maximize profitability of irrigation projects.

1.6. SCOPE OF THE STUDY

The study has evaluated the performance of the selected reference evapotranspiration estimation models based on alfalfa evapotranspiration when the experimental surface to becomes as a reference surface by using statistical analysis and to calibrate the gap between the measured alfalfa crop evapotranspiration and computed reference evapotranspiration obtained from the selected model by using Microsoft Excel and the least square error was chosen as the optimal parameter to determine the level of dispersion in this research. And side to side the study has determined the alfalfa crop water requirement and its crop coefficient at different growth stage from lysimeter experimental site.

2. LITRATURE REVIEW

2.1. EVAPOTRANSPIRATION

Evapotranspiration is the process in which water returned to the atmosphere through the process of evaporation and transpiration. This is one of the most important processes in the hydrological cycle, irrigation, water management and planning (Allen et al., 1998).

The evaporation component is the loss of water from soil and plant surfaces to the atmosphere whereas the transpiration is water loss from plant through its stomata and leaves (Jensen et al., 1990).

Evapotranspiration (ET) is affected by three factors including climatic parameters such as temperature, solar radiation, humidity, and wind speed; crop factors such as crop type, variety, plant density; and management and environmental factors such as soil salinity, poor land fertility (Allen et al., 1998; Jensen et al., 1990). Considering both components of evapotranspiration separately, transpiration is affected by soil moisture and crop characteristics where evaporation is affected by climatic parameters. ET is often expressed in units of depth per time (mm /day) or energy per unit area over a specified time (MJ/ m2 day) (Allen et al., 1998).

According to Penman Montith (1956) the concept of evapotranspiration can be expressed in two forms either actual evapotranspiration (AET) or Potential evapotranspiration (PET); Actual evapotranspiration (AET) occurs when soil water is limited which is the case in an arid environment. Therefore, the soil water content controls the evapotranspiration and Potential evapotranspiration (PET) the amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short of water.

The term "potential" is equivalent to the maximum possible level of water loss under given climatic conditions. As soil water depletes, evapotranspiration decreases and reduces from potential to actual evapotranspiration particularly, in arid and semi- arid regions where the potential evapotranspiration is extremely high and the available water is very limited (Katerji and Rana, 2011).

2.1.1. EVAPOTRANSPIRATION MEASUREMENT

Evapotranspiration measurement is accomplished by two different methods which are direct and indirect evapotranspiration measurement methods (Katerji and Rana, 2011);

i. DIRECT MEASUREMENT OF EVAPOTRANSPIRATION

Direct evapotranspiration measurement can directly measure the evapotranspiration rate from the cropped surface; it also divided in to three forms which are

1. THE HYDROLOGICAL APPROACH:

The soil water balance and Lysimeter are a part of hydrological approach methods:

a) SOIL WATER BALANCE METHOD

Measuring ET using changes in soil water has been used for nearly a century. Up to 1960, gravimetric analysis based on soil sampling was the primary method used to determine soil water content. After the 1980s, due to advances in technology, a number of electromagnetic devices based on dielectric and capacitance measurements were introduced to measure soil water content with the best results obtained in coarser textured soils. Time domain reflectometry-based methods as well as neutron thermalization methods presented by modern soil water sensors have also been used and intensively studied (Allen et al., 1998).

Evapotranspiration can be determined by measuring the various components of the water balance. The method consists of assessing the incoming and outgoing water flux into the crop root zone over some time period. Irrigation (I) and rain fall (P) are adding water to the root zone. I and P might be lost by surface runoff (RO) and by deep percolation (DP) that will eventually recharge the water table. Water might also be transported upwards by capillaries rise (CR) from a shallow water table towards the root zone or even transferred horizontally by subsurface flow in (SFin) or out of (SFout) the root zone (Allen et al., 1998).

The formula expressed as;

$$ET = I + P - RO - DP + CR \pm \Delta S \quad (2.1)$$

where; ET is evapotranspiration (mm); I is irrigation water (mm); P is precipitation (mm); RO run off (mm); DP is deep percolation (mm); CR is capillary rise (mm) and ΔS is change in soil moisture (mm).

b) LYSIMETER

Lysimeter are a large container filled with soil, located in the field so as to represent the field environment. With bare soil or a vegetated surface they can be used for determining the ET of a growing crop or evaporation from bare soils (Allen et al., 2011). The equation expressed as;

$$ET = R + I - D \pm \Delta S \quad (2.2)$$

where; ET is evapotranspiration (mm); R is rainfall (mm); I is irrigation water (mm); D is deep percolation (mm) and ΔS is change in soil moisture (mm).

2. ENERGY BALANCE AND MICROCLIMATOLOGICAL METHODS

Evapotranspiration is regarded as the energy employed for transporting water from inner leaves and plant organs to the atmosphere as vapor. From an energy perspective, this is referred to as "latent heat". Latent heat is measured as energy flux density. The following is a discussion of the main methods of latent heat flux measurement. These techniques are: energy balance, aerodynamic method and the eddy covariance (Katerji and Rana, 2011).

a) BOWEN RATIO AND ENERGY BALANCE

The Bowen ratio approach is a commonly used method in estimating evapotranspiration (Jensen et al., 1990). The evaporation of water requires energy; therefore, the process of ET is limited by the input of energy into the system. At one particular moment, the energy arriving at the surface must be equal to the energy leaving the surface (Allen et al., 1998).

This is described by the following energy balance equation;

$$R_n - G - \lambda E - H = 0 \quad (2.3)$$

where; Rn is net radiation (w/m2); H is sensible heat (w/m2); λE is latent heat flux (w/m2) and G is soil heat flux (w/m2).

According to Allen et al., (1998) other variables such as heat stored in the plant or the energy used by metabolic activities are not considered in the above equation due to their small values compared to the other four variables (Rn and G can be measured or estimated using climatic parameters. H requires accuracy of temperature gradients above the surface and therefore is difficult to measure. A positive value of Rn indicates an input of energy to the surface which is typical in a daytime condition. On the other hand, a positive value of the three other variables (G, and H) indicates a loss of energy from the surface. It should be noted that only the vertical flux gradient is considered while the horizontal gradient is omitted and should only be used in areas of homogenous land cover. Due to the dependency of the energy balance method on technical procedures, it is extensively used only in research.

A limitation to this method is its application to short periods of time (Jensen et al., 1990) and increase in the relative errors when the water is limited (Allen et al., 2011).

b) AERODYNAMIC METHOD

Assuming that a flux density is related to the gradient of the concentration in the atmospheric surface layer (ASL), then according to Katerji and Rana, (2011); the latent heat flux is determined by:

$$\lambda E = -\lambda \rho u^{*} q^{*} \tag{2.4}$$

Where; λE is latent heat of vaporization (MJ/Kg); λ is vapor density (Kg/M3); u is friction velocity (m/s) and q is the specific air humidity (%).

This method proposes a major difficulty in the correct measurement of the vapor pressure at different heights above the crop.

b) EDDY COVARIANCE

According to Allen et al., (1998) evapotranspiration can be measured using the Eddy covariance method that works to measure vertical wind fluctuations acquired to the vapor density. Vertical wind fluctuations can be measured using sonic anemometer; vapor density is measured using a fast response hygrometer, both of which have to be acquired at a frequency of 10-20 Hz.

Eddy covariance is a method based on the transport of scalar (vapor, heat, CO2) and momentum in low atmosphere in contact with the canopies that are mostly governed by air turbulence. According to Stull, R. B. (1988) Latent heat in this case is obtained as the covariance of vertical speed wind and vapor density (m/s and g/m3) is expressed as:

$$\lambda E = \lambda w q \tag{2.5}$$

Where; is latent heat of vaporization (MJ/Kg); w is vertical wind speed and q is specific air humidity (%).

3. PLANT PHYSIOLOGICAL APPROACH

Measurement of water loss from a whole plant or a group of plants is done using plant physiology methods. Of these methods, the Sap flow method and the Chambers system are mentioned in the following.

a) SAP FLOW METHOD

According to Katerji and Rana, (2011) closely linked to plant transpiration is sap flow. Sap flow is often measured using two different methods: heat pulse and heat balance. Heat pulse is estimated by measuring heat velocity, stem area and xylem conductive area. In spite of its simplicity, this method proved to be inaccurate at a low transpiration rate and is in constant calibration for every crop type.

b) CHAMBERS SYSTEM.

The Chambers system was first introduced by Reicosky and Peters, (1977) as a rapid measure for ET. Then first version of the system was portable, consisted of aluminum conduits covered with Mylar, polyethylene or other plastic or glass films and the air within the chambers was mixed with strategically located fans. The system was introduced for daily measurements of ET and is not suitable for long term measurements. Research has shown a number of weaknesses to this system including ET measurements being influenced by surrounding conditions.

The most recent improved chamber systems are very expensive due to the high cost of the key components (Rana et al., 2000).

II. INDIRECT MEASUREMENT OF EVAPOTRANSPIRATION

Owing to the difficulty of obtaining accurate field measurement, ET is commonly computed from climatic data. A large number of empirical or semi empirical equations have been developed for assessing crop or reference crop evapotranspiration from meteorological data.

Those are the two methods of indirect estimation of evapotranspiration.

a) CROP COEFFICIENT APPROACH

In the crop coefficient approach the crop evapotranspiration, ETc is calculated by multiplying reference crop evapotranspiration by crop coefficient (Jensen et al., 1990) expressed as;

$$ET_c = K_c * ET_o \tag{2.6}$$

Where; ETc is crop evapotranspiration (mm/day); Kc is crop coefficient (dimensionless) and ETo is reference crop evapotranspiration (mm/day).

b) PAN EVAPOTRANSPIRATION APPROACH

Potential evapotranspiration can be estimated by measuring rate of evaporation from a shallow, open-faced pan. The evaporation rate from pans filled with water can be easily determined. In the absence of rainfall, the amount of water evaporated during a given period corresponds to the decrease in water depth in the pan during the given period. Pan provides a measurement of the combined effect of radiation, wind, temperature and humidity on an open water surface. Despite the difference between pan evaporation and potential evapotranspiration, the use of pans to predict PET for periods of 10 days or longer is still practiced.

Crop water requrement at a specific development stage can determine as a product of crop coefficient and pan reference evapotranspiration (Jensen et al., 1990) expressed as;

$$ET_c = K_c * E_{pan} \tag{2.7}$$

where; ETc is crop evapotranspiration (mm/day); Kc crop coefficient (dimensionless) and Epan is pan evaporation (mm/day).

- ### METEOROLOGICAL FACTORS FOR DETERMINING EVAPOTRANSPIRATION

The methods for calculating evapotranspiration from meteorological data require various climatological and physical parameters. Some of the data are measured directly in meteorological stations. Other parameters are related to commonly measured data and can be derived with the help of a direct or empirical relationship.

The meteorological factors determining evapotranspiration are climatic parameters which provide energy for vaporization and remove water vapor from the evaporating surface.

According to Allen et al. (1988) the principal climatic parameters to consider are presented below.

SOLAR RADIATION

The evapotranspiration process is determined by the amount of energy available to vaporize water. Solar radiation is the largest energy source and is able to change large quantities of liquid water into water vapour. The potential amount of radiation that can reach the evaporating surface is determined by its location and time of the year. Due to differences in the position of the sun, the potential radiation differs at various latitudes and in different seasons. The actual solar

radiation reaching the evaporating surface depends on the turbidity of the atmosphere and the presence of clouds which reflect and absorb major parts of the radiation. When assessing the effect of solar radiation on evapotranspiration, one should also bear in mind that not all available energy is used to vaporize water. Part of the solar energy is used to heat up the atmosphere and the soil profile.

The portion of all radiation that is transformed into other forms of energy is called "net radiation". Net radiation is measured as the difference between incoming (downward) and outgoing (upward) radiation of all wavelengths by the net radiometer. As radiation varies between night and day, counters can be linked to the radiation measuring device to record these values separately for easy reading. Electronic pulses may be recorded on a strip chart, but increasingly (especially with small, automatic meteorological stations) the data are recorded on an electronic logger and can be downloaded directly in digital form on to a computer, for viewing and analysis.

Solarimeters (pyranometers) measure only incoming short-wave radiation and are sometimes used at meteorological stations. These can be used to calibrate radiometers and utilize directly in the estimation models.

SUNSHINE HOURS

Sunshine hours are commonly recorded where the cost and practicability of maintaining radiation meters are limiting. The widely-used Campbell-Stokes recorder consists of a glass sphere mounted on a pedestal which concentrates bright sunlight onto a chart and so burns a trace along it, thus sunlit periods are recorded. Instruments which are specified by ranges of operation latitude (for example 0° to 60° N or S) and the correct charts for the N or S hemisphere should be used. Electronic meters that measure photosynthetically active radiation (400-700 nm) are also available.

AIR TEMPERATURE

The solar radiation absorbed by the atmosphere and the heat emitted by the earth increase the air temperature. The sensible heat of the surrounding air transfers energy to the crop and exerts as

such a controlling influence on the rate of evapotranspiration. In sunny, warm weather the loss of water by evapotranspiration is greater than in cloudy and cool weather.

Agro meteorology is concerned with the air temperature near the level of the crop canopy. In traditional and modern automatic weather stations the air temperature is measured inside shelters (Stevenson screens or ventilated radiation shields) placed in line with World Meteorological Organization (WMO) standards at 2 m above the ground. The shelters are designed to protect the instruments from direct exposure to solar heating. The louvered construction allows free air movement around the instruments. Air temperature is measured with thermometers, thermistors or thermocouples mounted in the shelter. Minimum and maximum thermometers record the minimum and maximum air temperature over a 24-hourperiod. Thermographs plot the instantaneous temperature over a day or week. Electronic meteorological stations often sample air temperature each minute and report hourly averages in addition to 24-hour maximum and minimum values. The daily maximum air temperature (Tmax) and daily minimum air temperature (Tmin) are, respectively, the maximum and minimum air temperature observed during the 24-hour period, beginning at midnight. Tmax and Tmin for longer periods such as weeks, 10-day or months are obtained by dividing the sum of the respective daily values by the number of days in the period. The mean daily air temperature (Tmean) is only employed in the FAO Penman-Monteith equation to calculate the slope of the saturation vapour pressure curves (Δ) and the impact of mean air density (Pa) as the effect of temperature variations on the value of the climatic parameter is small in these cases. For standardization, Tmean for 24-hour periods is defined as the mean of the daily maximum (Tmax) and minimum temperatures (Tmin) rather than as the average of hourly temperature measurements.

AIR HUMIDITY

While the energy supply from the sun and surrounding air is the main driving force for the vaporization of water, the difference between the water vapour pressure at the evapotranspiring surface and the surrounding air is the determining factor for the vapour removal. Well-watered fields in hot dry arid regions consume large amounts of water due to the abundance of energy and the desiccating power of the atmosphere. In humid tropical regions, notwithstanding the high energy input, the high humidity of the air will reduce the evapotranspiration demand. In such an

Environment, the air is already close to saturation, so that less additional water can be stored and hence the evapotranspiration rate is lower than in arid regions.

Relative humidity is the ratio between the amount of water the ambient air actually holds and the amount it could hold at the same temperature. It is dimensionless and expressed as a percentage.

A Wide range of instruments is commercially available to measure air humidity. However, it is hard to obtain in the field a direct measure of vapour pressure. Most common instruments for field use are dry and wet bulb thermometers, the mercury-in-steel recording psychrometer, and the hair hydrograph. The latter gives a direct measure of relative humidity. Tables are available to convert temperature readings into air humidity data.

For twice daily observations, the ventilated dry and wet bulb or assmann psychrometer generally preferred; for recording of air humidity observations the dry and wet bulb recording psychrometer is generally preferred. However, the simpler unventilated dry and wet bulb thermograph and hair hydrograph are common found (USDA 1993)

In general, Relative humidity values are widely used in evapotranspiration equations and two methods are used to measure it: Psychrometer and Hair Hygrometer.

The former uses thermodynamic principles and measures temperature differences between wet and dry thermometers which are set together, with the wet thermometer slightly lower than the dry and are usually housed as one unit in a secure metal frame. Around the bulb of the wet thermometer is placed a wick sheath, which trails into a container of clean, distilled water. The wick should fit tightly; dust, dirt and insects are sometimes a problem and the wick may need replacement or cleaning each week. The simplest and most common type of psychrometer called a hygrometer is housed in a screened box. The use of psychometric tables converts the readings into dew point temperatures and relative humidity (RH).

WIND SPEED

The process of vapour removal depends to a large extent on wind and air turbulence which transfers large quantities of air over the evaporating surface. When vaporizing water, the air

above the evaporating surface becomes gradually saturated with water vapour. If this air is not continuously replaced with drier air, the driving force for water vapour removal and the evapotranspiration rate decreases.

The evapotranspiration demand is high in hot dry weather due to the dryness of the air and the amount of energy available as direct solar radiation and latent heat. Under these circumstances, much water vapour can be stored in the air while wind may promote the transport of water allowing more water vapour to be taken up. On the other hand, under humid weather conditions, the high humidity of the air and the presence of clouds cause the evapotranspiration rate to be lower.

2.2. REFERENCE EVAPOTRANSPIRATION

Reference evapotranspiration has been predicted either of two types of reference surface which are grass or alfalfa. The grass reference has generally been a cool season variety clipped grass to maintain about 0.08m and 0.15m (Doorenbos and Pruitt, 1977). Alfalfa use as a reference surface when the alfalfa height becomes 0.3m to 0.6m, fully cover to the ground and without water stress (Wright, 1982; Jensen et al, 1990).

Allen et al, (1998) defined reference evapotranspiration (ETo) as:

"The rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec/m and albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground".

ETo is well known as an expression for the evaporating power of the atmosphere at a specific location and time of year (Allen et al. 1998).

There are a many number of reference evapotranspiration models that can be applied to estimate reference evapotranspiration (ETo). Many studies have been conducted to evaluate their performance. Some of these models are physically-based and others are semi-empirical and empirical based (Jensen et al., 1990).

The researcher selects the most commonly used reference evapotranspiration estimation models according to Jensen et al., (1990).

1. PENMAN-MONTEITH METHOD

According to Allen et al. (1998), estimation of reference evapotranspiration (ETo) by globally accepted Penman-Monteith requires the climatic parameters like maximum and minimum temperature, solar radiation, sunshine hours, wind speed, relative humidity.

$$ETo = \frac{0.48\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2\,(e_s - e_a)}{\Delta + \gamma(1+0.34U_2)} \qquad (2.8)$$

where; ETo is the reference evapotranspiration (mm / day); Rn is the net radiation at the crop surface (MJ / m 2day1); T is the mean daily air temperature at a 2 m height (oC); U2 is the wind speed at a 2 m height (m /s); es is the saturation vapour pressure (kPa); ea is the actual vapour pressure (kPa); es-ea is the saturation vapour pressure deficit (kPa); Δ is the slope of the vapour pressure curve (KPa/oC); G is soil heat flux (MJ/day*m2) and γ is the psychrometric constant (KPa/oC).

The equation (2.8) computation of reference evapotranspiration variables calculated based on Allen et al., (1998);

Saturation Vapor Pressure (es)= $0.61exp^{\left(\frac{17.27T_a}{T_a+273}\right)}$ Where; Ta is air temperature (°C).

Actual Vapor Pressure (ea)= $0.61exp^{\left(\frac{17.27T_d}{T_d+273}\right)}$ Where; Td is dew temperature (°C).

Slope Vapor Pressure Curve (Δ)= $\frac{409*e_s(T_a)}{(T_a+237.3)^2}$ Where; Ta is air temperature (°C) and e_s is saturation vapor pressure (KPa).

Psychometric Constant (γ)= $0.00163\left(\frac{P}{\lambda}\right)$ where p is atmospheric pressure (KPa) and λ is latent heat of vaporization (MJ/Kg)

2. RADIATION BASED METHODS

Empirical radiation-based equations for estimating reference evaporation generally are based on the energy balance (Jensen et al., 1990).

a) Makkink model

The Makkink model was developed in the Netherlands as a modification of the Penman equation (Makkink, 1957) and has been used successfully in the US (Amatya et al., 1995). It can be considered as a simplified because only radiation and temperature as inputs. The difference is that, instead of using net radiation (Rn) and temperature, the Makkink formula uses incoming short-wave radiation (Rs) and temperature. Short-wave radiation can be easily obtained as, on the average, there is a constant ratio (≅ 40%) between Rn and Rs.

The Makkink formula is expressed as:

The Makkink formula is expressed as:

$$ETo = 0.61\left(\frac{\Delta}{\Delta+\gamma}\right)\frac{R_s}{2.45} - 0.12 \quad (2.9)$$

where; ETo is reference evapotranspiration (mm /day); Δ is the slope of the vapor pressure curve (KPa/°C); γ is the psychometric constant (kPa/°C) and Rs is solar radiation (MJ/m^2 day).

a) Turc model

The Turc-Radiation equation was presented by Turc, using data from the humid climate of Western Europe (France). This method only uses two parameters, average daily radiation and temperature, the model expressed as

If RH>50%

$$ETo = 0.01333\left[(23.9001R_s) + 50\left(\frac{T}{T+15}\right)\right] \quad (2.10)$$

If RH<50%

$$ETo = 0.01333[(23.9001R_s) + 50]\left(\frac{T}{T+15}\right)\left[\left(1+\left(\frac{50-RH}{70}\right)\right)\right] \qquad (2.11)$$

where; T is average temperature (°C); Rs is solar radiation (MJ/m^2 day) and RH is relative humidity (%).

3. TEMPERATURE BASED METHODS

Those reference evapotranspiration (ET) estimation methods that require only temperature as an input variable are considered as temperature-based methods in this study. The temperature-based methods are some of the earliest methods for estimating ET. The relation of ET to air temperature dates back to 1920s (Jensen et al., 1990).

Due to the wide-ranging inconsistency in meteorological data collection procedures and standards, many different evaporation equations have been used by different authors. Performance of the empirical equations usually varies from locations to location.

In the comparative study of Jensen et al. (1990), it was concluded that at humid locations the Hargreaves-samani methods ‘closely paralleled lysimeter result.

a) Hargreaves-Samanni model

Hargreaves, using grass evapotranspiration data from a precision lysimeter and climatic data from Davis, California, over a period of eight years, observed, through regressions in 1975 and after several amendment in 1985 Hargreaves and samani published the equation

$$\mathrm{ETo} = 0.0023(\mathrm{T} + 17.78)\sqrt{(\mathrm{T_{max}} - \mathrm{T_{min}})}\mathrm{R_a} \qquad (2.12)$$

Where; R_a is the extraterrestrial radiation [mm/day]; T is average temperature (°C); Tmax is maximum temperature (°C) and Tmin is minimum temperature (°C).

2.2.1. ADVANTAGES AND DISADVANTAGES OF ETO MODEL

A) Penman-Monteith (PM Methods) model advantages are well-documented compared to lysimeters under different climate conditions (Jensen et al., 1990), it is a close, simple representation of the physical and physiological factors governing the evapotranspiration process and additionally many researcher uses for calculate crop coefficients because the crop canopy and aerodynamic resistance relative to the hypothetical reference crop are accounted for within the crop coefficient (Allen et al, 1998).It have also a disadvantages such are requires many meteorological data Many assumptions Fixed r_c= 70 m/s. The data qualities of all-climatic parameter are poor except temperature (Droogers and Allen, 2002).

B) Radiation and temperature based model also have their own advantages and disadvantages. The advantages are requires temperature and radiation only; do not requires wind speed and relative humidity and disadvantages are it requires local calibration (Jensen, 1966) and Less sensitive to the quality of input climatic parameters (Hensen, 1984).

C) Temperature based model; the model advantages are requires only temperature; do not requires relative humidity, radiation and wind speed (Jensen, 1966) and the disadvantages are it needed local calibration because it sensitive to sensible heat Advection (Gavilán et al., 2006).

2.1.1 PERFORMANCE EVALUATION OF REFERENCE EVAPOTRANSPIRATION ESTIMATION MODELS

A) PENMAN MONTITH MODEL

The Penman model is considered to be the most accurate model for calculating reference evapotranspiration (ETo). According to Jensen et al, 1990 combination methods ranked the best among other models which correlated well with lysimeter measurements at ten tested sites located in different climates around the world.

According to Yoder et al, (2005) in humid climates compared eight reference evapotranspiration models to the measured ETo by used lysimeter. Based on their results, PM and the original Penman were the best among other models for estimating ETo.

B) RADIATION BASED MODEL

Radiation models are not surprising that these models did not perform well. However, their performances vary from under or over prediction depending on the area where they were applied. For instance, in a humid climate (Yoder et al., 2005) Priestly-Taylor overestimated ETo whereas performing well in Germany (Xu and Chen, 2005) Therefore, radiation-based models require calibration before being using to another environment or region.

C) TEMPERATURE MODELS

The temperature-based models have been used or tested around the world due to their simplicity because it required only temperature data. The performance of temperature-based methods varies for instance, Thornwhite and Blaney - Criddle performed well in a humid climate (Bautista et al., 2009). On the other hand, Hargreaves-Samani (HS) performed better in semiarid and arid regions (López-Urrea et al., 2006) while demonstrating poor performance in a humid climate (Yoder et al., 2005). Therefore all temperature-based models require calibration before using them to another environment or region.

2.3. CROP COEFFICIENT

Evapotranspiration rate of various crops are related to reference evapotranspiration ETo) by means of crop coefficient (Allen et al., 1998). The Kc value relates to evapotranspiration of a disease free crop grow in large fields under optimum soil water and fertility conditions and achieving full production potential under the giving growing environment (Doorenbos and Pruit, 1977). It serves as an aggregation of the physical and physiological difference between crops and the reference definition. The effect of characteristics that distinguish field crops from grass are integrated in to the crop coefficient (Allen et al., 1998). Differences in evapotranspiration and transpiration between field crops and the reference grass surface can be integrated in a single crop coefficient (Kc).

2.3.1 FACTOR OF AFFECTING THE CROP COEFFICIENT

Many factors of affecting crop coefficient such as crop type, climate, soil evapotranspiration and stage of growth.

a) Crop type

The large variation in Kc values in between major groups of crops is due to the resistance to transpiration of different crops, such as closed stomata during the day (pineapple) and waxy leaves (citrus). Also, differences in crop height, crop roughness, reflection and ground cover produce different Kc values (Allen et al. 1998).

b) Climate

General climate conditions, especially wind and humidity, affects crop coefficients. Variations in wind change the aerodynamic resistance of the crops and their crop coefficients, especially for those crops that are substantially taller than the grass reference crop. Crop aerodynamic properties also change with climate, in particular relative humidity. Kc for many crops increases as wind speed increases and relative humidity decreases. More arid climates and conditions of greater wind speed will have higher values for Kc. More humid climates and conditions of lower wind speed will have lower value for Kc (Allen et al. 1998).

c) Soil evaporation

Crop evapotranspiration is a combination of transpiration by the crop and evaporation from the soil surface. For low cover conditions Kc is large determined by how frequently the soil is wetted but for fully cover the contribution of soil evapotranspiration is relatively small (Allen et al. 1998).

d) Crop growth stage

The Kc for a given crop changes over the growing period as the ground cover, crop height and leaf area changes. Four growth stages are recognized for the selection of Kc: initial stage, crop development stage, mid-season stage and late season stage (Allen et al. 1998).

2.4. ALFALFA

Alfalfa is a perennial crop with a deep root system that can reach as deep as 1 m. Alfalfa is known to be a better crop as a reference crop because transpire the whole day and night.

Alfalfa is very drought tolerant and prefers well-drained loam soils and growing in higher elevations. It is also known as queen of forages because it gives high nutritional value for livestock's especially for cattle (dairy cows).

2.4.2. ALFALFA CROP MANAGEMENT

According to (Doorenbos and Kassam, 1986) stated that soil salinity, poor land fertility, limited application of fertilizers, the absence of control of diseases and pests, poor soil management, and the limited soil water content may limit the crop development and reduce the ETc. The effect of soil water content on ET is conditioned primarily by the magnitude of the water deficit and the type of soil. On the other hand, too much water will also result in water logging that might damage the root and limit root water uptake by inhibiting respiration (Allen et al., 1998).

2.5. LYSIMETER

The word 'lysimeter' is derived from the Greek 'lysis,' which means dissolution or movement, and 'metron,' which means to measure (Howell, 2005). Lysimeters are tanks filled with soil in which crops are grown under natural conditions to measure the amount of water lost by evaporation and transpiration (Allen et al., 1990). A lysimeter is the method of determining ET directly.

The lysimeters are divided basically in two types: Weighing and Non-weighing, each of which are described below.

1. NON-WEIGHING LYSIMETERS

According to Allen (1996) also called Drainage lysimeters, they operate on the principle that ET is equal to the amount of rainfall and irrigation water added to the system, minus percolation, runoff and soil moisture changes. Since the percolation is a slow process, the drainage lysimeters is accurate only for long periods for which the water content at the beginning exactly equals that at end. The length of such a period varies with the rainfall regime, frequency and amount of irrigation water application, depth of the lysimeters, water movement, and the like. Therefore, records of drainage lysimeters should be presented only in terms of a long-period more than one day.

According to Allen (1996) discuss two types the non-weighing lysimeters:

a) Non- weighing constant water-table type, which provides reliable data in areas where a high water table normally exists and where the water table level is maintained essentially at the same level inside as outside the lysimeters;

b) Non-weighing percolation type, in which changes in water stored in the soil are determined by sampling or neutron methods or other soil humidity sensors like neutron probe, the rainfall and percolation are measured.

General principles of a drainage lysimeter: Provisions are made at the bottom of the lysimeter container to collect and measure volumetrically the deep percolation. Precipitation is measured by rain gauge(s). Evapotranspiration is considered as the difference among water applied, water drainage and soil water change.

2. WEIGHING LYSIMETERS

A weighing Lysimeter is capable of measuring ET for periods as short as ten minutes. Thus, it can provide more additional information than a drainage lysimeter. Problems such as diurnal pattern of ET, the phenomenon of midday wilt, the short-term variation of energy partitioning, and the relationship between transpiration and soil moisture tension, can be investigated only by studying the records obtained from a weighing lysimeter (Allen, 1990).

Weighing lysimeters make direct measurements of water loss from a growing crop and the soil surface around a crop and thus, provide basic data to validate other water vapor flux prediction methods.

3. MATERIALS AND METHODS

3.1. DESCRIPTION OF THE STUDY AREA

The research was conducted at the Melkassa agricultural research center (MARC) of the Ethiopian institute of agricultural research, which was established in 1969 G. C. The research center is located in the central Rift Valley of Ethiopia, with latitude of 8º 24` north, and 39º 21` east longitude at an altitude of 1550 meters above sea level and it is about 120km southeast of Ethiopia. The climate is characterized as semi-arid type climate (MoA, 2000). For the period 1977 up to 2017 Years, the daily mean maximum and minimum temperatures of the area to be 28.7 and 13.8 °C, respectively. The monthly mean maximum temperature is between 30.95 °C during May and 27.57 oC during December and the annual average rain fall of melkassa 810.3 mm.

The cropping system during the main growing season, include cereals mainly teff, maize, and sorghum and others like haricot bean and soybean while tomato, onions, papaya, banana and sugarcane are the main crops grown during the off-season using irrigation from Awash River.

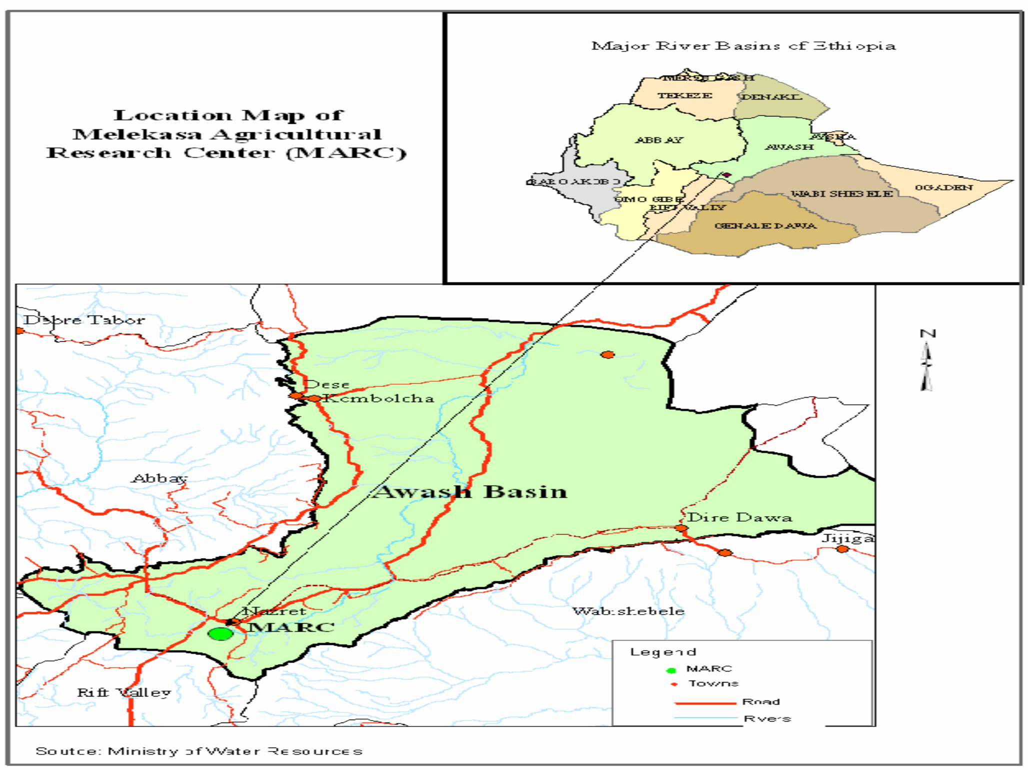


Figure3.1.Maps of Awash Melkassa Agricultural Research Center

3.2. EXPERIMENTAL SET-UP

Field experiment was undertaken using two drainage types of lysimeters, which are located 100m away from the meteorological station of the MARC. The dimension of the lysimeters is 1 m by 2 m and 2m by 2m. Total lysimeter area including experimental uniformity area is 36 m^2. The Lysimeters have a long inserted plastic pipe (vent) for aeration and underground steel pipes for collection of drainage water. The rim of each lysimeter protruded 10 cm above the soil surface to prevent surface water run-in and runoff. One access tube for each of the lysimeters was installed at the center down to 105 cm soil depth. The access tube was used as a hose road for probe at the time of taking soil moisture content reading using CPN 503DR hydro probe.

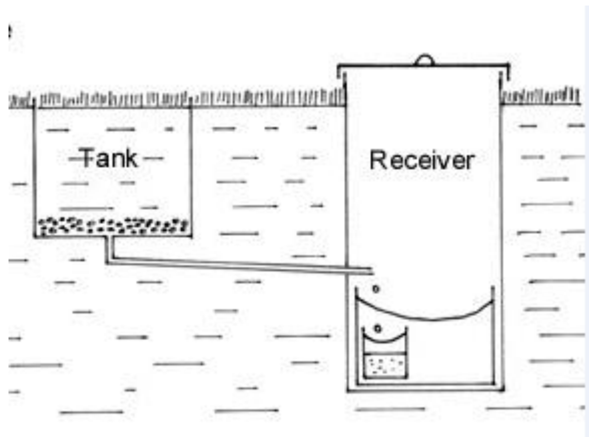


Figure 3.2.Schematic diagram of drainage lysimeter

3.3 NEUTRON PROBE CALIBRATION

The neutron probe was calibrated based on the procedure given in the user manual (Model 503DR CPN Hydro probe). The instrument allows rapid and periodically repeated measurements of volumetric wetness of a soil at different depths. During the calibration of the neutron probe, access tubes, volume sample, a scale and oven were used. Two aluminum access tubes were installed at depth of 105 cm at two points. This was done by digging a hole with an auger, and the aluminum access tube was driven into the hole.

Wet and dry points were established to obtain wide range of moisture and to make it possible for the probe to read these ranges. A field calibration required the probe, access tube, soil auger and drying oven. The access tube was installed in the middle of the lysimeter. Probe readings in the tube in count ratio or rat (count/standard count) unit and volume sampler in pairs around the tube.

(within 30 cm of the tube) were taken at the desired depth. Parallel to the neutron probe measurements, soil samples were taken at 30 cm interval up to 90 cm soil depth with the same depth of neutron probe readings using an auger and soil water at 30 cm soil depth was calculated using the gravimeter method (user manual) as:

$$\text{cm of water per cm of soil depth} = \left(\frac{W_w - W_d}{W_d}\right) * (BD * d) \quad (3.1)$$

where Ww is fresh weight of soil (g); Wd is dry soil weight (g); BD is bulk density (g/cm^3) and d is depth of soil (cm).

The result obtained from gravimeter assumed as dependent variable and the neutron-probe count ratio as independent variable and developed a linear relationship between the two variables.

$$M = A(CR) + B \quad (3.2)$$

where M is depth of equivalent moisture obtained from gravimetric method; A is the slop; CR is count ratio (count/ standard count) and B is intercept.

Therefore, the coefficients A and B were obtained from the paired measurements of count ratio and equivalent depth of water using linear correlation method. The values of the coefficients were stored in the neutron probe. Then, the daily soil moisture reading was taken in unit of centimeter per centimeter (CPC) and converted to mm/m which helps to know the daily soil moisture change and time of irrigation water application for alfalfa.

3.4 SOIL SAMPLING AND ANALYSIS

The soil samples collected from the lysimeters at the depth interval of 0cm to 15cm, 15cm to 30cm, 30cm to 45cm, 45cm to 60cm, 60cm to 75cm, 75cm to 90cm and 90cm to 105cm were analyzed for texture and water contents at field capacity (FC) and permanent wilting point (PWP).

The bulk density was determined by using the core sampler method and calculated as the ratio of mass of oven dried soil to bulk volume of soil.

The available water content calculated by the following formula:

$$AWC = (FC - PWP) \quad (3.3)$$

where AWC is available water content (mm); FC is field capacity (mm) and PWP is permanent wilting point (mm).

Soil moisture depletion (SMD) at any soil moisture level was calculated (Walker, 1989) as:

$$SMD = \left(\theta_{fc} - \theta_i\right) \quad (3.4)$$

where, SMD is soil moisture depletion at any soil moisture level; θ_{fc} is soil moisture at field capacity and θ_i soil moisture at a time of irrigation.

3.5 IRRIGATION WATER APPLICATION

After calibrating the neutron probe, soil moisture content was monitored daily using the neutron probe sensor at an interval of 15 cm to a depth of 105 cm through one access tube installed within the lysimeter whereas the top 15 cm soil depth was measured gravimetrically. Irrigation water was applied to the crop when 55% depletion of the available soil moisture occurred within the crop root zone (Doorenbos and Kassam, 1979; Allen et al., 1998). This 55% depletion was considered for the effective root zone of the crop (one meter). Similar irrigation amount at this depletion was given to the crop inside and outside the lysimeter to ensure uniform plant growth. The application of irrigation was carried out with known volume of buckets by converting the 55% depletion into volume of water. The amount of applied irrigation water was calculated using the following formula

$$V = A * d \tag{3.5}$$

where V is applied irrigation water (m^3); A is area of lysimeter (m^2) and d is irrigation depth (m).

3.6. ALFALFA CROP PLANTING AND MANAGEMENT

Alfalfa (medicago sativa) seed was sown on November 6, 2017 G.C on carefully prepared lysimeter site and around lysimeter for maintain uniformity of environment in and around the lysimeter. The furrow space and crop space was 30 cm and 10 cm, respectively.

Blanket recommended fertilizer for the area are 50 Kg/ha of urea and 100kg/ha of Dap.

The crop growth stage were divided based on canopy cover (crop ground cover), for perennial crops initiation stage starts from green up-date up to 10% ground cover, The crop development stage runs from 10% ground cover to effective full cover, The mid-season stage runs from effective full cover to the start of maturity and The late season stage runs from the start of maturity to harvest or full senescence (Allen et al, 1998).

3.7. DETERMINATION OF ALFALFA CROP EVAPOTRANSPIRATION

The crop evapotranspiration (ETc) at any period of time from lysimeter was calculated using water balance equation (Allen et al., 1998) and expressed as:

$$ET_c = I + P_e - D \pm \Delta S \tag{3.6}$$

where ETc is crop evapotranspiration (mm); I is applied irrigation depth (mm); Pe is effective rainfall (precipitation) (mm); D is drainage (mm) and ΔS is change in soil water (mm).

3.8. DETERMINATION OF THE CROP COEFFICIENT

The crop coefficient was obtained based on different growth stages, viz., initial, development, mid and late season stages. The crop coefficient values of alfalfa crop at different growth stages were calculated using the following equation (Allen et al., 1998):

$$K_{ci} = {ET_{ci}}/{ET_{oi}} \quad (3.7)$$

where ET_{ci} is crop evapotranspiration of the i^{th} growth stage (mm/day) measured from lysimeter; ET_o is reference evapotranspiration i^{th} growth stage (mm/day), calculated by PM method and K_{ci} is crop coefficient of the i^{th} growth stage (dimensionless).

3.9. ESTIMATING REFERENCE EVAPOTRANSPIRATION BY SELECTIVE MODEL

The meteorological data obtained from Melkassa agricultural research center metrology station was used to compute reference evapotranspiration by using selected models. Four different models were used in this research for the estimation of reference crop evapotranspiration: the Penman–Monteith; Hargreaves–Samani; Makkink; and Turc method. The reference evapotranspiration has been calculated by both software (daily ET calculator) and Microsoft excel.

3.10. EVALUATION AND CALIBRATION OF EVAPOTRANSPIRATION ESTIMATION MODELS

Daily alfalfa ET values measured in the lysimeter were compared with the calculated values obtained from the selected models used in this study. The performance evaluation was conducted for 31 observations.

The evaluation of evapotranspiration estimation models performance was done based on the measured alfalfa crop water consumption; Alfalfa use as a reference surface, when the alfalfa stand is 0.3m to 0.6m in height and free from water stress and fully ground cover (Wright, 1982; Jensen et al, 1990).

Evaluating a model performance is done using both statistical criteria (quantitative) and graphical displays (qualitative). The combined approach is useful in making comparative evaluations of model performance between alternative or competing models (Loague and Green, 1991). Quantitative and qualitative approaches were used to evaluate the performance of the different models discussed in this thesis. The qualitative approach consisted of representing the observed and estimated data graphically and quantitatively by the coefficient of determination (r^2). The coefficient of determination is an estimate of the combined dispersion against the single dispersion of the observed and predicted values since it represents the squared ratio between the covariance and the multiplied standard deviations of the observed and predicted values (Krause et al., 2005). The coefficient has values ranging from zero to one representing how much of the observed dispersion is explained by the prediction. The closer the value of the correlation coefficient to one, the stronger the correlation is. A value of zero indicates no correlation between the observed and predicated values.

The evaluation had been done using statistical (quantitative) evaluation techniques which are;

a) The Root Mean Square Error (RMSE; mm /day); it can measure the tendency of error it was assumed that the best methods were those that had the lowest Root Mean Square Error if the result of RMSE zero there is no error between measured and calculated alfalfa; which described as:

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)^2\right]^{\frac{1}{2}} \qquad (3.8)$$

where: N is the number of observations; P_i is calculated ETo (mm / day) by models and O_i is ETc values measured from lysimeter alfalfa crop (mm / day).

The value of RMSE is become zero, it describes there is no difference (error) between measured and calculated result.

a. Index of agreement (IA): The index agreement can measure a tendency of agreement; if index agreement one there is a perfect agreement between measured and calculated which described as:

$$IA = 1 - \left[\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}[(P_i - O_{avg}) + (O_i - O_{avg})]^2}\right] \qquad (3.9)$$

where; P_i is calculated ETo (mm / day) by models; O_i is ETc values measured from lysimeter alfalfa crop (mm / day); O_{avg} is mean value of the measured crop evapotranspiration and N is the number of observations.

Perfect agreement exist between P_i and O_i, if IA = 1.

b. The coefficient of residual mass (CRM): can measure a tendency of overestimate and underestimate; if the value of CRM positive the model underestimate but CRM negative overestimate is used to indicate prevalent model over or underestimation of the observed; which described as:

$$CRM = \frac{\sum_{i=1}^{N} O_i - \sum_{i=1}^{N} P_i}{\sum_{i=1}^{N} O_i} \qquad (3.10)$$

where: N is the number of observations; P_i is calculated ETo (mm / day) by models and O_i is ETc values measured from lysimeter alfalfa crop (mm / day).

The gap between the selected models reference evapotranspiration and the measured value of alfalfa crop evapotranspiration fixed by using Microsoft Excel; automatic optimization and least square error was chosen the optimal parameter for to determine the level of dispersion.

3.11. DEVELOP NEW LOCAL CALIBRATION COEFFICIENTS

After the calibration was done based on alfalfa evapotranspiration; the new local coefficients were developed for most commonly used models;

$$C_{local} = C * \left(\frac{\sum ET_{o\ lysi}}{\sum ET_{o\ model}}\right) \quad (3.11)$$

where C_{local} is new develop local coefficient; C is original model constant value; $ET_{o\ lysi}$ (mm/day) is evapotranspiration from lysimeter and $ET_{o\ model}$ (mm/day) is reference evapotranspiration computed by model.

3.12. DATA ANALYSIS PROCEDURE

Daily calculated evapotranspiration of the selected models performance evaluate and calibrated based on daily measured alfalfa evapotranspiration from lysimeter.

Microsoft excel spreadsheet 2013 and daily ETo compute V3 software was used to calculate reference evapotranspiration for penman- monteith, Hargraves-samanni, Turc and Makkink models.

Daily reference evapotranspiration values computed from four empirical methods for Awash Melkassa irrigation area were first compared with daily measured evapotranspiration values. In other words a visual comparison of the results was made. The purpose is to assess the performance of these models against to the measured alfalfa evapotranspiration.

Consequently ETo estimates from the four empirical methods (measured ET vs. Penman-Monteith, measured ET vs. Hargreaves-samanni, measured ET vs. Turc and measured ET vs. Makkink) were compared using root mean square error, index of agreement and coefficient of residual mass. The models were compared before and after adjustment for each model.

The original coefficients (constant) of the four empirical methods were calibrated against the measured potential evapotranspiration of alfalfa reference crop.

Reference evapotranspiration was computed using four empirical methods with the calibrated parameter values were compared the performance of the models with the measured ETo of alfalfa reference crop values using by the above performance evaluation methods and checked by regression analysis. .

Lastly examination of the results of root mean square error (RMSE), index of agreement (IA) and coefficient of residual mass (CRM) analysis between the measured PET of alfalfa reference crop and other four methods were done.

4. RESULTS AND DISCUSSION

4.2. SOIL PHYSICAL CHARACTERISTICS OF EXPERIMENTAL FIELD

The soil physical properties of the experimental field are given in Table 4.1. The soil texture generally belongs to clay loam based on the USDA soil textural classification system. The soil bulk density ranged between 1.21 and 1.02 g/cc with mean value of 1.13 g/cc. The total available water holding capacity forever 15 cm the soil depth ranged between 29.49 and 22.81 mm with an average water holding capacity of 176.75 mm per m depth of soil.

Table 4.1 Soil physical properties experimental field

Depth (cm)	*Texture*				*BD (g/cc)BD*	*FC (mm/15cm)*	*PWP (mm/15m)*	*TAW (mm/15c)*
	%Clay	*%Silt*	*%Sand*	*Class*				
0-15	33	37	26	Clay-Loam	1.11	51.34	26.05	25.29
15-30	15	46.25	38.75	Loam	1.12	51.14	28.33	22.81
30-45	29	36	35.75	Clay-loam	1.14	60.61	32.46	28.15
45-60	35	40	24.5	Clay-Loam	1.20	61.28	31.79	29.49
60-75	37	39.5	21	Clay-Loam	1.21	49	23.83	25.17
75-90	38	38.75	46.25	Clay-Loam	1.08	52.43	25.94	26.49
90-105	33.5	35.25	28.25	Clay-Loam	1.02	52.84	24.65	28.19
Total						378.64 mm	193.05	185.6

Depth (cm)	*Texture*				*BD (g/cc)BD*	*FC (mm/15cm)*	*PWP (mm/15m)*	*TAW (mm/15c)*
	%Clay	*%Silt*	*%Sand*	*Class*				
							mm	
Average					1.13			

4.2. Neutron-Probe Calibration

The neutron-probe calibration coefficients developed for lysimeter based on equivalent soil moisture depth and count ratio are given in Table 4.2. The coefficients assigned to A and B as described in equation 3.1. The value of Neutron-probe calibration coefficient illustrated in (Table 4.2) and in (Figure 4.1,4.2 and 4.3).

Table 4.2 Value of neutron-probe calibrated coefficients

Depth (cm)	Coefficient A	Coefficient B
15-30	3.23	-0.15
30-60	2.65	0.77
60-90	2.99	0.5

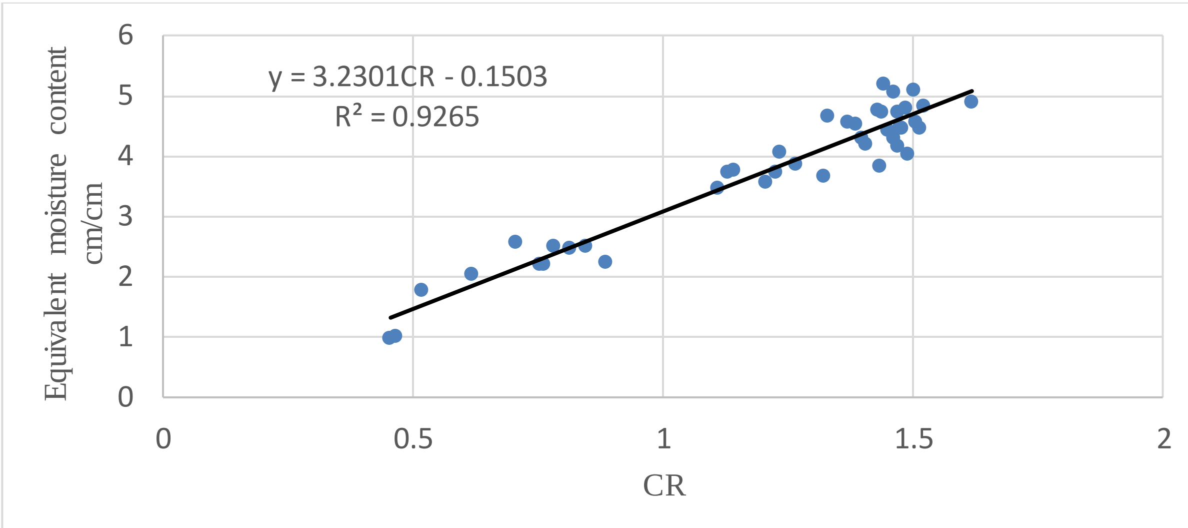


Figure 4.1 Neutron-probe calibration graph (15cm-30cm depth).

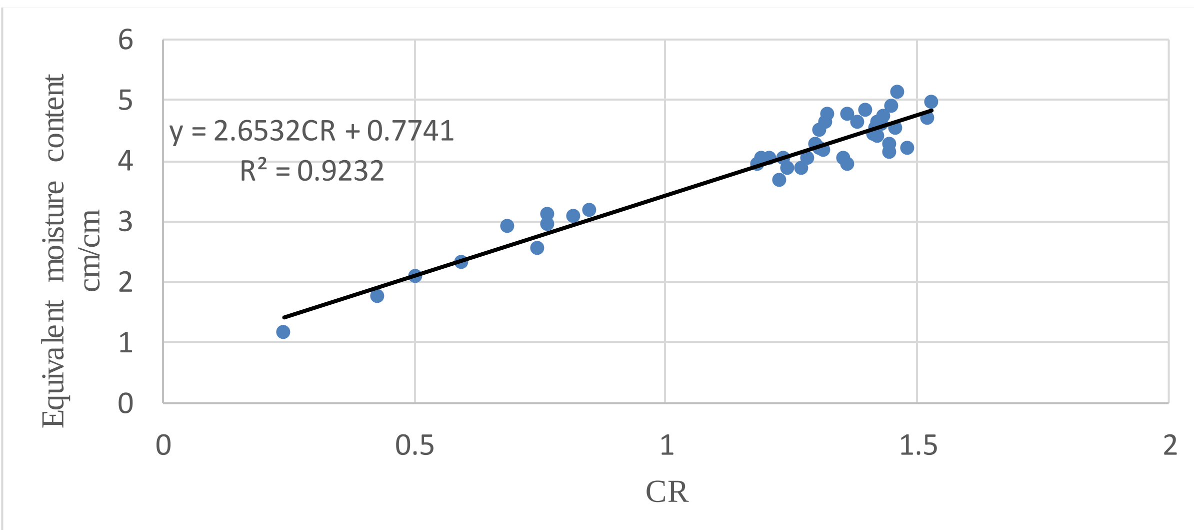


Figure 4.2 Neutron-probe calibration graph (30cm-60cm).

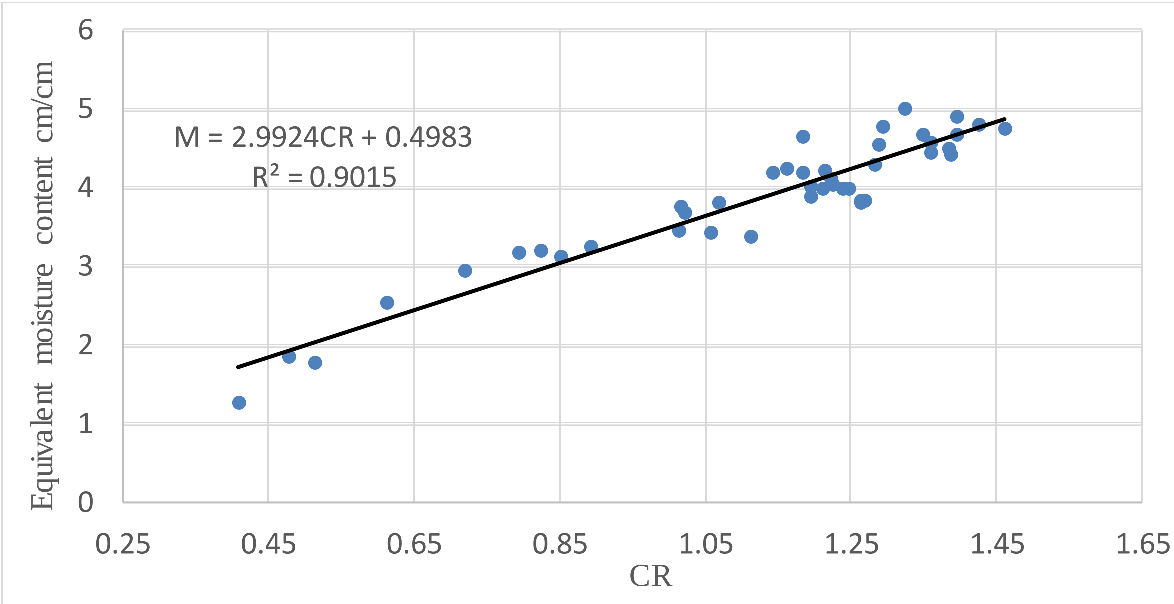


Figure 4.3 Neutron-probe calibration graph (60cm-90cm).

For all soil depth the neutron probe calibration are well done because coefficient of determination R^2 are greater than 0.7 it has excellent relationship between the result of gravimetric soil content and probe reading.

4.3. CROP EVAPOTRANSPIRATION

The crop evapotranspiration of alfalfa expressed as decadal value starts from 26 mm decadal^{-1} at the initial stage up to a maximum of 65 mm decadal^{-1} at mid stage. The crop consumed 310.29 mm per one cutting period (from germination up to late stage) in the form of irrigation and no drainage because applied irrigation water could refill to field capacity of a soil and during the experimental period no rainfall has occurred.

The higher value of crop evapotranspiration has occurred during mid-growth stage of the crop which is 6.92 mm day^{-1} and the mean seasonal crop evapotranspiration was 4.7 mm day^{-1}.

Generally the stage-wise values of alfalfa crop evapotranspiration indicate that there was increase in crop evapotranspiration from the initial to mid-season stage and slightly decrease from the mid-season stage to late stage as illustrated in Table4.3.

Table 4.3. Mean value of Alfalfa crop evapotranspiration at different growth stages

Crop growth stage	Mean value of ETc (mm /day)	ETc (mm/growth stage)
Initiation	2.07	30.10
Development	4.36	94.40
Mid	6.37	127.90
Late	6.00	60.00
Mean	4.7	312. 4 mm/season

4.4. Crop Coefficient

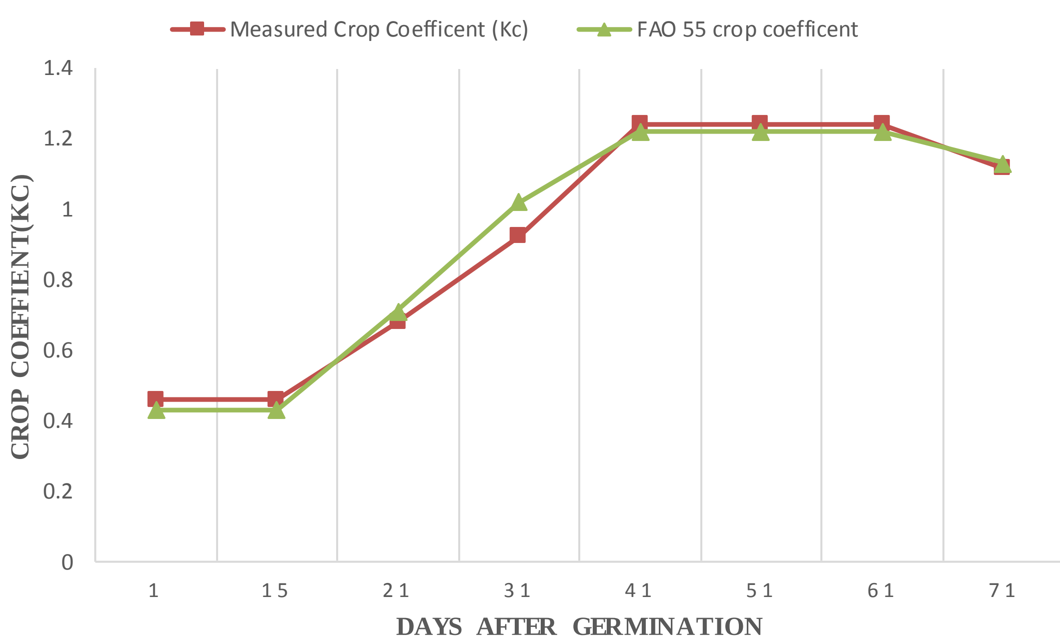
The crop coefficient values during the growing season varied from 0.46 to 1.24 in different growth stages as illustrated in Table 4.4.

Table 4.4. Mean value of Alfalfa crop coefficient at different growth stage

Crop growth stage	Mean value of ETc (mm/day)	Mean value of ETo (mm/day)	Mean value of crop coefficient (Kc)
Initiation	2.07	4.53	0.46
Development	4.36	5.31	0.80
Mid	6.37	5.13	1.24
Late	6.00	5.34	1.12

Table 4.5 Comparison of actual alfalfa crop coefficient and FAO 56 crop coefficient.

Crop growth stage	Crop coefficient (Kc) for alfalfa	FAO 56 Kc for alfalfa
Initiation	0.46	0.43
Development	0.62-0.92	0.71-1.02
Mid	1.24	1.22
Late	1.12	1.13



The curve presented in Figure 4.4 represents the changes in the Kc over the length of the growing season. The decadal Kc increased from the initial to development stages while reached its highest and relatively remained constant at the mid-season stage. The Kc declined slightly during the late season stage because Alfalfa harvested in fresh manner. Higher Kc values were recorded in the mid stage which is 1.26.

4.5. EVALUATION AND CALIBRATION OF REFERENCE EVAPOTRANSPIRATION ESTIMATION MODELS.

Based the daily ET result, evaluation and calibration of the four models were observed to ranked from the best to the worst. The performance of the four models is discussed as follows:

Penman Monteith model

The evaluation criteria such as RMSE, index of agreement and CRM values before calibration were 0.9 mm day^{-1}, 0.6 and 0.1, respectively. According to the evaluation, PM model was effective in predicting actual alfalfa ET before calibration and has a good performance for estimating ETo in Awash Melekassa irrigation area. The evaluation values of RMSE, index of agreement and CRM after calibration were 0.6 mm day^{-1}, 0.7 and 0 respectively. After calibration, PM model had best performance for estimating ET in Awash Melkassa irrigation area.

According to (Jensen et al,.1990) PM method is best compering to other models with RMSE 0.7 mm/day, index of agreement 0.84 and coefficient of determination 0.

According to (Bakhtiari et al,.2011) evaluation of evapotranspiration estimation models for semi-arid environment in Iran by using Lysimeter; the PM model is the second best method with RMSE 2.27 mm/day and index of agreement 0.63.

According to (Bander, 2012) assessment of evapotranspiration models under hyper arid environment; the PM model is the best method with RMSE 0.44mm/day and CRM 0.01.

Based on the observed value of CRM the model before calibration has slightly under estimated than measured alfalfa ET but after calibration there was no difference between calculated ETo and measured alfalfa ET.

The new coefficient has developed to calibrate the PM equation was 920. The new coefficient had increased by 2% from its original coefficient 900.

Generally the PM model can perform well without calibration but after calibration the model can best perform it illustrated in (Figure 4.4 and 4.5) the figure can described the slop change from 1.1 to 1.0(it has almost unity) so after calibration there is no difference between measured and computed ET .

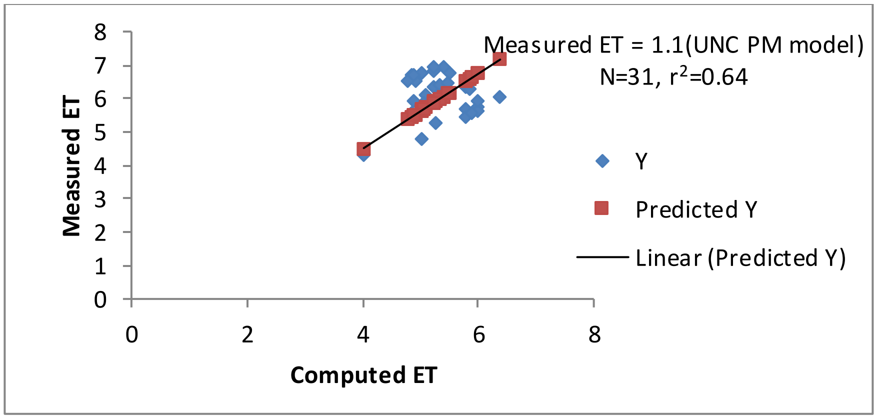


Figure 4.5 Regression Analysis of Measured ET and uncelebrated PM model

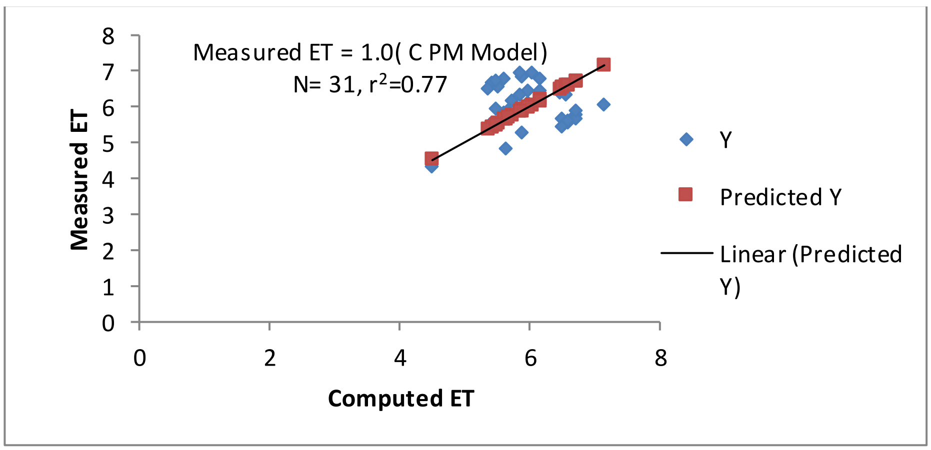


Figure 4.6 Regression analysis of Measured ET and calibrated PM model.

Hargreaves-Samani model

Based on a daily basis measured ET and computed HS ETo evaluation by statistical analysis used RMSE, Index agreement, and CRM before calibration were 1.1 mm day^{-1} , 0.35 and 0.14 respectively and after calibration values were 0.71 mm day^{-1}, 0.57 and 0 respectively. The value described HS model has good performance before and after calibration. The result of evaluation can described HS ETo model had better performance after calibration, less error and good estimate between measured ET and computed ETo than before calibration.

According to (Bakhtiari et al,. 2011) evaluation of evapotranspiration estimation models for semi-arid environment in Iran by using Lysimeter; the HS model is the best method with RMSE 1.63 mm/day and index of agreement 0.78 compared to other models.

According to (Bander, 2012) assessment of evapotranspiration models under hyper arid environment; the HS model is the second best method with RMSE 1.49 mm/day and CRM 0.2.

The new coefficient has developed to calibrate the HS model equation was 0.0027. The new coefficient had increased by 18% from its original coefficient 0.0023.

The slop of regression analysis illustrated in (Figure 4.6 and 4.7) change from 1.18 to 1; it described there was a slightly difference between measured alfalfa ET and computed HS ETo but after calibration the difference measured ET and computed ETo could be fixed because the slop reduced to one.

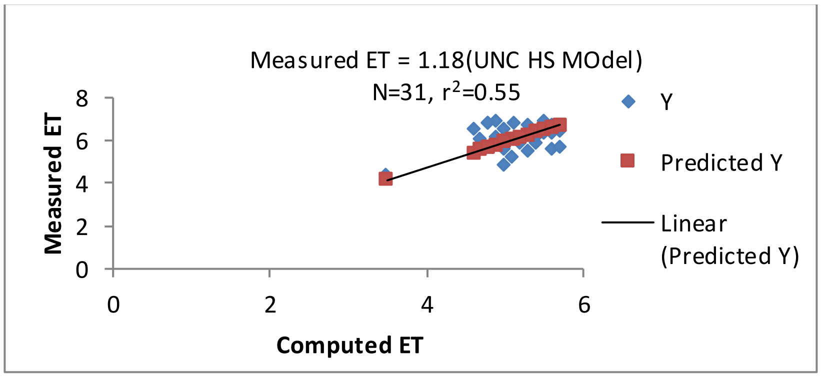


Figure 4.7 Regression analysis for measured ET and uncalibrated HS ETo model.

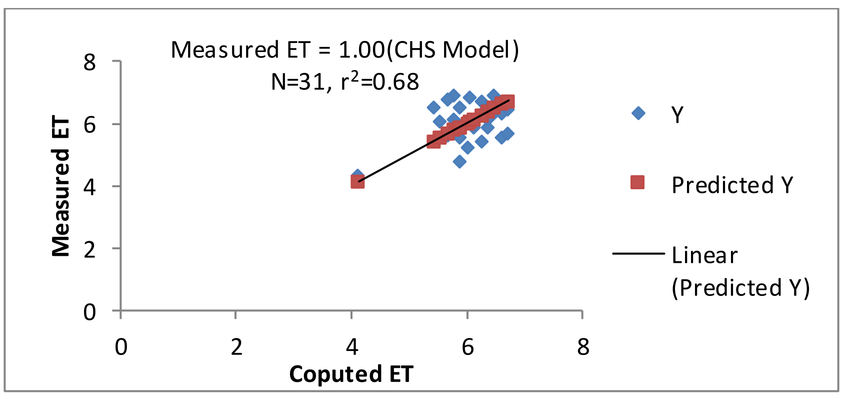


Figure 4.8 Regression analysis for measured and calibrated HS ETo model.

Turc model

Turc model before calibration has satisfactory performance for estimating ETo because the value of RMSE higher and index of agreement lower and highly underestimate than HS model and FAO 56 PM method. The statistical analysis RMSE, Index of agreement and CRM for evaluation criteria values before calibration where 1.12 mm day^{-1}, 0.56 and 0.15 respectively and values after calibration were 0.66 mm day^{-1}, 0.77 and 0 respectively so after calibration Turc model had good performance.

According to (Bander, 2012) assessment of evapotranspiration models under hyper arid environment; the TR model is the worst model among other models with RMSE 3.89 mm/day and CRM 0.6.

The new coefficient has developed to calibrate the TR equation was 0.011.The new coefficient had decreased by 20% from its original coefficient 0.0133.

Turc model after calibration has good performance for estimating ETo in Awash Melekassa irrigation area because the slop of regression analysis reduced to 1 from 1.18 after calibration; the slop becomes unit (1) it can describe there is no error between measured ET and computed ETo (Figure 4.8 and 4.9).

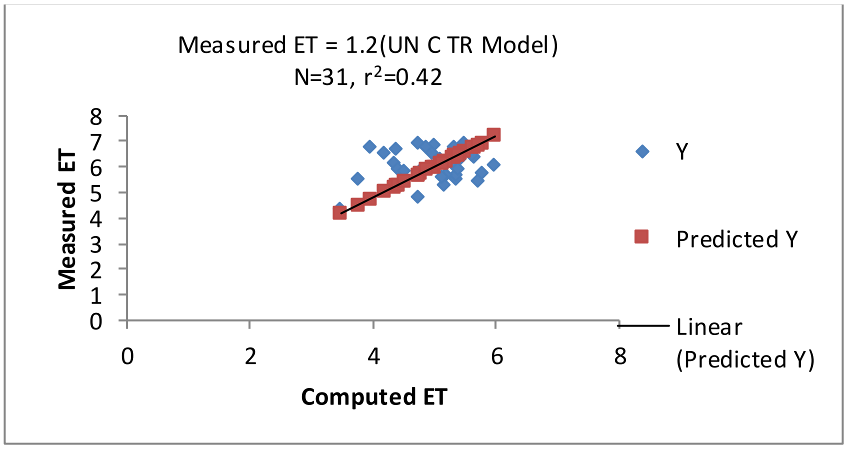


Figure 4.8 Regression analysis for measured alfalfa ET and uncalibrated TR model.

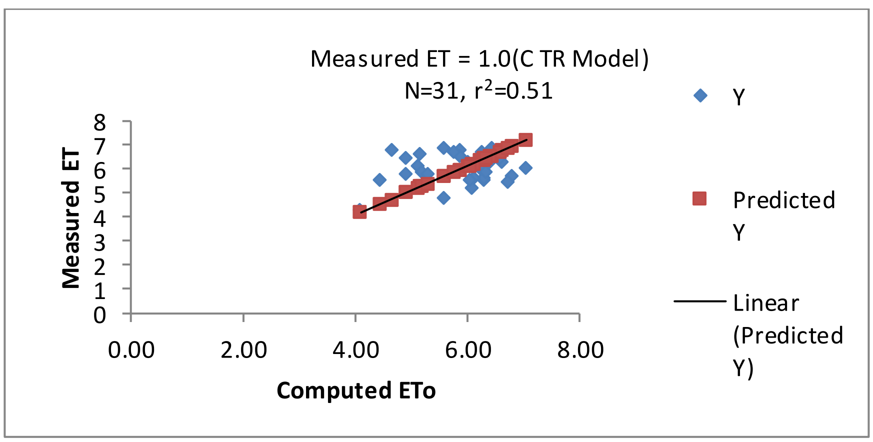


Figure 4.9 Regression analysis for measured alfalfa ET and calibrated TR.

Makkink model

Makkink model has poor performance for estimating ETo in Awash Melekassa irrigation area compared with other estimation models. The statistical analysis for evaluation criteria such as RMSE, Index of agreement and CRM values before calibration were 1.94 mm day^{-1}, 0.09 and 0.3 respectively and after calibration the values were 0.83 mm day^{-1}, 0.42 and 0 respectively. Before calibration the value of RMSE was highly far from zero it shows there was a high error between measured ET and computed ETo by makkink and there was no agreement between measured ET and computed ETo by makkink model because index of agreement approach to zero. This confirms that makkink model is had poor performance without calibration.

According to (Bander, 2012) assessment of evapotranspiration models under hyper arid environment; the MK model gives satisfactory result among other models with RMSE 2.39 mm/day and CRM 0.35 but in this research MK model had worst model for computation of evapotranspiration for Awash melekassa irrigation area.

The new coefficient has developed to calibrate the MK equation was 0.84. The new coefficient had increased by 40% from its original coefficient 0.6.

After calibration the makkink model has good performance because the slop of regression analysis becomes 0.998 it is almost one so there was no error between measured ET and computed Eto (Figure 4.10 and 4.11).

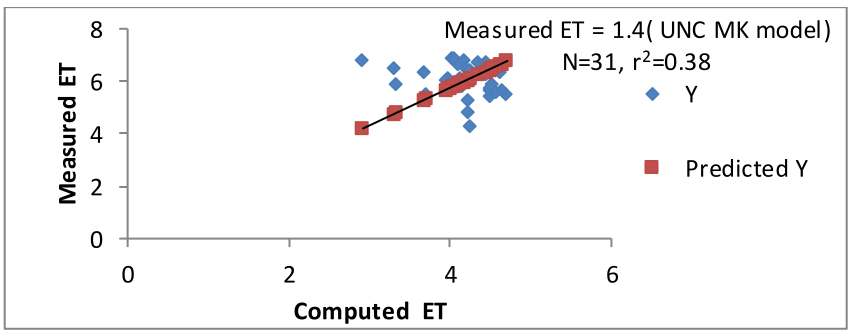


Figure 4.10 Regression analysis for measured alfalfa and uncalibrated MK ETo.

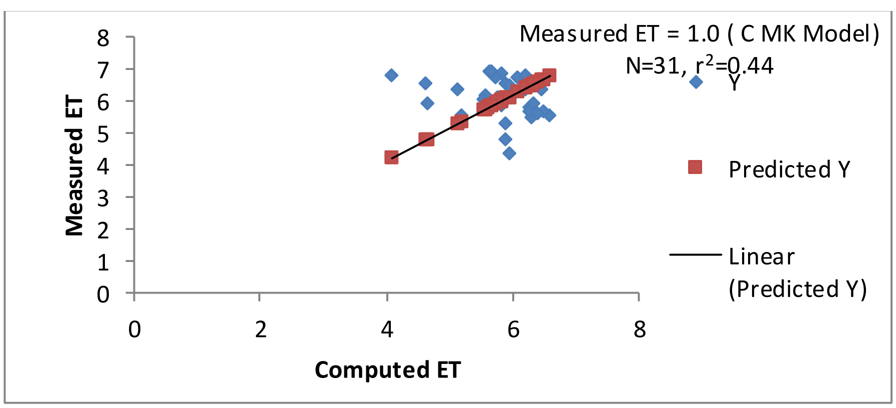


Figure 4.12 Regression analysis for measured alfalfa ET and Calibrated MK model.

5. CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

Study of evaluation and calibration of reference evapotranspiration estimation model have a vital role for hydrologic cycle study, irrigation scheduling and interval as well as for water consumption studies. However the relationship of environment and reference evapotranspiration estimation models for awash melekassa irrigation area are not yet well studied and till now, locally (areal) determined water requirement and crop coefficient for alfalfa crop is not available.

A lysimeter based experiment was conducted for evaluation and calibration of a selective reference evapotranspiration estimation models based on alfalfa actual evapotranspiration and side to side to determined alfalfa crop water requirement (ETc) and crop coefficient (Kc) at awash melekassa agricultural research center, which is located in a semi-arid climate zone.

The total crop water consumption of alfalfa crop 310.29 mm per one cutting period and maximum crop evapotranspiration occurred during at the mid stage of the crop, which is 6.92 mm day^{-1} and the mean value of crop coefficient at initiation, development, mid and late crop growth stage were 0.46, 0.8, 1.24 and 1.12 respectively.

Based on the results and statistical analysis, FAO-56 PM was the most accurate method for estimating reference evapotranspiration with a slight underestimation of 10%. On the other hand, both radiation and temperature-based models, such as turc and makkink model were not applicable in the awash melekassa irrigation area without calibration because those had satisfactory and poor performance respectively. However, temperature based model, which is Hargreaves–Samani model proved to be performing better than turc and makkink model with a slight underestimation of 18%.

5.2. RECOMMENDATION

FAO 56 PM is the most accurate model for estimation of reference evapotranspiration in awash melekassa irrigation area compared with Hargreaves-smani, Turc and Makkink model and areas that have the same weather conditions to awash Melekassa but it requires full climatic parameters.

Hargreaves-smani model was performed a second best model rather than Turc and Makkink model. It uses for area were full climate data is not available, because the model require only temperature data of the area.

Radiation-temperature based models which are Turc and Makkink model don’t use before calibration for awash melekassa irrigation due to low performance of the model.

The research conducted from October 2017 up to end of January 2018 but the alfalfa meet as a reference surface during January 2018, at this period the climate condition of the area was hot so the result of performance evaluation and calibration coefficient are more reliable during hot season rather than cold season and it is representative for semi-arid climatic condition.

In a future the research will uses for irrigation sector and hydrology sector enterprise as a guidelines for determination of actual alfalfa crop coefficient and water requirement and for selection of best evapotranspiration estimation model, additionally can also uses as a reference in academic area.

Since this experiment is a one season study in a single environment, further research over seasons are required so as to develop more reliable values.

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7. APPENDICES

7.1 Appendix Table

Appendix Table 1. Equivalent depth Vs count ratio for neutron probe calibration.

No	CR (Ratio)	Deq (cm/cm)	No	CR (Ratio)	Deq (cm/cm)	No	CR (Ratio)	Deq (cm/cm)
1	1.51	4.58	41	1.46	5.13	83	1.42	4.39
2	1.40	4.21	42	1.46	4.52	84	1.52	4.70
3	1.44	3.84	43	1.36	4.75	85	1.29	4.54
4	1.33	4.67	44	1.43	4.60	86	1.28	4.29
3	1.32	3.66	45	1.35	4.02	87	1.22	4.04
4	1.26	3.89	46	1.36	3.95	88	1.27	3.83
5	1.23	4.08	47	1.31	4.51	89	1.21	4.22
6	1.21	3.59	48	1.30	4.26	90	1.21	4.00
7	1.23	3.73	49	1.27	3.86	91	1.19	4.02
8	1.14	3.78	50	1.31	4.17	92	1.25	3.99
9	1.13	3.74	51	1.24	3.85	93	1.20	3.87
10	1.11	3.48	52	1.22	3.68	94	1.18	4.20
11	0.88	2.24	53	1.23	4.02	95	1.16	4.23
12	0.84	2.51	54	1.18	3.93	96	1.14	4.18
13	0.81	2.48	55	1.19	4.03	97	0.85	3.13
14	0.78	2.50	56	0.85	3.17	98	1.02	3.76
15	0.75	2.21	57	0.82	3.09	99	0.89	3.25
16	0.76	2.23	58	0.74	2.55	100	0.82	3.20
17	0.71	2.57	59	0.77	3.10	101	0.72	2.94
18	0.62	2.06	60	0.76	2.94	102	0.61	2.55

No	CR (Ratio)	Deq (cm/cm)	No	CR (Ratio)	Deq (cm/cm)	No	CR (Ratio)	Deq (cm/cm)
19	0.46	1.00	61	0.68	2.90	103	0.51	1.78
20	0.52	1.78	62	0.60	2.32	104	0.48	1.84
21	1.44	4.75	63	0.50	2.07	105	0.41	1.26
22	1.46	5.08	64	0.43	1.74	106	1.35	4.67
23	1.37	4.56	65	0.24	1.17	107	1.36	4.58
24	1.47	4.17	66	1.38	4.62	108	1.33	4.99
25	1.48	4.47	67	1.42	4.52	109	1.46	4.76
26	1.47	4.73	68	1.32	4.76	110	1.39	4.42
27	1.52	4.83	69	1.53	4.96	111	1.11	3.37
28	1.50	5.09	70	1.45	4.13	112	1.39	4.50
29	1.62	4.90	71	1.45	4.27	113	1.40	4.68
30	1.49	4.81	72	1.45	4.91	114	1.18	4.66
31	1.44	5.19	73	1.43	4.74	115	1.29	4.78

Appendix Table 1(continued)

No	CR (Ratio)	Deq (cm/cm)	No	CR (Ratio)	Deq (cm/cm)	No	CR (Ratio)	Deq (cm/cm)
32	1.43	4.78	74	1.32	4.62	116	1.22	4.10
33	1.49	4.05	75	1.40	4.83	117	1.39	4.90
34	1.46	4.31	76	1.31	4.20	118	1.24	3.99
35	1.40	4.30	77	1.28	4.04	119	1.26	3.83
36	1.47	4.46	78	1.21	4.03	120	1.26	3.82
37	1.45	4.45	79	1.43	4.60	121	1.06	3.43
38	1.39	4.53	80	1.41	4.45	122	1.07	3.82

No	CR (Ratio)	Deq (cm/cm)	No	CR (Ratio)	Deq (cm/cm)	No	CR (Ratio)	Deq (cm/cm)
39	1.52	4.46	81	1.42	4.63	123	1.01	3.46
40	0.47	1.03	82	1.48	4.19	124	0.79	3.18
						125	1.36	4.44
						126	1.43	4.81
						127	1.02	3.68

CR = Count Ratio; Deq = Equivalent depth of water; CPC = Centimeter per centimeter;

Appendix Table 2. Lysimeter daily water balance components.

Date	I (mm)	RF (mm)	D (mm)	S (mm)	ΔS (mm)
18/11/17	0	0	0	363.7	
19/11/17	0	0	0	361.6	2.1
20/11/17	0	11.7	0	358.2	3.4
21/11/2017	0	0	0	367.8	-9.6
22/11/2017	0	0	0	366.4	1.4
23/11/2017	14.3	0	0	364.5	1.9
24/11/2017	0	4.1	0	375.9	-11.4
25/11/2017	0	0	0	379.3	-3.4
26/11/2017	0	0	0	377.05	2.25
27/11/2017	0	0	0	374.45	2.6
28/11/2017	0	0	0	371.5	2.95
29/11/2017	0	0	0	367.6	3.9
30/11/2017	21.4	0	0	365.08	2.52
1/12/2017	0	0	0	385.28	-20.2

Date	I (mm)	RF (mm)	D (mm)	S (mm)	ΔS (mm)
2/12/2017	0	0	0	382.9	2.38
3/12/2017	0	0	0	378.3	4.6
4/12/2017	0	0	0	374.45	3.85
5/12/2017	0	0	0	371.1	3.35
6/12/2017	0	0	0	366.25	4.85
7/12/2017	0	0	0	362.1	4.15
8/12/2017	25.2	0	0	358.19	3.91
9/12/2017	0	0	0	381.44	-23.25
11/12/2017	0	0	0	376.49	4.95
12/12/2017	0	0	0	371.32	5.17
13/12/2017	0	0	0	366.68	4.64
14/12/2017	0	0	0	362.47	4.21
15/12/2017	0	0	0	358.18	4.29
16/12/2017	0	0	0	353.52	4.66
17/12/1027	0	0	0	348.4	5.12
18/12/2017	0	0	0	344.39	4.01
19/12/2017	0	0	0	339.71	4.68
20/12/2017	47.5	0	0	335.6	4.11
21/12/2017	0	0	0	380.8	-45.2
22/12/2017	0	0	0	375.5	5.3
23/12/2017	0	0	0	371.4	4.16
24/12/2017	0	0	0	366.73	4.62

Date	I (mm)	RF (mm)	D (mm)	S (mm)	∆S (mm)
25/12/2017	0	0	0	361.88	4.85
26/12/2017	0	0	0	356.83	5.05
27/12/2017	0	0	0	352.47	4.36
28/12/2017	0	0	0	348	4.47
29/12/2017	61.9	0	0	343.25	4.76
30/12/2017	0	0	0.91	401.85	-58.6
1/1/2018	0	0	0	396.02	5.82
2/1/2018	0	0	0	390.15	6.81
3/1/2018	0	0	0	384.9	5.25
4/1/2018	0	0	0	380.14	4.8
5/1/2018	0	0	0	373,42	6.68
6/1/2018	0	0	0	366.5	6.92
7/1/2018	0	0	0	360.37	6.13
8/1/2018	0	0	0	353.83	6.54
9/1/2018	0	0	0	348.29	5.54
10/1/2018	66	0	0	343.97	4.32
11/1/2018	0	0	0	405.87	-62.5
12/1/2018	0	0	0	399.08	6.79
13/1/2018	0	0	0	393.17	5.91
14/1/2018	0	0	0	386.85	6.32
15/1/2018	0	0	0	380.43	6.43
16/1/2018	0	0	0	374.58	5.85

Date	I (mm)	RF (mm)	D (mm)	S (mm)	ΔS (mm)
17/1/2018	0	0	0	368.47	6.11
18/1/2018	0	0	0	361.55	6.92
19/1/2018	0	0	0	354.82	6.73
20/1/2018	0	0	0	348.05	6.77
21/1/2018	60	0	0	342	6.05
22/1/2018	0	0	0	399.7	-57.7
23/1/2018	0	0	0	393.35	6.35
24/1/2018	0	0	0	387.81	5.54
25/1/2018	0	0	0	382.15	5.66
26/1/2018	0	0	0	375.69	6.46
27/1/2018	0	0	0	370.24	5.45
28/1/2018	0	0	0	364.59	5.65
29/1/2018	0	0	0	358.28	6.31
30/1/2018	0	0	0	352.72	5.58
31/1/2018	0	0	0	346.82	5.9

I=Irrigation, RF=Rainfall, D=Drainage, S=Daily Soil Moisture and ΔS = Change in Soil Moisture.

Appendix Table 3. Daily weather data

	monthly wheater data					
	month	November	2017			
Date	Rainfall(mm)	Temprature (C0)		RH(%)	wind(m/s)	Sunshine(hr)
		Tem.min	Tem.max.			
1	0	10	29	46	2.76	9.9
2	0	9.5	29.5	53	1.98	10.7
3	0	9	30.5	52	1.78	9.1
4	0	10.5	30.5	51	2.35	10.4

	monthly wheater data					
	month	November	2017			
Date	Rainfall(mm)	Temprature (C0)		RH(%)	wind(m/s)	Sunshine(hr)
		Tem.min	Tem.max.			
5	0	14.5	29.5	46	2.89	10.6
6	0	12.5	29	53	3.32	10.6
7	0	14.5	27.5	50	3.43	10.7
8	0	14	28.5	49	3.02	10.5
9	0	15	29	48	2.53	10.6
10	0	9.6	29.5	54	3.05	10.5
11	0	16.5	29.8	49	3.24	10
12	0	16	29	55	3.73	9.3
13	2	13	28.5	45	3.18	10.3
14	0	10	29.5	40	2.7	10.7
15	0	8	29.6	46	2.28	10.6
16	0	7.5	28.5	46	2.66	10.4
17	0	5.5	28	42	2.39	10
18	0	4.6	28.4	44	2.4	10.6
19	0	7.5	28	42	2.64	10.6
20	12	5	28	49	1.6	10.7
21	0	5.5	30.5	46	1.53	10.4
22	0	7.5	30.6	46	1.71	10.2
23	0	9	30	45	2.27	10
24	4	13.5	29.5	51	2.99	9.2
25	0	16	28	51	4.19	8.6
26	0	12.5	27.5	49	3.62	10.4
27	0	12	28.5	51	3.43	10.4
28	0	17.5	26	50	3.79	8.2
29	0	10	28.2	49	3.58	10.4
30	0	14	27.5	40	3.38	10.4

	monthly wheater data					
	month	November	2017			
Date	Rainfall(mm)	Temprature (C0)		RH(%)	wind(m/s)	Sunshine(hr)
		Tem.min	Tem.max.			
1	0	10	29	46	2.76	9.9
2	0	9.5	29.5	53	1.98	10.7
3	0	9	30.5	52	1.78	9.1
4	0	10.5	30.5	51	2.35	10.4

	monthly wheater data					
	month	November	2017			
Date	Rainfall(mm)	Temprature (C0)		RH(%)	wind(m/s)	Sunshine(hr)
		Tem.min	Tem.max.			
5	0	14.5	29.5	46	2.89	10.6
6	0	12.5	29	53	3.32	10.6
7	0	14.5	27.5	50	3.43	10.7
8	0	14	28.5	49	3.02	10.5
9	0	15	29	48	2.53	10.6
10	0	9.6	29.5	54	3.05	10.5
11	0	16.5	29.8	49	3.24	10
12	0	16	29	55	3.73	9.3
13	2	13	28.5	45	3.18	10.3
14	0	10	29.5	40	2.7	10.7
15	0	8	29.6	46	2.28	10.6
16	0	7.5	28.5	46	2.66	10.4
17	0	5.5	28	42	2.39	10
18	0	4.6	28.4	44	2.4	10.6
19	0	7.5	28	42	2.64	10.6
20	12	5	28	49	1.6	10.7
21	0	5.5	30.5	46	1.53	10.4
22	0	7.5	30.6	46	1.71	10.2
23	0	9	30	45	2.27	10
24	4	13.5	29.5	51	2.99	9.2
25	0	16	28	51	4.19	8.6
26	0	12.5	27.5	49	3.62	10.4
27	0	12	28.5	51	3.43	10.4
28	0	17.5	26	50	3.79	8.2
29	0	10	28.2	49	3.58	10.4
30	0	14	27.5	40	3.38	10.4

	month	December	2017			
Date	Rainfall(mm)	Temprature (C0)	(oC)	RH(%)	wind(m/s)	Sunshine(hr)
		Tem.min	Tem.max.			
1	0	6	28.5	45	1.79	10.4
2	0	5.5	29	45	2.46	10.4
3	0	7.5	27.5	45	2.74	10.4

	month	December	2017			
Date	Rainfall(mm)	Temprature (C0)	(oC)	RH(%)	wind(m/s)	Sunshine(hr)
		Tem.min	Tem.max.			
4	0	6.5	27.5	41	2.82	10.6
5	0	5.6	28.2	43	2.06	10.6
6	0	7.5	28.8	45	1.63	10.1
7	0	9	28.5	46	1.91	10.1
8	0	10	27.2	47	2.95	10
9	0	7.5	26.5	53	3.12	10.4
10	0	6	26	50	2.84	7.4
11	0	4	25.2	47	2.68	10.2
12	0	1.5	26	42	2.44	9.9
13	0	0.5	27	36	2.32	10.1
14	0	0.5	30	40	1.31	10.4
15	0	3.5	30.8	38	2.14	10.1
16	0	6.6	30	44	2.15	9.9
17	0	10.5	28	45	2.86	10
18	0	13.5	27.5	54	3.56	9.7
19	0	12.5	25.5	53	3.71	10
20	0	10.5	24.8	48	3.39	9.6
21	0	4	24	48	3.27	10.1
22	0	3.5	24	52	3.15	10
23	0	4	24.5	52	2.95	10
24	0	3	26.5	47	2.34	10.1
25	0	2.5	28	49	2.28	10.1
26	0	11.5	28	36	3.41	10.1
27	0	11	26.5	39	3.75	10.2
28	0	4.5	26.6	41	2.76	10.2
29	0	5.5	27.3	42	2.81	10
30	0	5	26.9	40	2.7	10.3

	month	December	2017			
Date	Rainfall(mm)	Temprature (C0)	(oC)	RH(%)	wind(m/s)	Sunshine(hr)
		Tem.min	Tem.max.			
31	0	3.3	25.5	43	2.62	9

	monthly wheater data					
	month	January	2018			
Date	Rainfall(mm)	Temprature (C0)		RH(%)	wind(m/s)	Sunshine(hr)
		Tem.min	Tem.max.			
1	0					
2	0	5	26.5	41	2.78	10.2
3	0	8.5	27	45	2.45	10
4	0	7.5	28	49	2.2	9.6
5	0	8.5	26.5	42	3.11	9.5
6	0	9.5	27	47	2.7	9.6
7	0	10.5	27.5	47	2.71	7.5
8	0	11.5	26.5	55	2.77	9.4
9	0	14.5	25.5	61	2.6	5.8
10	0	15.5	23.5	49	2.2	4.6
11	0	9.6	25.5	58	2.8	7.1
12	0	9	26	53	3.2	8.4
13	0	5.5	26	43	2.8	10.3
14	0	0.5	28	35	2.3	10.4
15	0	0	27.5	47	2.25	10.4
16	0	1	27.5	37	2.36	10.5
17	0	3.5	28	41	2.25	10.3
18	0	5	28.5	41	1.77	10.3
19	0	6.6	29.5	41	2.68	8.6
20	0	15	28.5	40	3.76	9.6
21	0	14.5	28	43	3.32	10.2
22	0	15.5	29.5	47	2.84	10.2
23	0	11	30.5	46	2.82	10.3
24	0	9	30	46	2.77	10.5
25	0	7	30.2	41	2.16	10.4

	monthly wheater data					
	month	January	2018			
Date	Rainfall(mm)	Temprature (C0)		RH(%)	wind(m/s)	Sunshine(hr)
		Tem.min	Tem.max.			
26	0	7	30	39	2.53	10.4
27	0	7.5	28	44	3.46	10.4
28	0	14	28	45	3.18	10
29	0	10.5	29	54	2.96	10.2
30	0	15	29.5	52	2.8	9.5
31	0	10.5	28.5	43	3.55	10.3

% = Percent, hrs = Hours, m = Meters and m/s = Meter per Second.

Appendix Table 4. Measured ET and computed ETo before calibration.

Date	Measured ET(mm)	PM Model(mm)	HS Model (mm)	TR Model(mm)	MK Model(mm)
1/1/2018	5.82	5.02	5	4.76	4
2/1/2018	6.81	5.25	5.13	4.98	4.17
3/1/2018	5.25	5.27	5.1	5.17	4.22
4/1/2018	4.8	5.04	5	4.73	4.22
5/1/2018	6.68	4.85	5.3	4.38	4.1
6/1/2018	6.92	5.4	4.9	4.73	4.04
7/1/2018	6.13	5.11	4.9	4.34	3.98
8/1/2018	6.54	4.92	5	4.97	4.21
9/1/2018	5.54	4.85	4.7	3.76	3.71
10/1/2018	4.32	4.02	3.5	3.48	4.25
11/1/2018	6.5	4.8	4.6	4.17	3.3
12/1/2018	6.79	5.02	4.8	3.94	2.92

Date	Measured ET(mm)	PM Model(mm)	HS Model (mm)	TR Model(mm)	MK Model(mm)
13/1/2018	5.91	4.91	5	4.41	3.33
14/1/2018	6.32	5.23	5.5	5.09	3.67
15/1/2018	6.43	5.34	5.4	5.33	4.25
16/1/2018	5.85	5.06	5.4	4.5	4.16
17/1/2018	6.11	5.34	5.4	5.28	4.13
18/1/2018	6.92	5.24	5.5	5.47	4.06
19/1/2018	6.73	4.91	5.6	4.88	4.34
20/1/2018	6.77	5.51	4.8	5.32	4.44
21/1/2018	6.05	6.38	4.7	5.98	3.96
22/1/2018	5.77	6	5	5.77	4.49
23/1/2018	6.35	5.79	5.6	5.63	4.63
24/1/2018	5.54	5.89	5.6	5.345	4.71
25/1/2018	5.66	5.81	5.7	5.34	4.64
26/1/2018	6.46	5.5	5.7	5.6	4.52
27/1/2018	5.45	5.81	5.3	5.7	4.51
28/1/2018	5.65	6	4.8	5.19	4.49
29/1/2018	6.31	5.86	5.3	5.43	4.44
30/1/2018	5.58	5.89	5	5.12	4.58
31/1/2018	5.9	6	5.2	5.38	4.53

PM = Penman Montith, HS = Hargraves-Samani, TR = Turc, MK = Makkink

Appendix Table 5. Measured ET and computed ETo after calibration.

Date	Measured ET(mm)	C PM Model (mm)	CHS Model (mm)	C TR Model (mm)	C MK Model (mm)
1/1/2018	5.82	5.52	5.88	6.98	5.60
2/1/2018	6.81	5.78	6.03	8.17	5.84
3/1/2018	5.25	5.80	5.99	6.30	5.91
4/1/2018	4.8	5.54	5.88	5.76	5.91
5/1/2018	6.68	5.34	6.23	8.02	5.74
6/1/2018	6.92	5.94	5.76	8.30	5.66
7/1/2018	6.13	5.62	5.76	7.36	5.57
8/1/2018	6.54	5.41	5.88	7.85	5.89
9/1/2018	5.54	5.34	5.52	6.65	5.19
10/1/2018	4.32	4.42	4.11	5.18	5.95
11/1/2018	6.5	5.28	5.41	7.80	4.62
12/1/2018	6.79	5.52	5.64	8.15	4.09
13/1/2018	5.91	5.40	5.88	7.09	4.66
14/1/2018	6.32	5.75	6.46	7.58	5.14
15/1/2018	6.43	5.87	6.35	7.72	5.95
16/1/2018	5.85	5.57	6.35	7.02	5.82
17/1/2018	6.11	5.87	6.35	7.33	5.78
18/1/2018	6.92	5.76	6.46	8.30	5.68
19/1/2018	6.73	5.40	6.58	8.08	6.08
20/1/2018	6.77	6.06	5.64	8.12	6.22
21/1/2018	6.05	7.02	5.52	7.26	5.54

Date	Measured ET(mm)	C PM Model (mm)	CHS Model (mm)	C TR Model (mm)	C MK Model (mm)
22/1/2018	5.77	6.60	5.88	6.92	6.29
23/1/2018	6.35	6.37	6.58	7.62	6.48
24/1/2018	5.54	6.48	6.58	6.65	6.59
25/1/2018	5.66	6.39	6.70	6.79	6.50
26/1/2018	6.46	6.05	6.70	7.75	6.33
27/1/2018	5.45	6.39	6.23	6.54	6.31
28/1/2018	5.65	6.60	5.64	6.78	6.29
29/1/2018	6.31	6.45	6.23	7.57	6.22
30/1/2018	5.58	6.48	5.88	6.70	6.41
31/1/2018	5.9	6.60	6.11	7.08	6.34

PM = Penman Montith, HS = Hargraves-Samani, TR = Turc, MK = Makkink and C = calibrated

Table 6. Recorded maximum temperature for 41 years (1977-2017).

	Month												
Year	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	Annual
1977	25.85	25.83	29.16	29.27	29.40	27.17	25.54	25.40	26.97	27.35	25.79	26.70	27.04
1978	27.83	27.66	28.80	30.77	31.16	30.15	26.01	26.02	27.12	27.49	27.43	26.60	28.09
1979	25.44	27.92	29.17	30.90	29.69	29.01	26.10	26.36	27.17	28.29	28.16	27.57	27.98
1980	27.09	29.94	31.53	31.00	31.85	29.71	26.83	25.83	27.47	28.52	28.60	27.63	28.83
1981	29.22	28.73	27.58	27.75	32.00	32.50	26.89	25.92	26.10	28.63	27.92	27.11	28.36
1982	27.87	28.24	30.28	29.61	30.21	30.81	27.86	24.93	27.11	26.57	26.11	25.90	27.96
1983	26.50	28.78	29.62	29.66	29.88	29.89	26.65	25.72	27.31	28.65	28.51	26.94	28.18
1984	27.13	28.76	31.77	32.82	29.88	28.32	25.58	26.89	27.23	29.61	29.13	26.74	28.66
1985	28.44	28.27	31.06	28.43	29.52	30.54	26.32	24.71	26.59	28.60	28.52	27.29	28.19
1986	27.53	22.48	28.76	29.05	31.26	28.23	29.18	27.07	27.45	28.95	29.38	27.72	28.09
1987	27.22	29.81	29.36	29.76	28.78	29.58	25.56	27.15	29.17	30.36	29.92	29.06	28.81
1988	28.35	30.26	32.29	31.36	32.11	30.36	26.18	26.12	26.71	28.29	28.34	27.63	29.00
1989	27.18	27.20	30.26	28.43	31.38	31.41	27.14	26.41	27.48	28.75	28.91	27.73	28.52
1990	28.05	27.33	27.86	28.60	32.06	31.34	25.98	25.94	26.90	28.82	29.41	27.86	28.34
1991	29.52	29.18	30.46	30.20	32.00	30.00	32.70	27.50	29.61	31.09	28.31	28.42	29.92
1992	27.66	28.34	31.55	31.38	31.87	31.20	26.08	28.20	28.24	29.10	29.62	27.42	29.22
1993	26.48	26.10	30.83	29.51	29.05	29.35	25.49	26.27	27.00	28.89	28.88	28.50	28.03
1994	28.57	29.90	31.05	31.35	31.70	29.65	27.44	25.19	26.50	28.44	26.77	27.37	28.66
1995	27.93	30.12	29.50	29.15	31.66	32.21	28.01	25.72	27.15	29.24	29.29	28.47	29.04
1996	27.59	30.28	30.16	29.53	22.33	22.43	26.34	26.62	27.30	29.15	28.23	28.16	27.34
1997	28.08	29.10	31.42	29.16	31.73	30.08	27.34	26.26	29.61	28.39	27.29	28.17	28.89
1998	26.97	29.38	29.85	32.16	31.92	32.04	25.50	25.71	26.98	27.33	28.53	28.09	28.70
1999	28.75	31.70	29.40	32.27	32.42	30.72	25.77	25.91	27.39	26.51	27.16	27.55	28.79
2000	28.93	30.15	31.39	31.12	30.92	30.18	26.39	25.64	26.77	26.90	27.74	27.61	28.65
2001	27.08	29.52	28.90	31.15	30.46	28.52	29.65	25.79	28.22	29.99	28.42	28.15	28.82
2002	26.82	30.36	30.17	30.81	32.40	31.03	25.88	26.91	28.33	30.28	29.33	27.28	29.13
2003	27.79	30.51	30.56	29.36	32.96	30.11	26.67	25.64	26.63	29.17	28.52	26.24	28.68
2004	28.17	28.39	29.54	29.05	32.67	30.36	27.00	26.96	28.29	27.85	28.19	27.67	28.68
2005	28.25	31.01	30.66	31.94	32.00	32.00	29.00	27.19	27.95	29.45	28.68	27.93	29.67
2006	29.05	30.51	29.82	28.95	31.18	30.45	27.25	27.00	27.74	28.96	28.45	26.87	28.85
2007	27.75	29.82	31.26	30.02	32.31	29.40	26.50	25.88	27.16	28.51	27.95	27.60	28.68
2008	29.15	28.94	32.29	31.21	31.06	29.96	28.11	26.30	27.69	28.18	26.18	27.20	28.86
2009	27.70	30.22	32.30	31.27	32.55	32.34	26.15	26.71	29.99	28.55	29.21	27.42	29.54
2010	28.30	28.18	28.26	30.95	30.55	30.42	26.50	26.52	27.58	29.88	28.73	27.86	28.64
2011	29.15	28.94	32.29	31.21	31.06	29.96	25.41	26.30	27.69	28.18	26.18	27.20	28.63
2012	28.42	29.77	31.95	30.73	32.69	31.40	26.12	25.19	26.99	28.54	29.46	28.38	29.14
2013	28.03	30.66	31.87	31.79	31.84	30.87	28.38	26.40	28.30	28.69	28.04	27.26	29.34
2014	29.05	30.37	29.98	31.84	31.19	32.41	29.98	26.73	27.17	27.36	28.48	27.38	29.33
2015	28.58	32.01	32.66	32.59	31.43	31.13	26.77	29.61	30.17	31.26	28.93	28.72	30.32
2016	29.10	29.88	33.03	30.00	29.64	29.82	28.21	27.09	28.62	30.46	28.14	27.24	29.27
2017	28.94	29.24	32.43	32.34	28.00	28.00	28.67	27.50	30.30	28.90	28.40	27.60	29.19
Monthly Mean	27.94	29.12	30.51	30.45	30.95	30.12	27.05	26.37	27.71	28.73	28.27	27.57	
Annual Mean													28.73

Appendix Table 7. Recorded minimum temperature for 41 years (1977-2017).

	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1977	13.74	11.23	14.63	14.08	14.18	14.06	14.60	18.07	15.76	15.03	13.58	12.85	14.32
1978	11.35	13.36	15.05	15.62	15.69	16.40	15.32	14.61	14.23	13.00	11.11	11.68	13.95
1979	14.18	13.54	14.14	15.24	15.15	15.31	14.47	14.27	14.06	11.20	10.23	12.00	13.65
1980	12.03	15.08	16.24	15.82	16.05	15.26	14.55	13.75	13.55	11.03	11.07	8.68	13.59
1981	12.88	13.93	17.05	16.12	16.16	17.47	15.89	15.55	14.90	12.03	10.93	10.71	14.47
1982	14.50	15.82	16.13	16.19	16.25	16.74	15.79	15.31	14.27	11.80	13.02	12.59	14.87
1983	11.73	16.29	17.14	16.74	16.85	16.38	15.88	15.48	15.39	11.77	10.80	10.58	14.59
1984	9.60	9.50	15.41	16.74	16.50	16.29	15.56	15.91	14.23	12.09	14.10	12.35	14.02
1985	12.12	13.38	16.48	16.12	16.30	16.95	15.29	14.96	14.45	12.61	12.36	11.74	14.40
1986	9.82	15.55	15.17	16.80	16.50	16.37	15.45	15.18	14.35	11.18	11.32	11.21	14.08
1987	11.41	13.21	16.32	14.68	15.22	17.14	16.65	16.04	14.52	12.53	9.74	11.25	14.06
1988	13.59	16.28	15.20	16.19	15.93	16.90	16.83	15.78	15.44	11.84	7.01	9.49	14.21
1989	9.82	14.17	14.47	15.95	14.24	15.49	16.02	15.47	14.32	10.37	9.40	14.16	13.66
1990	11.15	15.71	14.11	14.31	15.40	16.58	15.86	15.77	15.20	9.99	9.89	9.42	13.62
1991	12.78	15.02	15.79	15.15	15.10	16.32	15.48	16.60	14.18	9.77	9.97	8.75	13.74
1992	12.65	14.70	16.91	16.20	15.44	16.29	16.38	12.78	12.74	11.85	13.18	13.12	14.35
1993	14.29	12.96	12.39	15.70	15.18	16.91	15.57	15.28	15.04	12.51	11.89	9.75	13.96
1994	9.26	12.14	15.96	16.55	15.73	17.43	16.28	14.67	14.52	11.25	11.61	9.88	13.77
1995	9.13	14.59	15.15	15.33	14.99	16.58	16.56	16.23	14.18	12.00	9.93	14.38	14.09
1996	14.34	12.12	16.05	15.13	15.03	16.75	16.60	16.22	14.90	10.05	10.76	9.64	13.96
1997	13.45	11.79	15.52	15.27	14.71	15.25	14.48	14.12	13.15	13.91	13.94	10.97	13.88
1998	14.25	14.94	14.85	15.10	14.80	15.17	14.04	13.80	12.79	11.03	5.43	4.74	12.58
1999	8.17	8.94	11.48	10.81	11.69	12.42	11.47	11.00	10.00	8.66	3.98	4.85	9.46
2000	5.75	6.58	13.60	14.13	15.53	16.52	15.89	15.83	14.76	12.31	10.44	9.44	12.56
2001	9.65	11.80	15.50	14.90	16.66	16.28	16.23	15.75	13.48	12.34	10.54	11.42	13.71
2002	12.40	12.81	15.79	15.44	17.16	17.53	16.63	15.82	15.03	12.45	11.36	15.10	14.79
2003	12.07	13.37	15.28	15.88	14.04	16.62	16.21	16.19	14.99	11.65	12.56	10.79	14.14
2004	15.06	12.57	13.40	15.49	14.68	16.92	15.77	16.12	15.13	12.50	11.64	12.62	14.32
2005	11.80	13.06	15.57	15.01	15.85	16.86	16.50	16.12	15.45	11.86	11.31	8.14	13.96
2006	13.29	15.51	14.71	15.36	15.72	16.86	16.37	15.56	15.18	13.41	11.60	12.90	14.71
2007	13.54	14.83	14.69	16.07	16.71	17.20	16.68	15.65	15.70	9.52	10.87	7.23	14.06
2008	12.14	12.26	11.68	17.00	16.54	16.65	15.91	15.88	15.36	12.10	9.89	8.19	13.63
2009	11.12	13.91	15.50	15.45	15.01	16.82	15.62	15.55	15.01	12.20	9.35	14.40	14.16
2010	12.52	15.09	15.62	16.08	17.26	17.47	16.47	16.57	15.20	10.98	10.80	5.61	14.14
2011	12.14	11.05	11.07	10.70	10.96	11.54	10.30	10.44	8.78	4.47	6.65	7.11	9.60
2012	10.15	9.93	13.42	16.10	15.06	17.41	16.12	16.11	15.32	10.05	9.50	10.87	13.34
2013	10.11	11.68	15.92	14.06	17.09	17.27	15.96	16.15	14.74	12.19	11.40	7.66	13.69
2014	11.63	15.60	15.57	16.10	16.52	16.79	16.98	16.05	14.92	12.45	11.37	9.05	14.42
2015	8.85	12.98	15.47	15.05	16.51	17.52	16.94	16.53	16.36	15.54	13.71	13.68	14.93
2016	15.30	13.38	17.56	17.30	16.13	16.51	16.16	16.08	15.62	11.98	11.83	10.02	14.82
2017	6.22	15.37	15.59	15.98	16.08	15.96	16.18	16.05	15.84	12.18	11.01	6.38	13.57
Monthly M	11.71	13.32	15.06	15.41	15.53	16.32	15.66	15.35	14.46	11.65	10.76	10.38	
Annual Mean													13.80

Appendix Table 8. Recorded annual rainfall for 41 years (1977-2017).

Year	Annual rain
1977	1310.4
1978	749.3
1979	875.7
1980	668.6
1981	800.3
1982	739.7
1983	816.7
1984	567.6
1985	795.5
1986	642.3
1987	694.6
1988	703.9
1989	702.2
1990	719.7
1991	923.5
1992	780.8
1993	873.7
1994	737.5
1995	733.4
1996	836.9
1997	804
1998	1046.1
1999	788.6
2000	851.4
2001	814.8
2002	548.7
2003	899
2004	822.5
2005	882.4
2006	928.6
2007	1064.5
2008	1052.7
2009	679.4
2010	1093.1
2011	810.1
2012	924.7
2013	922.1
2014	792.6
2015	477.1
2016	1084.7
2017	261.3
Annual Aver	810.26098

Appendix Table 9. Measured ground cover and leaf area index.

Days after germination	Ground cover (%)	Leaf area index
10	8.4	0.98
20	17.6	1.55
30	44.8	1.83
40	69.1	2.91
50	82.62	3.89
60	96.35	4.59
70	88.09	4.08

7.2. Appendix Figures

Appendix figure 1 soil moisture measurement by using Neutron-probe device and alfalfa covered lysimeter site.