Field Evaluation of Center Pivot Irrigation System: The case of Wonji-Shoa Sugar Estate, Ethiopia

By: Chala Wakjira Taressa

A Thesis Submitted to

Department of Water Resources Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master of Science in Water Resources Engineering (Specialization in Irrigation Engineering)

Office of Graduate Studies

Adama Science and Technology University

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June, 2020

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Approval Sheet of the Board of Examiners

We, the undersigned, members of the Board Examiners of the final open defense by Chala Wakjira Taressa have read and evaluated his thesis entitled " Field Evaluation of Center Pivot Irrigation System: The case of Wonji-Shoa Sugar Estate, Ethiopia" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Masters in Water Resources Engineering (Irrigation Engineering).

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Declaration

I hereby, declare that this MSc Thesis is my own original work and that it has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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This MSc Thesis has been submitted for examination with my approval as thesis advisor.

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Advisor's approval sheet

To: Water Resources Engineering Department

Subject: Thesis Submission

This is to certify that the thesis entitled "Field Evaluation of Center Pivot Irrigation System: The case of Wonji-Shoa Sugar Estate, Ethiopia, submitted in partial fulfillment of the requirements for the degree of Master's in Water Resources Engineering (Irrigation Engineering), the Graduate program of the department of Water Resources Engineering, and has been carried out by Chala Wakjira Taressa Id. No PGR/18033/11, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the department.

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LIST OF ABRIVATIONS AND ACRONYMS

ASAE	American Society of Agricultural Engineering
ASABE	American Society of Agricultural and Biological Engineering
CP	Center Pivot
CU	Coefficient of Uniformity
CUHH	Coefficient of Uniformity of Herman and Hein
DU	Distribution Uniformity
EWDL	Evaporation and Wind Drift Losses
FAO	Food and Agricultural Organization
FSPS	Fixed Spray Plate Sprinkler
MAE	Mean Absolute Error
NRCS	Natural Resources and Conservation Service
RMSE	Root Mean Square Error
RSPS	Rotating Spray Plate Sprinkler
SPSS	Software Package for Social Science
WSSE	Wonji-Shoa Sugar Estate

ABSTRACT

Center Pivot (CP) Irrigation System is one of the recent irrigation technologies to apply water efficiently and uniformly over the wide range of area and topography. This the study was conducted to evaluate uniformity of water distribution and estimate water losses for center pivot irrigation system, using double row of catch can at morning, midday and Late afternoon. The results showed that the system gives low distribution uniformity. The average values of coefficient of uniformity (CU) and distribution uniformity (DU), during morning, midday and late afternoon were, 77% and 63%, 66% and 60%, 80% and 65%*, respectively. In all test times the distribution uniformity is at poor performance range. Water losses from these systems were ranged between 1.03% and 7.74%. The study was also investigated the effect of main factors on water distribution and water losses in the study area by developing a statistical model in order to determine relationship between the losses and the factors affecting them under operating field conditions during different irrigation times of the day. The study concludes that wind speed, air temperature, relative humidity and travel speed of the last tower is the main factor affecting the applied water, Hence, the study recommends the managers of the system to operate when the climate demand is low to increase yield per applied water and save energy.*

Keywords: Center Pivot, Coefficient of Uniformity, Distribution Uniformity, Catch Cans, Water Losses.

1. INTRODUCTION

1.1 Background

Irrigation is an increasingly important practice for sustainable agriculture in the arid and semiarid regions of the world. It plays a crucial role in addressing the main challenges caused by food insecurity and rainfall uncertainty (Akbar, 2017). However, water is becoming the most important resource and limiting factor for agricultural development. It is expected that as population and economy grow, a larger fraction of available water will be required for nonagricultural purposes, e.g., urban and industrial applications (Boserup, 2005). Also, climate change has already limited water resources in many regions of the world (Sadeghi *et al.,* 2015). Therefore, effective utilization of water is important to mitigate this problem.

Center Pivot (CP) irrigation is a form of sprinkler irrigation, in which a small amount of water is applied at frequent intervals (Mekonnen, 2017; Ruffino, 2009). It consists of lateral circulating around a fixed pivot point (Salih, 2013). Center pivot irrigation systems are invented over 60 years ago to reduce labor requirements, enhance agricultural production, and optimize water use and experienced worldwide success because of their advantages relative to other irrigation systems. Such advantages typically include, high potential for uniform and efficient water application; high degree of automation and ability to apply water and nutrients over a wide range of soil, crop and topographic conditions (El-Marazky, 2018; Evans and King, 2012; Almasraf *et al*., 2011).

Irrigation systems apply water uniformly in order to achieve maximum benefit from the water applied. Uniformity of a system is a measure of its ability to apply the same depth of water to every unit area. Without good uniformity, it is impossible to irrigate adequately and efficiently; parts of the field will be either over-irrigated or under-irrigated (Akbar, 2017; Sabah *et al*., 2011; Acar *et al*., 2010).

Poor management, uniformity and distribution of water have been cited as the most frequent problems of flood irrigation, resulting in waterlogging, salinization and less water use efficiency (Singh, 2018 ; Ali and Mohammed, 2015). Proper irrigation uniformity in center pivot systems is important since it has both economic and environmental implications.

Uniformity of water distribution of the applied water could be influenced by climatic and irrigation system parameters (El-Marazky, 2018; Clemmens and Solomon, 1997). In addition, the uniformity of center irrigation systems is influenced by center pivot pressure, wind speed, nozzle wear, climatic condition and variation in pressure (Mostafa and Alsayim, 2015; Rinders, 2001).

Field evaluation is an excellent procedure for determining the actual water distribution at field level (El-Marazky, 2018). The uniformity of water application under a center pivot could be determined by setting out identical catch-cans along the length of the pivot, bringing the irrigation system up proper operating pressure, and letting the system pass over them (Harrison and Perry, 2013; Akbar, 2017;Al-Ghobari, 2014). The two most common methods of expressing uniformity are the coefficient of uniformity (CU) and Distribution uniformity (DU) (Mostafa and Alsayim, 2015).

Center pivot sprinkler has been operational at Wonji-Shoa Sugar Estate in Ethiopia. The effect of different weather and system parameter on its performance has not yet been conducted in the area. To know the reality of water application, water losses and distribution uniformity by system, a study was conducted using double row of catch can at different irrigation time of the day. The water distribution, wind drift and evaporation losses during the evaluations were measured during morning, midday and late afternoon. The study evaluates the uniformity of water distribution and identifies the factors that affect applied water at the field condition using double row of catch can to increase accuracy of measurement. The purpose of the study was also to develop the statistical Regression model that estimates water loss in the center pivot system.

1.2 Statement of the Problem

Water is one of the constraints for irrigation. Due to climate change, water is going to be scarce. Poor design, physical constraint, improper management and operation of surface irrigation methods is leading to ineffective and inefficient application of water, water losses and the non-uniformity of water (Singh, 2018). According to Wang *et al* (2015) the high uniformity by drip irrigation brings economic benefits in return high due to increase in yield. Also the non-uniformity of water applied by sprinkler irrigation the high increase yield (Wang *et al.*, 2017; Salmerón *et al.*, 2012; Li, 1998).

Center pivot is very expensive system it has to be operated well so as to high returns or yield per water applied. Uniformity of water distribution by the system is affected by the operating conditions and environmental factors, especially wind (Rogers *et al*., 2017). Center pivot is prone to wind effects on uniformity of water distribution, especially where saline irrigation water is applied and cause high damage to crop (Mekonnen, 2017; Keller, 1990). Wind speed (Mostafa and Alsayim, 2015; Playa´n *et al.*, 2005), as a meteorological variable, is more directly related to the sprinkler irrigation performance through its effects on the uniformity coefficient through wind drift and evaporation losses. At higher wind speeds, larger droplets can be transported by the wind, and droplets can be transported greater distances (Bishaw and Olumana, 2015; Smajstrla, *et al*., 2002; Smajstrla and Zazueta, 2003).

The high wind speed together with operational pressure and leakage conditions are believed to be the limiting factors for poor water application uniformity at Wonji-Shoa Sugar Estate (Bishaw and Olumana, 2015). As a result was decline of production from year 2013 to 2017 from 160 ton/ha to 100 ton/ha, respectively. The wind drift effect of the study area is more significant in-field water application uniformity during irrigation events. It is the main factor for decline of yield per hectare and non-uniformity. The study by Mengistie (2019) recommended the investigation of effect of wind drift on irrigation. The center pivot at Wonji-Shoa Sugar Estate is sprinkler with R3000 type rotator spray which is mounted on the lateral of center pivot located on 4.2 m above the ground in all. It is affected to a greater degree by winds and subject to greater pattern distortions because of its higher application elevation above the ground or crop (Howell, 2000). Under wind condition, uniformity of rotator type sprinkler decreases (Hanson and Orloff, 1996). These affect uniformity of water distribution which makes non-uniform growth that reduces crop yield, by making water stress. Center pivot has to handle and use water in its most efficient ways to prevent unnecessary losses (Mohammed, 2018; Dukes and Perry, 2006).

Therefore, considering the problem, this study evaluated uniformity of water distribution using double row of catch can, and identified the factors performance of water application by the system.

1.3 Objective

1.3.1 General objective

The general objective of the study was to evaluate uniformity of water distribution and determine water losses for center pivot irrigation system at Wonji-Shoa Sugar Estate.

1.3.2 Specific objectives

The specific objectives of the study were:

1. To evaluate Coefficient of uniformity (CU) and Distribution Uniformity (DU).
2. To identify the factor predominately affecting the applied water.
3. To estimate water loss from center pivot irrigation system.

1.4 Research Questions

The following questions were addressed on this study:

1. How uniformly is water being applied by the center pivot irrigation system?
2. Which factor is responsible for water loss from center pivot irrigation system?
3. What equation predicts water loss from the center pivot irrigation system?

1.5 Significance of the Study

The study provides baseline information for managers and decision makers on how to evaluate the uniformity of water distribution during data collection. The evaluation also helps to give attention to the system for saving water and energy while increase productivity. From the result of uniformity indicator, it is simple to identify the performance of operating factor along the lateral which is useful for the maintenance of the system.

The data to be gathered, processed and interpreted will potentially assist decision makers in assessing the performance of the system and it may assist to develop new design configuration to increase the performance of the system and to conduct regular maintenance and evaluation of the system.

Additionally the study proposed the empirical model to predict water loss at different wind conditions, which could be important for management of system operation and input for future researches in the area.

1.6 Scope of the Study

The study was focused on field evaluation of uniformity of water distribution of center pivot system, under existing environmental condition by generating data using double row of catch can. Additionally the study includes determination of the uniformity indicator and develops water loss estimation equation, using meteorological and system operating factor affecting the applied water during different irrigation time of the day.

1.7 Thesis Organization

This thesis is consists of five chapters. Chapter 1 detail with introduction and followed by a literature review in Chapter 2 of the historical development of irrigation in world, Africa, Ethiopia and Dodota expansion sprinkler irrigation farm, performance indicators of center pivots irrigation and factors affecting them. Chapter 3 provides a description of study area; experimental design and arrangement conducted for measuring different performance indicators and collect basic data for evaluation of the performance of systems, to meet objectives and indicators commonly used for performance evaluation of center pivots irrigation system. Chapter 4 results and discusses the irrigation performance indicators and identification of factors affecting the performance the center pivots irrigation system.

Finally, Chapter 5 This chapter discusses the key issues in the method studied and draws conclusions and recommendations for improving the performance the center pivots irrigation system.

2 LITERATURE REVIEW

2.1 Irrigation Methods

Irrigation is an application of water to soil for growth of plant. Irrigation with drainage system provide moist and aerated soil ideal for plant roots. The four basic methods of irrigation are: surface or gravity irrigation, sub-surface irrigation, trickle irrigation (also, called drip irrigation) and sprinkler irrigation (Mustafa, 2004; Scherer, 1998).

Surface irrigation can be defined as the application of water on the ground at the ground level and the water flows by gravity over the surface of the field. Surface irrigation can be conveniently divided into three classes, namely, furrows, borders and check basins irrigation (Siddig and Mohammed, 1997).Improper designed surface irrigation results in inefficient and non-uniform application of water (Singh, 2018). A sprinkler system may be well designed for the crop and field, but if it is not efficiently operated the result will be disappointing. A correctly designed sprinkler system will supply adequate water during periods of maximum water demand by the crop. Poorly designed and managed pressurized irrigation systems results non-uniform water distribution (Kacar and Direk, 2010). The center pivot irrigation is one of the modern irrigation method that has capable to improve climate, increase productivity and decrease operation costs of irrigation by reduce usable power(Mohamed,2010).

2.2 Irrigation Performance Indicators

Improvement of irrigation method requires the considerations of the factors influencing the hydraulic process, the water infiltration and uniformity of water application to the entire field. Different indices have been developed that are used for evaluating the performances of Individual irrigation systems. The most commonly used performance parameters to measure the Center pivot irrigation system performance are: precipitation rate and application efficiency, distribution uniformity and uniformity coefficient (Merriam *et al.*, 1983 and Burt *et al.,* 1997).The two most common methods of expressing uniformity are the Coefficient of Uniformity (CU) and Distribution Uniformity (DU) (Mostafa and Alsayim, 2015).

Distribution Uniformity (DU) compares the lowest quarter of the water depth caught to the entire set of data from the catch cans. DU is useful as an indicator of the magnitude of the distribution problems. DU was calculated by dividing the weighted average of the lowest quarter of samples by the average of all samples (Akhabar, 2017). Distribution and coefficient of uniformity are a measure of non-uniformity of water application for a given sprinkler head, nozzle type, operating pressure, and sprinkler spacing combination. This method sort all data points in the overlap area and ranks them from low to high with the mean value for lowest (25) percent (low quarter) divided by the mean value for the entire area (Mustafa ,2004). Wilson and Zoldoske, (2001) stated that the disadvantage of the DU coefficient is that it treats under watering as the critical element but does not indicate how big or severe the dry spot really is. The value of DU was sub-divided into five groups based on the value for center pivot sprinkler irrigation (Bloomer 2006).

Coefficient of uniformity (CU) is a measurable index of the degree of uniformity obtainable for any size sprinkler under given condition (Akhabar, 2017). Irrigation uniformity is how evenly water is distributed to different areas of the Field. Irrigation uniformity actually refers to the variation, or non-uniformity in the amounts of water applied to locations within the irrigated area. For a center pivot irrigation system, the easiest and most widely used method/formula is the Christiansen Uniformity coefficient. A second method/formula specifically for center pivots is the Heerman and Hein Uniformity coefficient. It is the method recommended by the American Society of Agricultural and Biological Engineers (ANSI/ASAE S436.1) (Harrison and Perry, 2013).

The Heerman and Hein uniformity coefficient (CU_{HH},) have used for center pivot irrigation performance characterization of measured application data (Heerman and Hein, 1968). The coefficient is computed from field observations of the depths of water caught in open cans placed at regular intervals (assuming that the catch cans represent the same area). Kelley, (2004) asserts that irrigation uniformity is a concept that all areas within an irrigated field received the same amount of water. Montero *et al* (2002) stated that low values of CU are usually indicators of a faulty combination of factors such as nozzle sizes, working pressure and spacing of sprinklers. The result of CU_{HH} will be evaluated according to Harrison and Perry (2013). CU values of 80-94% is attainable for set-move systems which are properly designed and maintained, operating under moderate wind speeds less than 17.3 km/hr (Bradley et al., 2011). It has been found that CU values as low as 60% can occur with systems on undulating topography, with worn or plugged nozzles, and/or under windy conditions (King et al, 2000 Mengistie (2019) conduct study in Wonji-Shoa Sugar Estate on comparative performance evaluation of dragline and center pivots irrigation system using both internal and external indicator. The study concludes that, even if center pivots irrigation is performing better than dragline sprinkler, the wind drift affecting the study area was more significant in-field water application uniformity during irrigation events irrigation system directly influenced productivity per unit land or unit water and main potential factor for decline of yield per hectares and non-uniformity.

2.3 Hydraulics of Center Pivot Irrigation

Center pivot system consists of sprinkler lateral which rotates around a fixed pivot point. Each tower is supported on two rubber-tired wheels powered by electric or hydraulic motors. The rotation speed is controlled by varying the average travel speed of the end tower for machines with electric motors drivers, this is done by cycling the power on and off using a percentage timer mounted at the pivot point (Mekonnen, 2017; El-badawi, 2001 and Scheres, 1998).

Centre pivot systems are either electric, water, or oil-drive and can handle slopes up to 15 percent. Sprinkler packages are available for low to high operating pressures (55 to 80 psi) at pivot point. Sprinkler can be mounted on top of the spans or on drop-tubes, which put them closer to the crop.

Manufacturers have recently improved center pivot drive mechanisms (motors, gears and shafts), control devices, optional mainline pipe sizes and outlet spacing, span lengths, and structural strength.

Operating an irrigation system differently than assumed in the design will alter the application rate, uniformity of coverage, and subsequently the application uniformity. Operating with excessive pressure results in smaller droplets, greater potential for drift, and accelerating wear of the sprinkler nozzles. Pump wear tends to reduce operating pressure and flow. With continued use, nozzle wear results in an increase in nozzle opening, which will increase the discharge rate, while decreasing the wetted diameter. Clogging of nozzles or crystallization of main lines can result in increased pump pressure but reduce operating pressure. An operating pressure below design pressure greatly reduces the coverage diameter and application uniformity (Evan et al., 1996).

The center pivots very adaptable water application systems have experienced tremendous growth around the world in recent years due to: their potential for highly efficient and uniform water application; high degree of automation requiring less labor than most other irrigation methods; large areal coverage; and their ability to economically apply water and water soluble nutrients over a wide range of soil, crop and topographic conditions (AL-Ghobari, 2014). Center Pivots are replacing surface and other sprinkler irrigation systems due to the ability to program them, coverage of a large area, reliability, high application uniformity, and the ability to operate these systems on relatively rough topography. Center pivot systems generally entail a larger upfront investment but require less labor to operate and have a lower water application cost than a solid set system (El-Marazky, 2018; Ortiz *et al.*, 2010). However, as its initial cost is high, prone to wind effects on uniformity of water distribution, can cause crop damage where saline irrigation water is applied (Mekonen, 2017; Keller, 1990). The center pivot systems were technically evaluated by determining uniformity coefficient, distribution uniformity (pattern efficiency) water loss, application efficiency, irrigation efficiency and percentage of loss in the cultivable area.

2.4 Methods for Evaluation of Center Pivot Irrigation System Performance

The most common procedure for evaluating the uniformity of center pivot system is to measure the application depth. Two commonly accepted standards or methods are available as guidelines for performing evaluations of Irrigation System Uniformity (Heermann, 1998; Harrison and Perry, 2013, Kelly, 2007).

1. ASAE Standards (436.1) and
2. Natural Resource and Conservation Service (NRCS) Handbook.

The ASAE S346.1, (1999) and National Engineering Handbook (1983) are the commonly used standard by United States and internationally for the evaluation of center pivot system (El-marazky, 2018; Al-ghobari, 2014; Abedinpour, 2017, Akhabar, 2017). The ASAE standard recommends double row of catch can with the outer row not more than 50m and NRCS recommends only single row of catch can.

Simulation model and catch can data

The evaluation requirement of the current standard provides a single estimate of the CU at the time of the test and documenting the test and climatic condition of the system to make comparison between the tests. The other alternative of the evaluation procedure is computer simulation presented by Herman and Hein (1968), user friendly simulation program Center pivot Evaluation and Design (CPED), currently used by NRCS for center pivot evaluation. The advantage of simulation over field test is the large design option and operating condition, when compared with limited time and resource. But simulation model have many disadvantages, such as: difficult to obtain pump curve, elevation data, require intensive labor, need to know draw down of water level. In addition to simulating center pivot system and analyzing its uniformity, catch can data be entered to analysis, and will be saved for the future comparison. Catch Can data Provide visual real field data, simple to install, readily used by system owners and do not need computer and processed by simple software (Herman and Stanford, 1998).

In general the catch can data is the most accurate test for the evaluation of uniformity of water distribution (Akhabar, 2017; Dudek and Fernandez, 2005; Kelly, 2007)

2.5 Factors Affecting Center Pivot System Performance

The distribution uniformity of center pivot system depends both on the system characteristics and on managerial decisions (Pereira *et al.,* 2002). It is also influenced by the strength and direction of the wind (Mekonnen, 2017; Burt *et al*., 1997; Heermann, 1998). The uniformity of water application could be influenced by many factors, some of the main ones being improper sprinkler nozzles and spacing, wear of sprinklers and pipes, variation in pressure distribution along the lateral as well as climatic parameters, such as wind speed and air temperature (El-Marazky, 2018; Al-Ghobari, 2014). Theoretically, continuous move systems provide greater irrigation uniformity. However, other factors influence uniformity, including travel speed (and thus, the amount of water applied), system design, type of water applicator, and operator management, in combination with the amount of water (gallons per minute or GPM) the machine nozzles to deliver. The age of the system have effect on uniformity, the new system have high distribution uniformity (El-marazky, 2018; Mulu and Alamirew, 2012). Water leakage due to old system from the system is affecting the performance of the sprayers and the distribution of the water pressure at the sprayer's outlets (Abedinpour, 2017).

Operating pressure below design pressure greatly reduces the coverage diameter and application uniformity. Pump wear tends to reduce operating pressure and flow. With continued use, nozzle wear results in an increase in nozzle opening, which will increase the discharge rate, while decreasing the wetted diameter clogging of nozzles or crystallization of main lines can result in increased pump pressure but reduce operating pressure (Mustafa, 2004; Evan *et al.*, 1996). Also the ground speed of the system affects the applied depth. Center pivots apply water at different working speed; hence the performance is affected by it (Msibi *et al.*, 2014; Abedinpour, 2017). But the travel speed affects the applied water, causes losses of water.

Evaluation is done to determine how much water reached the crop, how uniformly it is distributed, and how much is lost during the application process. The end result is water savings that are achieving the efficient and effective application of water. An ideal irrigation system should apply the right amount of water, minimize the losses, and apply the water uniformly (Mengistie, 2019). El-Marazky (2018) predicts water loss due to evaporation, wind drift and leakage with combined effect of climatic and operating factor that, wind speed, air temperature, travel speed and relative humidity are the predominant factors affecting the applied water from center pivot systems hence on uniformity of water application. It is not possible to apply the exact amount of irrigation water required with perfect uniformity because of variations in soil properties, variations in irrigation system components, pressure losses in systems due to friction and elevation changes, or other causes (Smajstrla et al., 2002). Evaporation, wind drift, and deep percolation are chief causes of water loss (Hill et al., 2008).

Water losses occur in four areas: air loss**,** foliage loss, ground loss and deep percolation. The two components of air water loss are drift and droplet evaporation. Droplet Evaporation is the water from droplets that evaporates while in flight before reaching the crop Canopy or the soil surface (Rogers *et al*., 2017). The amount of evaporation losses from sprinklers are dependent upon both climatic demand, time available for evaporation to occur, surface area of water droplet and operating conditions (Mengistu, 2019; Baha, 2002). Wind increases evaporation rates by transporting water vapor away from the evaporating surface.

Drift is the water droplets that move off the field or onto a non-targeted area of the field, usually by wind (Rogers *et al*., 2017). In sprinkler irrigation the climatic factors which causes wind drift loss are wind speed and direction. As wind speeds increase and as droplet sizes decrease; wind drift loss increases. At higher wind speeds, larger droplets can be transported by the wind, and droplets can be transported greater distances (Smajstrla and Zazueta, 2003). This losses are reduced by not be operating when wind speed high. In this system, the water distribution pattern is strongly affected by wind speed and distribution. Consequently, some areas of the field may not receive an adequate amount of irrigation water and makes spot (Dechmi, 2002).

In general, both wind drift and evaporation losses are due to system (center pivot) malfunctioning and environmental (weather impact) condition that was investigated under the present study.

Foliage loss is occur when water entering the canopy of the crop, lost to plant interception or to evaporation. Ground loss occurs after water enters the soil. Deep percolation loss is when excess water enters beyond the storage capacity of the soil (Rogers *et al*., 2017).

In the present study the general objective were focused on the estimation of air losses during the irrigation considering different weather and system operating factor at different evaluation time to be quantified.

3. MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

This study was carried out at Wonji-Shoa Sugar Estate on Dodota farm. The site is located at Central Rift Valley of Ethiopia and lies downstream of Koka Dam, 110 km southeast of Addis Ababa and 18 km south of Adama town. It is situated in the Awash Basin at an elevation of 1555 meters above mean sea level at $8^{0}21'$N to $8^{0}28'$N latitude and $39^{0}11'$E to $39^{0}19'$E longitude.

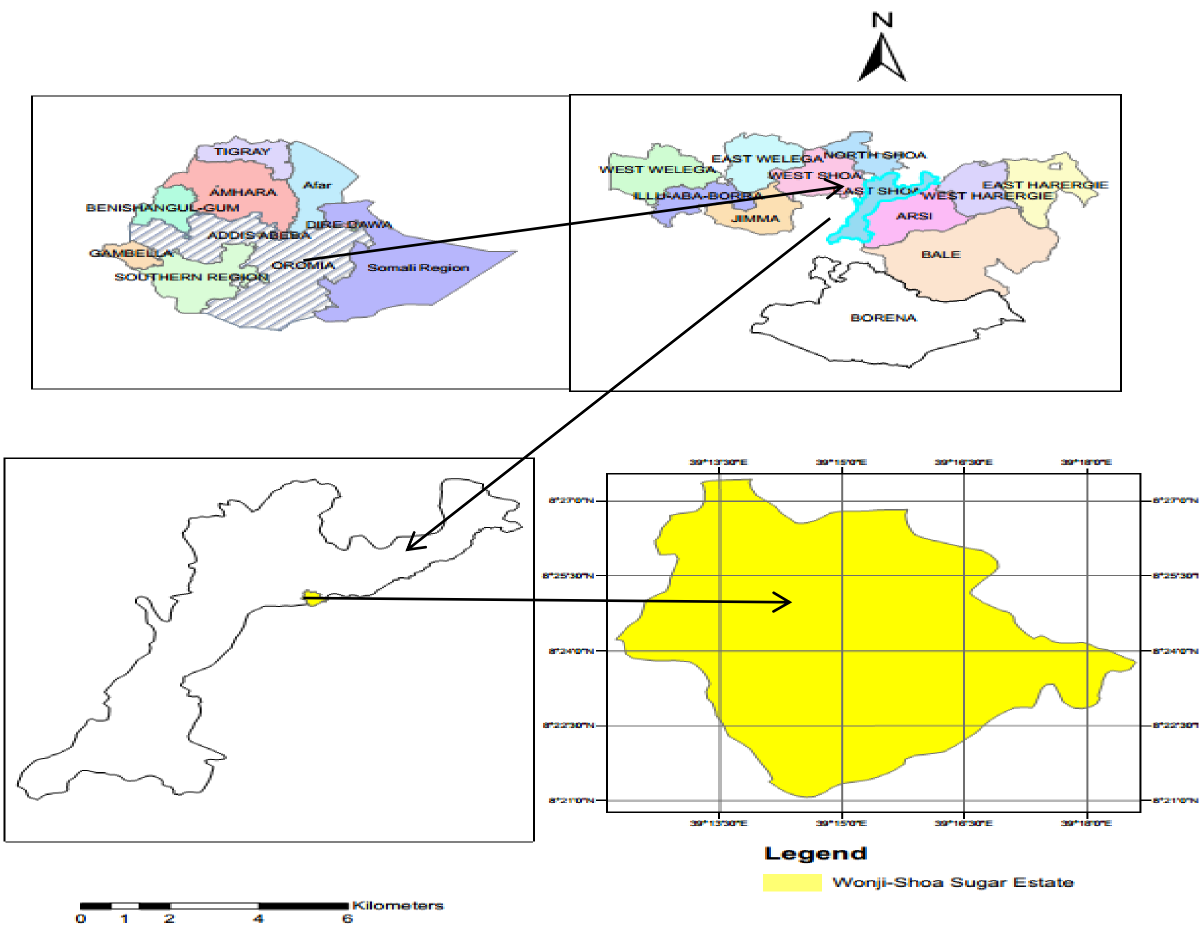

Figure 3.1 Location Map of the Study Area

3.1.2 Climate

The area experiences a bimodal rainfall distribution pattern, receiving the Kremt rains during July to September and Belg rains during March to June. The long-term wind speed, relative humidity, reference evapotranspiration and sunshine hours are reported as 2.6 m/s, 53.3%, 6.4 mm/day and 8.3 hours/day, respectively.

Table 3.1 Location and weather data of the study area

No.	Description	Value
1	Latitude/longitude	8.12^0 to 8.53^0, 39.03^0 to 39.05^0
2	Average relative humidity	54.5
3	Average Max and Min Temperature	33.4 ^{0}C and 17.6^{0}C
4	Average Rain fall	849.6 mm
5	Altitude	1555 m a.s.l

(Source: Awash Melkasa Meteorology station)

3.1.3 Topography

The main irrigated land lies south west of Awash River, which is found at about 500 meters in the north-western side of the Wonji-Shoa Sugar Factory. It has very flat slopes ranging from 0.05% to 0.1% on south and south east direction. In other words the maximum vertical drop in topography from north to south is about 6m within a horizontal distance of some 12 km. The surrounding topography is steep on all sides toward the plantation area.

3.1.4 Irrigation practice

Two types of sugarcane of Plant cane fields and Ratoon fields groups with 22 and 12 months age respectively were there. The state owned sugar cane estate is 5905.15 ha and located on the right bank of the Awash River approximately 16.2km downstream of Koka Dam. The irrigation water application system for Weketio is dragline sprinkler of 604 that have a net 587ha and for Dodota dragline around1890 that have a net 1841ha and center pivot on 652ha that have a net 632ha cane.

3.1.5 Soil

The soils in the study area are described as loams, silty loams and clay loams formed from volcanic derived colluviums and alluvium on plains and terraces. Soils of the whole canals system is categorized as clay or fine textured constructed on very flat plain having longitudinal slope of 0.05 to 0.06%. In wonji field capacity can be assumed 2-4 days after water giving the soil reaches (reaches at -0.3bar). Permanent wilting point (PWP): is the point where the plant starts wilting (reaches at 15bar).

3.2 Description of the Center Pivot

The center pivot found at Wonji-Shoa is Electrical driven system. It consists of a lateral circulating around a fixed pivot point. The systems have nine spans and the first three span with 48 m spacing and the rest of the span have 55m spacing. The total length from Last span up to the end gun last (Overhang) is 17 m. The lateral is supported above the field by a series of A-frame towers, each having two driven wheels at the base. Tower structure provides extra stability for moving across uneven terrain. All towers are moved by the two electrical driven wheels. It consists of a beam on which a drive motor and two wheels are mounted. At the top of each tower there is an electrical box through which the electric power is transferred to the drive motor. The wheels are operated by the drive motor via connecting rod (shaft) and a gearbox between the two wheels. All machines have nine towers each of which move by two pair of wheel, 488.6m pipe/lateral length, R3000B type sprinkler nozzle, and last tower ground speed of 3.10m/min at 100% timer setting. The outermost tower speed is the greatest, and each succeeding tower moves continuously at proportionally reduced speeds. Computerized control panel allows the operator to specify speed changes at any place in the field, reverse the pivot turns on auxiliary pumps at specified time and many other features. This makes the pivot operation very complex and modern. There is automatic control station that controls amount of water delivered according to the design and crop scheduling. The system controls the delivery of water to the 12 pump station according to water delivery required. It also controls the pressure and head needed.

3.3 Data Collection

3.3.1 Sample size and sampling techniques

At Dodota site, all center pivots are equipped with R3000B rotator type sprinkler mounted on the lateral. There are totally nine center pivots at this study area. From all one pivot not functional due to technical problem, the rest irrigating 75.4 ha each with total of 603.2 ha. The pivot under operation was selected depending on the similarities and differences of their manufacturer design or design document and their suitability during data collection from all operational pivots. Purposive sampling technique was used. From those eight machines, four were selected, which were comfortable for conducting the test according to ASAE 436.1 experimental standard. The Sample used for the present study included almost machine of all sizes. Also the Height between lateral and sugarcane was considered for ease of catch can data collection to minimize canopy losses. In general, the samplings have been made as per the ASAE 436.1 standard, such that the experiment was conducted immediately after harvesting and when the crop is at early stage of growth.

3.3.2 Data sources and method of data collection

Data sources for the present study were primary and secondary data. The primary data is the water application depth which was collected using catch can and center pivot system parameter was collected from Wonji-Shoa Sugar Estate (WSSE). The secondary data are collected daily weather parameter of wind speed; air temperature and relative humidity were collected from Awash Melkasa meteorological station.

3.3.3 Experimental design and arrangement

The average applied depth caught by catch can was collected at morning (9:00 am-09:30am), mid-day (12:00 am-12:30am) and late afternoon (6:00pm-06:30pm) irrigation for each selected pivot. Field tests were carried out on both bare soil (immediately after harvesting) and early staged crop growth. Double row of radially placed catch can with spacing 5m were placed along the lateral. According to Harrison and Perry (2013) placing the first gauge about 150 to 200 feet from the pivot point were recommended. It is not necessary to place gauges any closer to the pivot point than this because the uniformity under the first tower is usually not good, and the area represented is small. So**,** the first catch can was placed 50m away from the pivot.

Simultaneously, volume of water applied by the system was recorded from pivot flow rate gauge during the evaluation and time it takes to apply this known volume is recorded from center pivot control panel using hour time installed on the control panel. The system is gauged and operating pressure was recorded from pressure gauge attached to lateral. This pressure gauge read as the atmospheric pressure (in Bar) or the operating pressure of the machine in pound per second inch (psi). Timer of the machine is also recorded from the control panel by reading. The effective length of the machine was also determined by measuring the radius of throw terminal emitter at outlet and distance of the terminal emitter from the pivot in meter (m). Ground speed of last tower is measured using stopwatch and two woods of 10m distance far apart from each other by recording time taken to complete this known distance. Type of nozzle, diameter of nozzle number of towers, types of the machine and the designed performance of the system were collected from the design document.

Evaporation from the four control collector (catch can) installed to know the amount of water evaporated or lost before the data is recorded at each time taken experiment from the double row of catch can during the evaluation by filling water of known volume at the start and end time of the field evaluation, and finally the volume of water evaporated are measured by subtracting the initial and final volume of water in the control collector (ASAE 436.1).

Radially placed double row of Plastic Catch Can with spacing between the rows less than 50 m, in which the spacing is varied from pivot to the outer edge (the maximum spacing used in these were 12m which were at outer edge) and catch can 5 m were used. Identical 180 catch can with diameter of 6 cm and height 12 cm of a light color to reflect solar radiation and minimize evaporation were used. The first catch can was placed 50m away from pivot point or in front of the first tower. By passing the system perpendicular over radially placed catch can at 30^o, the volume of water collected for each catch can placed with known distance from the center of pivot.

The Catch Can locations were depends on the height of sugarcane to avoid canopy hindrance to collect water when the pivot passes over the catch can as shown in figure 3.2 below. Field tests were carried out on either bare soil or soil with early staged crop growth. When the pivot is started, no water is entering the cups until the system is at full pressure and speed. Volume of water collected by catch can is measured immediately after the pivot is passed over the collector using graduated cylinder to minimize evaporation losses. The data have been collected during morning, mid-day and late afternoon time of irrigation for the selected pivot following the experimental standard.

Figure 3.2 Catch can alignment during test

3.4 Parameters Measured for Center Pivot Sprinkler Irrigation Evaluation

3.4.1 Pressure measurement

Pressure at the inlet of pivot was measured by a standard pressure gage, installed on the Lateral.

3.4.2 Pivot speed

Average pivot speed plays a significant role in calculating time of revolution, the evaluation undertaken by measuring the distance the last pivot tower traveled and the time it took to travel that distance. In this study the pivot speed were measured by the time taken to complete 10m distance of two wooden installed in side using stopwatch.

3.4.3 Hour time and operating speed (percentage timer)

Hour times were recorded from the control panel at the start and end of the field evaluation. Flow rate were recorded during the field evaluation at the start and end from flow meter installed on the machine.

Since the system is gauged, reading of percentage timer of the machine was taken from control panel during the evaluation.

3.4.4 Water application depth caught by catch can

The application depth was determined by measuring water caught using double row of catch can installed radially with spacing of 5m along the lateral. The average depth of water caught by catch can (Dw) is composite depth of both rows according to the ASAE standard 436.1, which is given by:

$$Dw=\frac{\sum_{i=1}^{n}|di*Si|}{\sum_{i=1}^{n}|Si|} \quad 3.1$$

Where Dw is weighted average depth of water caught by catch can, n is the number of catch can used during the evaluation, di is the collected depth of water in the i^{th} catch can and Si is distance from pivot point to i^{th} collector.

3.4.5 Hours per pivot revolution

The actual time of revolution for the CP lateral was estimated from the speed of last tower and distance to the last tower from pivot point using relation given by Mekonnen (2017) and Almasraf *et al*., (2011) which is expressed as:

$$Tr = \frac{0.105*Lt}{Vt} \quad 3.2$$

Where, Tr is time of revolution (hrs.), Vt is last tower ground speed (m/min) and Lt is distance to last tower (m).

3.4.6 Estimation of volume of water

The water meter reading was used to measure the flow rate into the system. Calculation of the volume of water applied into the CP irrigation system was done by multiply the reading of the flow rate (m^3/s) by the time required to complete one full revolution by CP lateral line expressed as:

$$V = Q * Tr \qquad 3.3$$

Where, Q is flow rate recorded from Pivot rate gauge (m^3/hr), Tr is time it takes for center pivot to complete full revolution (hr),

3.4.7 Applied depth by the system

It is depth of water applied from the system for irrigation, as per crop water requirement in (mm).

$$Dg = \frac{V}{A} * 1000 \qquad 3.4$$

Where: V is actual volume of water applied by the system during the operation (in m^3), A is irrigated area (in m^2) and 1000 is conversion factor to change meters to millimeter

3.5 Estimation of Different Performance Parameters

3.5.1 Coefficient of uniformity

The coefficient of uniformity (CU), proposed by Christiansen (1942) and modified by Heerman and Hein (1968), is the most popular uniformity coefficient used with center pivot catch-can data to include a term representing the distance from the center to the catch-can . It is the method recommended by the American Society of Agricultural and Biological Engineers (ASAE S436.1) to evaluate the uniformity of water application as follows:

$$CuHH = 100 * [1 - \frac{\sum_{i=1}^{n} |Vi - Vp| * Si}{\sum_{i=1}^{m} |Vi * Si|}] \qquad 3.5$$

Where: Cu_{HH}= Heerman -Hein uniformity coefficient (%)

Si = distance from pivot point to i^{th} collector.

Vi = the collected volume of water in the i^{th} catch can

n= the number of catch can used during the evaluation and

Vp =the weighted average of of the volume of water caught.

$$Vp = \frac{\sum_{i=1}^{n} |Vi * Si|}{\sum_{i=1}^{n} |Si|} \qquad 3.6$$

The result of CUHH were interpreted according to (Harrison and Perry, 2013)

Table 3.2 Basic interpretation of uniformity coefficients

Value of CUHH	Performance class	Description
90 to 100	Excellent	No changes required
85 to 90	Good	No changes required unless problem area is obvious
80 to 85	Fair	No improvements needed but system should be monitored closely
Below 80	Poor	Improvement needed, particularly if chemicals are to be injected.

3.5.2 Distribution uniformity

DU compares the lowest quarter of the water depth caught to the entire set of data from the catch cans and is useful as an indicator of the magnitude of the distribution problems.

According Burt *et al*., (1997), DU is calculated by dividing the weighted average of the lowest 25% of the catch cans by the weighted average of the entire catch cans.

$$\mathrm{Du} = \frac{\mathrm{dw}}{\mathrm{Dw}} * 100 \qquad 3.7$$

Where: DU= low quarter distribution uniformity, %; dw= Weighted low-quarter depth caught in all cans (mm); Dw = Weighted average depth of water accumulated in all cans (mm).

The result was interpreted according to (Bloomer, 2006).

Table 3.3 Basic interpretation of distribution uniformity

Result	Perfect	Excellent	Good	Fair	Poor
DU	100	99-92	89-85	84-75	<74

3.6 Water Losses during Irrigation

3.6.1 Observed water loss

Water loss from the system was calculated by subtracting the average depth of water reaching the ground as determined in catch cans from the average depth of application as monitored by the system flow meter. It is the actual amount of water lost under existing field condition.

The actual amount of water lost by evaporation, wind drift and leakage due to environmental condition and system malfunctioning during the irrigation from Center Pivot system that were evaluated in the field, for each system is determined by the following equation (Almasraf *et al*., 2011; El-Marazky, 2018; Mustafa, 2004; Faci *et al*., 2001):

$$\mathrm{WL}(\%) = \frac{\mathrm{Dg} - \mathrm{Dw}}{\mathrm{Dg}} * 100 \qquad 3.8$$

Where, Wl is observed water losses (%), Dg is average depth of water applied by the system (mm), Dw is average weighted depth caught by catch can (mm).

The observed water loss was calculated using the above equations under different irrigation time of the day during morning, mid-day and late afternoon.

3.6.2 Estimated water losses using regression technique

Water losses during water application due to evaporation and wind drift as a function of environmental condition and system parameter were related and estimated by regression analysis.

The calculated water loss using equation 3.8 were input for the model as the dependent variable and selected predictors parameter of Wind Speed (m/s), Temperature (^{0}c), Relative Humidity (%), System Flow Rate (m^3/ hr) and Travel Speed (m/min) as input variable recorded and measured simultaneously at different test time, during morning, mid-day and late afternoon. To determine this relationship, a multiple linear regression analysis was performed to get the equation for all the different controlling variables. The criteria of a better fit were:

1. The square of the multiple correlation coefficients (R^2) should be higher and
2. The standard error of regression (s) should be smaller.

Using the above criteria, the highly influential factor in the study area that affect the applied water was selected. The empirical model that was developed to predict water losses under different irrigation time of the day due to evaporation, wind drift and leakage with the combined effect of the selected metrological and system operating parameter, by calibrating regression coefficient for all controlling variables were developed:

R^2 reflects the degree of fit for the regression model. The values of R^2 range from 0 to 1. The closer the R^2 value is to 1, the better the model fits to the actual data. Finally, the best empirical model was developed depending on the above the criteria.

The Statistical model of multiple linear regression models was performed using Software Package for Social Science (SPSS) in different methods of screening best predictor variable as it is discussed in the following:

Stepwise Regression Method

Stepwise regression is a combination of the forward and backward selection techniques. Stepwise regression is a modification of the forward selection so that after each step in which a variable was added, all candidate variables in the model are checked to see if their significance has been reduced below the specified criterion (Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100 were selected as criterion). If a non-significant variable is found, it is removed from the model. Stepwise regression requires two significance levels: one for adding variables and one for removing variables. The cutoff probability for adding variables should be less than the cutoff probability for removing variables so that the procedure does not get into an infinite loop.

Backward Regression Method

This procedure is the removal phase of the stepwise procedure and can be used only after at least one independent variable has been entered in the model. Probability of F-to-remove >= .100 were selected as criterion. The backward selection model starts with all candidate variables in the model. At each step, the variable that is the least significant is removed. This process continues until no non-significant variables remain.

Forward Regression Method

This procedure is the entry phase of the stepwise procedure. Probability-of-F-to-enter <= .050 were selected as criterion. This method is often used to provide an initial screening of the candidate variables when a large group of variables exists. It is the best method by applying the entire possible algorithm for selecting the candidate variable. The method begins with no candidate variables in the model. The variable with the highest R^2 was selected first. At each step, the candidate variable that increases R^2 the most was selected. The method stops adding variables when none of the remaining variables are significant. Note that once a variable enters the model, it cannot be deleted.

4 RESULTS AND DISCUSSIONS

4.1 Center Pivot Sprinkler Irrigation System Performance Parameters

4.1.1 Center pivot speed and hours per pivot revolution

The estimated values of speed and time of revolution are given in Table 4.1. The speed for different locations varied from 1.087 m /min for CP1 to 1.341 m/min for CP4. The actual values of time of revolution were higher as compared to the design values for CP2 and CP4. The deviation varied from -0.5% for CP5 to 5% for CP2 which shows there is small variation of time of revolution for CP1 and CP5. The variation of the time of revolution between the actual and the design is due to the fact that the speeds of the last tower ground speed have great effect on time of revolution, Hence result in poor performance of the system (El-marazky, 2018).

Table 4.1 Actual and design values of time of revolution (Tr)

Center Pivot	Length of lateral (m)	Timer (%)	Actual Speed (m/min)	Design Speed (m/min)	Tr. Actual (hr.)	Tr. design (hr.)	Tr. deviation (%)
CP1	488	35	1.087	1.08	45.49	45.54	-1
CP2	488	45	1.33	1.39	37.2	35.42	5
CP4	488	45	1.341	1.39	36.85	35.42	4
CP5	488	35	1.093	1.08	45.3	45.54	-0.5

4.1.2 Estimation of volume of water

The calculated values of the amount of water pumped to the system for all test machines given in Table 4.2. The actual volume of water pumped to the system was lower for all except CP4 machines as compared to the design values. This result happen due to the fact that time of revolution and actual flow rate for CP machines, which is due to conveyance losses, leakage and other factor in the delivery pipe from the source to point of delivery.

Table 4.2 Volume of water pumped to the system

Center pivot	Design flow rate (m^3/hr.)	Actual flow rate (m^3/hr.)	Design Tr. (Hr.)	Actual Tr. (Hr.)	Design Volume system (m^3)	Actual Volume system (m^3)
CP1	235	225	45.54	45.49	10702	10235.25
CP2	235	223	35.42	37.2	8324	8295.6
CP4	235	226	35.42	36.85	8324	8328.1
CP5	235	228	45.54	45.3	10702	10328.4

4.1.3 Operating pressure

The actually recorded and design values of operating pressure for different locations is given in Table 4.3. The actual operating pressure was higher than the design values for all test center pivots machine. It is 29%, 47%, 45% and 38% for CP1, CP2, CP4 and CP5, respectively. The higher pressure needed in CP1, is due to the system is very far from the source as well as some difficult topography when compared to the other machine. Operating the system without recommended pressure range may result in unacceptable breakup of the nozzle spray pattern and poor irrigation uniformity.

Table 4.3 Actual and design pivot pressure

Center pivot	Actual Pivot Pressure (Bar)	Design Pivot Pressure (Bar)	Pressure Deviation (%)
CP1	4	3.1	29
CP2	5	3.4	47
CP4	4.8	3.3	45
CP5	5	3.6	38

4.1.4 Water distribution uniformity indicator

The uniformity is presented in table 4.4, 4.5 and 4.6. Since the test is conducted in the double row, the value is presented for each row such that line 1, line 2 and the average/ the composite of the two lines. The interpretations of the performance indicator below were according to table 2.1 and 2.2 presented in the previous section.

Table 4.4 Water distribution uniformity indicators for center pivot machines during morning

			CU (%)	Rate	DU (%)	Rate
CP	Wind Speed (m/s)	LINE				
CP1	1.76	1	79	Poor	60	Poor
CP1	1.76	2	77	Poor	60	Poor
CP1	1.76	AVERAGE	78	Poor	60	Poor
CP2	1.5	1	75	Poor	66	Poor
CP2	1.5	2	75	Poor	70	Poor
CP2	1.5	AVERAGE	75	Poor	68	Poor
CP4	1.85	1	75	Poor	60	Poor
CP4	1.85	2	73	Poor	58	Poor
CP4	1.85	AVERAGE	74	Poor	59	Poor
CP5	1.65	1	80	Fair	65	Poor
CP5	1.65	2	80	Fair	61	Poor
CP5	1.65	AVERAGE	80	Fair	63	Poor

The average results of the coefficient of uniformity (CU_{HH}) and distribution uniformity (DU) for all center pivots for ranges from 74% to 80% and 59% to 68%, respectively. Good CU_{HH} were achieved for CP5 and distribution uniformity was poor for all center pivots during the morning (Harrison and Perry, 2013). The average values of DU during morning were 63% and CU_{HH} were 77%. The value shows it is poor performance level.

According to Bloomer (2006) value of the DU of all center pivots were below 74% which is poor range and that needs more monitoring the system and takes corrective action on time to improve DU value.

Table 4.5 Water distribution uniformity indicators for center pivot machines during midday

			CU (%)	Rate	DU (%)	Rate
CP	Wind Speed (m/s)	LINE				
CP1	2.2	1	68	Poor	57	Poor
CP1	2.2	2	69	Poor	56	Poor
CP1	2.2	AVERAGE	68	Poor	56	Poor
CP2	1.66	1	70	Poor	65	Poor
CP2	1.66	2	69	Poor	62	Poor
CP2	1.66	AVERAGE	69	Poor	64	Poor
CP4	3.33	1	61	Poor	58	Poor
CP4	3.33	2	59	Poor	62	Poor
CP4	3.33	AVERAGE	60	Poor	60	Poor
CP5	1.81	1	68	Poor	62	Poor
CP5	1.81	2	67	Poor	58	Poor
CP5	1.81	AVERAGE	67	Poor	60	Poor

The average values of DU and CC_{HH} during midday were 60% and 66% respectively. The values of performance indicators during midday time shows uniformity of water distribution were at poor performance level (Bloomer, 2006 and Harrison and Perry, 2013). The result shows both environmental and system operating factor has the significant effect on the uniformity under the midday evaluation because of due to dry air in these evaluation time. Mekonnen (2017) also concluded the low value of uniformity of water distribution during the midday time evaluation were due to high wind velocity when compared to the night time evaluation.

Table 4.6 Water distribution uniformity indicators for center pivot machines during late afternoon

			CU (%)	Rate	DU (%)	Rate
CP	Wind Speed (m/s)	LINE				
CP1	1.48	1	79	Poor	62	Poor
CP1	1.48	2	78	Poor	65	Poor
CP1	1.48	AVERAGE	78	Poor	64	Poor
CP2	1.03	1	82	Fair	70	Poor
CP2	1.03	2	80	Fair	69	Poor
CP2	1.03	AVERAGE	81	Fair	70	Poor
CP4	1.63	1	76	Poor	61	Poor
CP4	1.63	2	77	Poor	61	Poor
CP4	1.63	AVERAGE	76	Poor	61	Poor
CP5	1.29	1	82	Fair	66	Poor
CP5	1.29	2	84	Fair	65	Poor
CP5	1.29	AVERAGE	83	Fair	66	Poor

The average values of DU and CU_{HH} during late afternoon were 65% and 80%, respectively. The average result of CU_{HH} shows fair performance ranges and was due to low weather demand during the test times. Distribution uniformity for all center pivots during late afternoon test times were poor and the values shows improvement were needed (Bloomer, 2006).

The highest CU_{HH} were 83% which is obtained during late afternoon for CP systems No.5 and lowest values of CU_{HH} 60% were obtained during midday at CP 4. The highest value of DU of 70% was at late afternoon measurement for CP2 due to lower wind velocity during the test times and lowest value was for CP1 which is 56%.

The average values of CU_{HH} and DU, during morning, midday and late afternoon were, 77% and 63%, 66% and 60%, 80% and 65%, respectively. Coefficient of uniformity (CU_{HH}) and distribution uniformity (DU) for all center pivots were 60% to 83% and 56% to 70%, respectively for all test times. According to Harrison and Perry (2013) the average value of CU_{HH} during all test times was 80% which indicates it's in fair performance range and need close monitoring and daily inspection of the system for taking corrective measures to improve the uniformity. In all test time the distribution uniformity is at poor performance range.

Mengiste (2019) reported that the value of CU and DU were 82.64% and 78.25%, respectively in this study area. Depending on both study, the performance of the system is decreasing in terms of uniformity and therefore, regular checkup is needed.

For all center pivots and test times, the results of DU were not within recommended standards according to (Mekonnen, 2017; Bloomer, 2006). Almasraf *et al*., (2011) reported that water distribution uniformity coefficient decreased with increase of wind velocity. Salih (2013) attributed the low DU values (less than 74 %) to be due to center pivot speed variations and may also be attributed to some factors such as different spacing between nozzles and wind drifting. El-marazky (2018) concludes weather and system operating factor have great impact on uniformity of water distribution and performance of center pivot irrigation system.

In general, better uniformity was obtained when weather demand is low during late afternoon. Due to high temperature and wind speed and low relative humidity during midday test times, uniformity was poor in all center pivots.

4.1.5 Depth of water application

The measured values of the depth of water application in catch cans along the CP sprinkler irrigation system lateral line for all locations are given in Appendices 12 and the variation is shown in Figures 4.1 “a” to 4.3 ” d”. The average values of depth of water application along the lateral line are given in Table 4.7. The average value of depth of water application varied from 9.7 mm for CP4 to 13 mm for CP5.

Table 4.7 Average value of application depth for test CP machines

Center pivot	Evaluation Time	Average Application Depth (mm)	Design Depth (mm)
CP1	Morning	12.33	14.12
CP1	Midday	12	14.12
CP1	Late afternoon	12.65	14.12
CP2	Morning	10.6	11
CP2	Midday	10.45	11
CP2	Late afternoon	11	11
CP4	Morning	10.4	11
CP4	Midday	9.7	11
CP4	Late afternoon	10.6	11
CP5	Morning	12.6	14.12
CP5	Midday	12.42	14.12
CP5	Late afternoon	13	14.12

From the above result the applied depth during the evaluation were lower than the design value by the manufacturer. From the design document, the applied depth (CP2 and CP4) and 35 (CP5 and CP1) were 11mm and 14.12mm, respectively. Therefore center pivot of CP2 during late afternoon apply water as per the manufacturer standard, but CP4 and CP1 applied water less than the manufacture value therefore regular checkup of the nozzle package, operating pressure and the overall system operation as per the design standard should have to be checked. It was observed here that the value were lower due to the wind effect is severe during the midday in addition to other weather and system operating factor. The variation is compared to the water applied by the system and shows water lost due to system and weather factor.

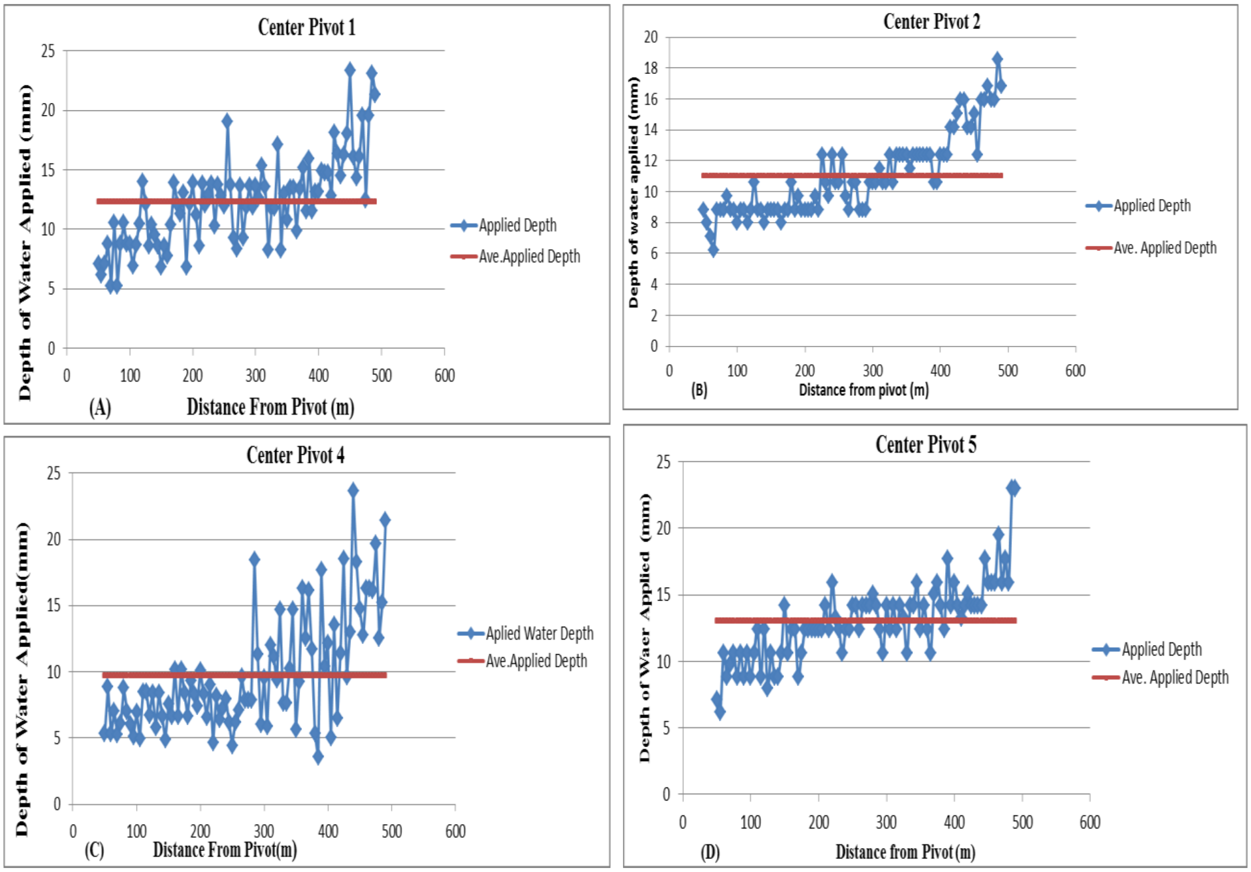

Figure 4.1 (A) CP1depth of water application during midday (B) CP2 depth of water application during late afternoon (C) CP4 depth of water application during midday (D) CP5 depth of water application during late afternoon test times.

As seen from the above figures there is a variation of water caught by the catch can as we can see from the graph. Midday water applied shows there is a large turbulence from the graph. The high peak and low values that show non uniform application in all test. But the morning and late afternoon test condition shows there is smooth increment of water from pivot to the outer edge and there is no significant variation.

In general, it is important to know proper working of the nozzle along the lateral as well as to identify inoperative working and old nozzle for the maintenance. Therefore variation can easily inspected when climate demand is varied during the evaluation time of the day throughout all test center pivot. Regular proper maintenance of the system is crucial.

4.2 Observed Water Loss

This is the amount of water losses from center pivot irrigation system calculated according to equation 3.8 and presented in Table 4.8. Higher water losses occurred in CP1 during midday time evaluation as weather demand is high when compared to other evaluation time.

Table 4.8 Observed water loss

Center Pivot (CP)	Evaluation Time	Applied water (mm)	Caught water (mm)	Water lost (%)
CP1	Morning	13.35	12.33	7.6
CP1	Midday	13.46	11.98	11
CP1	Late afternoon	13.25	12.64	4.62
CP2	Morning	10.78	10.6	1.69
CP2	Midday	10.96	10.448	4.66
CP2	Late afternoon	10.69	11.01	-2.95
CP4	Morning	10.85	10.4	4.2
CP4	Midday	10.96	9.7	11.5
CP4	Late afternoon	10.76	10.6	1.54
CP5	Morning	13.45	12.6	6.3
CP5	Midday	13.5	12.42	8
CP5	Late afternoon	13.35	13	2.66

The value of water losses ranges from -2.95% to 11.55%. The negative estimation of water losses above were due to over or under estimation of time of revolution of center pivot during test times, leakage lost on the ground before reaching catch can and other losses like head losses. Evaporation and drift loss was high during midday evaluation time when compared to the morning and late afternoon. The high water losses during Midday evaluation times were air losses are severe because of high temperature and wind speed, and low relative humidity.

4.3 Estimated Water Losses by Regression Techniques

The multiple linear regression models were developed using SPSS with backward, forward and stepwise method.

4.3.1 Stepwise method

Result of Stepwise method was reported in the table 4.9, 4.10 and 4.11 below. Finally, the best predictor variable that affects water loss was screened and the model was developed. Temperature (T), last tower Ground speed (VT), Relative humidity (RH) and Wind Speed (WS) were entered to the model sequential.

Table 4.9 Excluded variable by stepwise method

Excluded Variables [a]

Model		Beta	t-test	Significance	Partial Correlation	Collinearity Statistics
						Tolerance
1	Wind Speed	-.222[b]	-.978	.335	-.168	.121
	Relative Humidity	-.420[b]	-2.190	.036	-.356	.153
	Discharge	.178[b]	2.351	.025	.379	.964
	Last Tower Ground Speed	-.411[b]	-11.356	.000	-.892	.999
2	Wind Speed	.226[c]	2.144	.040	.354	.106
	Relative Humidity	-.220[c]	-2.515	.017	-.406	.147
	Discharge	-.046[c]	-1.077	.290	-.187	.717
3	Wind Speed	.226[d]	2.339	.026	.387	.106
	Discharge	.002[d]	.037	.971	.007	.556
4	Discharge	-.027[e]	-.612	.545	-.111	.515

a. Dependent Variable: Water Loss

b. Predictors in the Model: (Constant), Temperature

c. Predictors in the Model: (Constant), Temperature, Last Tower Ground Speed

d. Predictors in the Model: (Constant), Temperature, Last Tower Ground Speed, Relative Humidity

e. Predictors in the Model: (Constant), Temperature, Last Tower Ground Speed, Relative Humidity, Wind Speed

In this method from the output of the model developed, Discharge were not the predictor variable from the candidate variables by stepwise method.

Table 4.10 Regression coefficient of stepwise method

coefficients [a]

Model		Unstandardized Coefficients		Standardized Coefficients	t-test	Significance
		B	Std. Error	Beta		
1	(Constant)	-12.614	1.601		-7.877	.000
	Temperature	.837	.074	.888	11.246	.000
2	(Constant)	3.853	1.625		2.371	.024
	Temperature	.825	.034	.875	24.181	.000
	Last Tower Ground Speed	-13.372	1.178	-.411	-11.356	.000
3	(Constant)	12.642	3.806		3.322	.002
	Temperature	.634	.082	.673	7.716	.000
	Last Tower Ground Speed	-12.818	1.115	-.394	-11.500	.000
	Relative Humidity	-.124	.049	-.220	-2.515	.017
4	(Constant)	15.010	3.706		4.050	.000
	Temperature	.434	.115	.460	3.769	.001
	Last Tower Ground Speed	-13.729	1.114	-.422	-12.320	.000
	Relative Humidity	-.124	.046	-.220	-2.683	.012
	Wind Speed	1.676	.716	.226	2.339	.026

a. Dependent Variable: Water Loss

From the above table the regression model that predicts water loss under different evaluation times using Beta coefficients developed using the fourth model with predictor parameter by stepwise method was as follows:

$$Wl = 15 + 0.434T - 13.729VT - 0.124RH + 1.676WS \qquad 4.1$$

Table 4.11 Model summary of stepwise method

Model Summary

Model	Correlation coefficient (R)	Coefficient of determination (R^2)	Adjusted (R^2)	Std. Error of the Estimate
1	.888	.788	.782	1.9
2	.978	.957	.954	.87
3	.98	.964	.961	.81
4	.985	.969	.965	.76

From the result of the above model, the predictor parameter that predominately affects the applied water which is responsible for water loss was Air temperature, Travel speed and Relative Humidity was identified by stepwise method. In each model as the variable is entered to the model the R^2 was increased and the standard error of the estimate is decreased. The best model is the last with Coefficient of determination is 0.969 and the standard error of the estimate was 0.76. The value of R^2 shows the model have capable of predicting the water lost under system and weather parameter with small error.

4.3.2 Backward method

Backward method follows the criteria for removal from the candidate variable and the result was reported in the table 4.12, 4.13 and 4.14 below. Last Tower Ground Speed, Temperature, Relative Humidity and Wind Speed were selected as the predictors.

Table 4.12 Excluded variables by backward method

Model		Beta	t-test	Significance	Partial Correlation	Collinearity Statistics
						Tolerance
2	Discharge	-.027[b]	-.612	.545	-.111	.515

a. Dependent Variable: Water Loss

b. Predictors in the Model: (Constant), Last Tower Ground Speed, Temperature, Relative Humidity, Wind Speed

According to this method discharge does not satisfies the required criterion and it is not a factor that affect the applied water. Therefore it was removed from the second model.

Table 4.13 Regression coefficient of backward method

Coefficients [a]

Model		Unstandardized Coefficients		Standardized Coefficients		
		Beta	Std. Error	Beta	t-test	Significance
1	(Constant)	28.862	22.937		1.258	.218
	Wind Speed	1.801	.752	.243	2.394	.023
	Temperature	.448	.119	.475	3.778	.001
	Relative Humidity	-.108	.054	-.192	-2.019	.052
	Discharge	-.064	.104	-.027	-.612	.545
	Last Tower Ground Speed	-14.307	1.469	-.440	-9.741	.000
2	(Constant)	15.010	3.706		4.050	.000
	Wind Speed	1.676	.716	.226	2.339	.026
	Temperature	.434	.115	.460	3.769	.001
	Relative Humidity	-.124	.046	-.220	-2.683	.012
	Last Tower Ground Speed	-13.729	1.114	-.422	-12.320	.000

a. Dependent Variable: Water Loss

From the result of the above table, using Beta coefficients of the second model, water loss estimating model developed with predictor variable was as follows.

$$Wl = 15 + 1.676WS + 0.434T - 0.124RH - 13.729VT \qquad 4.2$$

Table 4.14 Model summary of backward method

Model	Correlation coefficient (R)	Coefficient of determination (R^2)	Adjusted R^2	Std. Error of the Estimate
1	.985[a]	.970	.965	.765
2	.985[b]	.969	.965	.76

From the result of the above model, the predictor parameter that Predominately affects the applied water which is responsible for water loss was Air temperature, Travel speed and Relative Humidity was identified by backward method. From the above result the best model is the last model with decreasing standard error of the estimate as discharge was removed from the regression model. Coefficient of determination is 0.969 and the standard error of the estimate was 0.76. The value of R^2 shows the model have capable of predicting the water lost under system and weather parameter with small error.

4.3.3 Forward method

The result forward method for the candidate variable was reported in the table 4.15, 4.16 and 4.17 below.

Table 4.15 Excluded variables by forward method

Model		Beta	t-test	Significance	Partial Correlation	Collinearity Statistics
						Tolerance
1	Wind Speed	-.222[b]	-.978	.335	-.168	.121
	Relative Humidity	-.420[b]	-2.190	.036	-.356	.153
	Discharge	.178[b]	2.351	.025	.379	.964
	Last Tower Ground Speed	-.411[b]	-11.356	.000	-.892	.999
2	Wind Speed	.226[c]	2.144	.040	.354	.106
	Relative Humidity	-.220[c]	-2.515	.017	-.406	.147
	Discharge	-.046[c]	-1.077	.290	-.187	.717
3	Wind Speed	.226[d]	2.339	.026	.387	.106
	Discharge	.002[d]	.037	.971	.007	.556
4	Discharge	-.027[e]	-.612	.545	-.111	.515

b. Predictors in the Model: (Constant), Temperature

c. Predictors in the Model: (Constant), Temperature, Last Tower Ground Speed

d. Predictors in the Model: (Constant), Temperature, Last Tower Ground Speed, Relative Humidity

e. Predictors in the Model: (Constant), Temperature, Last Tower Ground Speed, Relative Humidity, Wind Speed

The result shows, Discharge was not predictor variable by the Forward method.

Table 4.16 Regression coefficient of forward method

Coefficients [a]

Model		Unstandardized Coefficients		Standardized Coefficients	t-test	Significance
		Beta	Std. Error	Beta		
1	(Constant)	-12.614	1.601		-7.877	.000
	Temperature	.837	.074	.888	11.246	.000
2	(Constant)	3.853	1.625		2.371	.024
	Temperature	.825	.034	.875	24.181	.000
	Last Tower Ground Speed	-13.372	1.178	-.411	-11.356	.000
3	(Constant)	12.642	3.806		3.322	.002
	Temperature	.634	.082	.673	7.716	.000
	Last Tower Ground Speed	-12.818	1.115	-.394	-11.500	.000
	Relative Humidity	-.124	.049	-.220	-2.515	.017
4	(Constant)	15.010	3.706		4.050	.000
	Temperature	.434	.115	.460	3.769	.001
	Last Tower Ground Speed	-13.729	1.114	-.422	-12.320	.000
	Relative Humidity	-.124	.046	-.220	-2.683	.012
	Wind Speed	1.676	.716	.226	2.339	.026

a. Dependent Variable: Water Loss

Table 4.17 Model summary of forward method

Model	Correlation coefficient (R)	Coefficient of determination (R^2)	Adjusted (R^2)	Std. Error of the Estimate
1	.888[a]	.788	.782	1.9
2	.978[b]	.957	.954	.87
3	.982[c]	.964	.961	.81
4	.985[d]	.969	.965	.76

$$Wl = 15 + 0.434T - 13.729VT - 0.124RH + 1.676WS \qquad 4.3$$

From the result of the above model, the predictor parameter that Predominately affects the applied water which is responsible for water loss was Air temperature, Travel speed and Relative Humidity was identified by forward method. In general, all the regression method (backward, forward and stepwise) gives the same result. Air Temperature (T), Travel Speed of the last tower (VT) and Relative Humidity (RH) were the parameters that predominantly affect the applied water in this study area.

In general all methods give the same results, such that the same predictor variables and regression model that estimates water losses.

Table 4.18 Estimated water loss by regression model developed by stepwise, forward and backward method

Center Pivot	Evaluation time	Estimated water loss (%)
CP1	Morning	7.74
CP1	Midday	11.11
CP1	Late afternoon	4.09
CP2	Morning	1.24
CP2	Midday	4.15
CP2	Late afternoon	-2.29
CP4	Morning	4.2
CP4	Midday	11.57
CP4	Late afternoon	1.55
CP5	Morning	6.3
CP5	Midday	8.3
CP5	Late afternoon	2.6

The estimated water loss by the multiple regression model were ranges from -2.29% to 11.57%. The value was similar with observed water losses computed.

The criteria of a better fit (reliability of the model) were the square of the multiple correlation coefficient (R^2) equal to 0.969, the standard error of regression (s) or root mean square error (RMSE) equal to 0.76 and mean absolute error (MAE) of 0.52 was achieved.

Therefore, the above model were the regression model that are capable to estimates water losses under given wind speed, air temperature and relative humidity and travel speed for the center pivot system in the study area.

Faci et al (2001) also develops the empirical model that estimates water losses from center pivot machine equipped with rotator and spray nozzle package. The resulting determination coefficient was 69 % and only nozzle diameter, wind speed and air temperature proved to have an effect on wind drift and evaporation losses.

EL-Marazk (2018) also made the study under the title Field assessment of water losses and performance of center pivot irrigation systems under Riyadh area conditions. The results of the regression analysis of the data indicated that wind speed, air temperature, travel speed and relative humidity are the predominant factors affecting the water loss from center pivot systems. The resulting determination coefficient was equal to 0.94 and standard error of estimation equal to 1.91.

4.4 Comparison of Observed and Predicted Water Losses from Center Pivot Systems

The comparison shows, which center pivots are highly affected due to identified factor above in the study area. The average observed water loss from Table 4.8 and predicted water losses developed by the model in the study area are presented in the Figure 4.2 below.

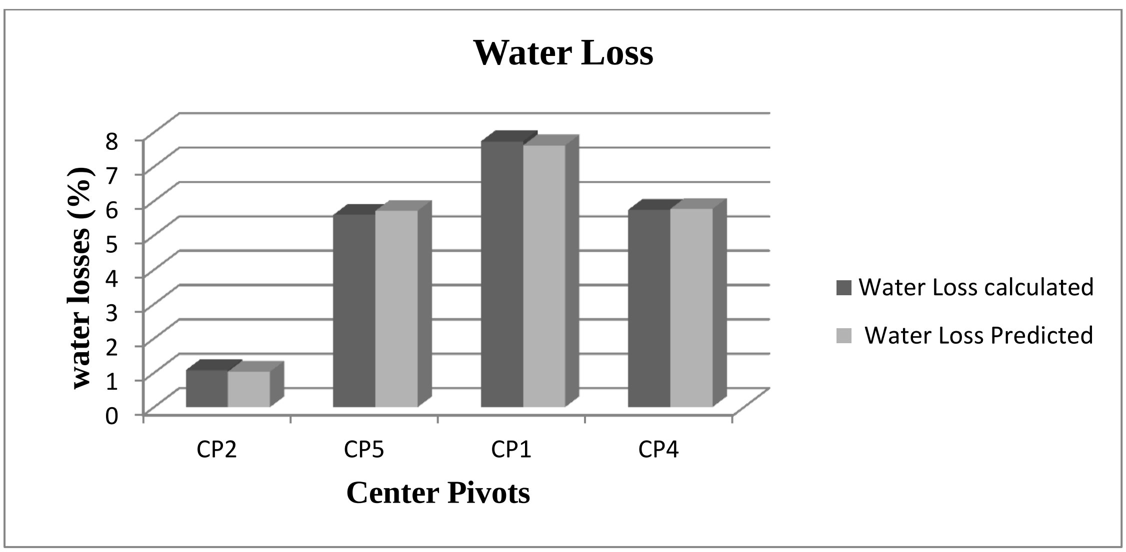

Figure 4.2 Comparison of water losses from center pivot systems in the study area

Water losses from Center pivots system were ranges between 1.03% and 7.74%, for CP1 and CP2, respectively. High water loss in the CP1 was due to temperature, travel speed of the last tower, relative humidity and wind speed. The results were similar to Shaughnessy *et al.*, (2015) reported as evaporation and drift losses for all tested center pivots at wind speed greater than 5m/s were ranged from 1.0% to 19.0%. Faci *et al.*, (2001) reported for fixed spray plates at 1 and 2.5 m height, simulated range of air losses was (7% to 20%).The high percentage of water loss for center pivot of 34.8% can be attributed to the wind drift and/or inadequate system pressure (Mustafa, 2004; Evan *et a*l., 1996). Evaporation and drift losses are typically from 5 to 20%, but can be higher when the air is dry, there is a lot of wind and the water droplets are small (Mengistu, 2017; Merkley and Allen, 2004). El-marazky, (2018) concludes water losses from center pivots machine at different test site due to system and environmental conditions ranges from 7.5% to 14%.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study was undertaken to evaluate uniformity of water distribution and estimates water losses from center pivot irrigations systems at Dodota expansion farms of the Wonji-Shoa Sugar Estate. The study was made to evaluate uniformity using performance indicators of coefficient of uniformity and distribution using double row of the catch can at different test times. During the evaluation, the effect of center pivots system parameter and weather factors were also quantified to estimate water losses. Finally, the statistical model that estimates water losses were developed and the factor highly influenced the applied water is also identified.

The overall average values of DU and CU_{HH} during morning were 62.5% and 76.75% respectively. The value generally shows it is at poor performance level. The average values of DU and CU_{HH} during midday were 60% and 66.25% respectively. The average values of DU during late afternoon were 65% which is poor range and CU_{HH} 80% were which is fair performance level. In general, better uniformity was observed during the late afternoon evaluation in all center pivots. The cause of non-uniformity was due primarily to temperature, relative humidity, wind speed and Travel speed of the last tower of center pivot. The performance of the system is decreasing when compared to the previous study conducted.

Water losses from Center pivots system were ranges between 1.03% and 7.74%, for CP1 and CP2 respectively. High water losses occur for CP2. Air temperature, Travel speed of the last tower and Relative humidity was identified in the area to be the factor predominately affecting the applied water by the center pivot system, hence responsible for the water loses. The observed water loss was related linearly with the relative humidity, wind speed, air temperature and last tower ground speed with an R^2 of 96.9%. The developed model was capable to estimate water losses under the given predictors variables identified.

The developed water losses model indicated that meteorological and center pivot system parameters have interactive effects on water losses during irrigation, and hence on the performance of center pivot systems.

The system should be operated where the climate demand is low such that at low wind speed and air temperature and high relative humidity to increase the uniformity of water distribution and to minimize water losses, hence during midday the system should have not to be operated with its full operating pressure.

5.2 Recommendations

Based on the results the following recommendations were drawn:

- To improve CU and DU, circular uniformity of water distribution will have to be conducted rather than radial tests.
- Ultrasonic discharge Measuring device have to be used to get more sound result.
- Regarding the effect of wind drift on irrigation pattern further experimental investigations is recommended by considering combination of operating pressure and nozzle diameter.
- The center pivots system should be operated when air temperature and wind speed low and relative humidity is high in the area and hence during midday the system should have not to be operated with its full operating pressure.
- Travel speed of the last tower have impact on the performance of the system, so, should have to be adjusted well.
- The developed model is water losses estimating equation for center pivot irrigation system at this study area using identified predictor variables above. By increasing the validity of the results as tried to recommend above, the company can use the developed model to increase the performance of the system, such that, to increase the productivity per applied water, to save precious resource like water, energy and reduces the effect of over or under irrigation.

REFERENCES

Abd El-Wahed, M. H., Medici, M., and Lorenzini, G. (2015). Harvesting Water in a Center Pivot Irrigation System: Evaluation of Distribution Uniformity with Varying Operating Parameters. Journal of Engineering Thermo physics, 2015, Vol. 24, pp. 143–151.

Abedinpour, M. (2017). Field evaluation of center pivot sprinkler irrigation system in the North-East of Iran. Journal of Water and Land Development. No. 34 pp. 3–9.

Acar, B., Topak, R. and Direk, M. (2010). Impacts of pressurized irrigation technologies on Efficient water resources uses in semi-arid climate of Konya Basin of Turkey. Int. J. of Sustainable Water and Environmental Systems, Vol. 1 (1), pp.1 - 4.

Akbar, G. (2017). Application and distribution of irrigation water under various sizes of center Pivot sprinkler systems. Article in Pakistan Journal of Agricultural Research· vol.30.pp.2

Al-Ghobari, H.M. (2014). Effect of Center Pivot System Lateral Configuration on Water Application Uniformity in an Arid Area. Journal of Agricultural Science. Vol.16.pp. 577-589.

Ali, A. M. and Ahmed Mohammed, S. H. (2015). Performance evaluation of gated pipes Technique for improving surface irrigation efficiency in maize hybrids. Agricultural Sciences. Vol.6, pp. 550–570

Almasraf, S., Jury, J. and Miller, S. (2011). Field Evaluation of Center Pivot Sprinkler Irrigation Systems in Michigan. Department of Bio systems and Agricultural Engineering. Michigan State University (MSc. Thesis). East Lansing, MI, USA.

ASABE, Standard, S436.1. (2007). Test Procedure for Determining the Uniformity of Water Distribution of Center Pivot and Lateral Move Irrigation Machines Equipped with Spray Or Sprinkler Nozzles. St.Joseph, Mich, USA.

Ascough, G.W and Kiker, G.A. (2004). The effect of irrigation uniformity on irrigation water Requirement. Article in Water S.A ·vol.28.No.2.

Bishaw, D. and Olumana, M. (2015). Evaluating the Effect of Operating Pressure and Riser Height on Irrigation Water Application under Different Wind Conditions in Ethiopia. ISSN 2313-0008.Volume 2, No 1/2015.

Bloomer DJ. (2006). Irrigation Evaluation Code of Practice, February 2006, Page Bloomer Associates Ltd, 20 Selwyn Rd., Napier, New Zea area.

Boserup, E. (2005). The conditions of agricultural growth: The economics of agrarian change Under population pressure (p. 137).

Burt, C. M., et al. (1997). "Irrigation performance measures: efficiency and uniformity." Journal of irrigation and drainage engineering, v.123 (6) pp.423-442. DOI: 10.1061/ (ASCE) 0733-9437(1999)125:2(97)

Burt C.M., Clemmens A.J., Strelkoff, T.S., Solomon, K. H., Bliesner, R.D., Hardy La, Howell Ta and Eisenhauer, D.E. (2017).Irrigation Performance Measures: Efficiency and Uniformity. Journal of Irrigation and Drainage Engineering. 123 (6) 423-442.

Clemmens, A. J. and Solomon, K. H. (1997). Estimation of Global Irrigation Distribution Uniformity. Journal of Irrigation and Drainage Engineering. 123:454-461.

Dudek, A. D. and Fernandez, R. T. (2015). Conducting a Water Application Uniformity Evaluation for an Overhead Sprinkler Irrigation System in the Nursery. Agricultural And Biological Research. Michigan state university.

Dukes, M. D. and Perry, C. (2006). Uniformity Testing of Variable-rate Center Pivot Irrigation Control Systems. Precision Agriculture, 7(2006), 205 - 218.

El Badawi, A.M., (2001). Centre pivot performance at Omdoum: Faculty of Agriculture, University of Khartoum.

El-Marazky M.S. (2018). Field assessment of water losses and performance of center pivot Irrigation systems under Riyadh area conditions. Article in Journal of King Saud University.2018.

Evans, R.G. and King, B.A., (2012). Site-specific sprinkler irrigation in a water-limited Future. Trans. ASABE 55 (2012), 493–504.

Faci, J. M., R.Salvador, and E.playan. (2001). Comparison of fixed and rotating spray plate Sprinklers. Journal of Irrigation and Drainage Engineering.127 (4):224-233.

Grant, C. and Osanloo, A. (2014). Understanding, Selecting, and Integrating a Theoretical Framework in Dissertation Research: Creating the Blueprint for 'House'. Administrative Issues Journal: Connecting Education, Practice and Research, Pp. 12-22.DOI: 10.5929/2014.4.2.9.

Hanson, B.R. and Orloff, S.B. (1996). Rotator nozzles more uniform than spray nozzles on Center-pivot sprinklers .California Agriculture.

Harrison, K. and Perry, C. (2013). Evaluating and Interpreting Application Uniformity of Center Pivot Irrigation Systems. Circular 911, University of Georgia, Athens, GA (2007).

Hawait, E. (2015). Technical Evaluation of performance of center pivot sprinkler Irrigation System at West Omdurman. Sudan. A thesis Submitted in Partial Fulfillment of the Requirement for the Master of Science in agriculture Engineering.

Heermann, D. F. and Hein, P. R., (1968). Performance Characteristics of Self-propelled Center Pivot Sprinkler Irrigation Systems. Trans. ASAE, 11(1968), 11-15.

Heermann, D. L. and T. L. Stophord, (1998). Evaluating center pivot irrigation system. ASAE Paper 98-2608.St.Joseph mobile laboratory.

Hezarjaribi .A and Sourell .H, (2008). Variable water application depth from center pivot Irrigation control system.

Howell, (2000). Water losses associated with center pivot nozzle package. USDA-Agricultural Research Service. Bush land, Texas.

Jensen, M.E. (1983). Design and operation of farm irrigation system, ASAE. In ASAE Monograph series, No.3 Michigan.

Kacar, M. and Direk, M. (2010). Impacts of pressurized irrigation technologies on efficient Water resources uses in semi-arid climate of Konya Basin of Turkey. International Engineering Conference on Hot Arid Regions. Al-Ahsa, KSA, March 1-2, 2010.

Keller, J. and Blisner, R. D. (1990). Sprinkle and Trickle Irrigation.” Reinhold, New York.p. 58-79.

Kelley, L., (2004). Evaluating Irrigation System Uniformity, Michigan State University 1st Extension, USA. Accessed on January 2008. Khartoum.

King, B. A., Stark, J. C. and Kincaid, D. C., 2000. Irrigation Uniformity, University of Idaho, USA Accessed on 28thJune 2007 from http://info.ag.uidaho.edu/pdf/BUL/BUL0824.pdf, 1-11

King, B. A., Stark, J. C. and Kincaid, D. C., (2004). Irrigation Uniformity, University of IdahoUSA, Accessedon28thJune2007from http://info.ag.uidaho.edu/pdf/BUL/BUL0824.pdf, 1-11.

Li J. (1998). Modeling crop yield as affected by uniformity of sprinkler irrigation system. Agricultural Water Management38: 135–146.

Li, J. and Rao, M. (2000). Sprinkler Water Distributions as Affected by Winter Wheat Canopy. Irrig. Sci., 20: 29-35.

Mekonnen, K., (2017). Performance evaluation of center pivot sprinkler irrigation system: Case study on Hiwot Agricultural mechanization, Ethiopia. (MSc Thesis), AMU, Ethiopia.

Mengiste, T.L. (2019). Comparison of dragline and center pivot sprinkler irrigation method Using performance indicators: The case of Wonji-Shoa Ethiopia (MSc Thesis), AAU, Ethiopia.

Merkley, G.P. And Allen, R.G., (2004). Sprinkle and Trickle Irrigation Lecture Notes, Utah State University, USA. Accessed on 3rd August 2007.

Msibi T., Kihupi, N., and Tarimo, A., (2014). Evaluation Of Speed Effect On The Technical Efficiency of Centre Pivot Irrigation at Ubombo Sugar Estate, Swaziland. Journal of Agricultural Science and Bio resource Engineering Research Vol. 3(1&2), pp. 14-22

Montero, J., Trujillo, J.M. and Ortega, J.F., (2002). Heterogeneity Analysis of the Irrigation in Fields with Medium Size Sprinklers, CIGR, USA. Accessed on 27thJuly2007 from http://cigrjournal.tamu.edu/submissions/volume2/CIGRLW00_0002/Sprinklers.pdf, 1-11

Mostafa, N.A. and Alsayim H.E. (2015). Field Evaluation of Center Pivot Sprinkler Irrigation Systems, Atbara Food Security Scheme. Nile Journal for Agricultural Sciences. ISSN: 1585 – 5507.http://www.nilevalley.edu.sd

Mulu, A. and Alamirew, T. (2012). Evaluating Coefficient of Uniformity for Center Pivot SprinklerIrrigation. Global journal of biology, agriculture and health science. Vol. 1(1). P.17-21.

Mustafa, A. H. (2004). Evaluation of the Centre Pivot and Linear Move Sprinkler Irrigation Systems under Sudan Conditions. A Thesis Submitted to the University of Khartoum in Partial Fulfillment of the Requirement for the Degree of Master of Science in Agricultural Engineering.

O’ Shaughnessy, S.A., Urrego, Y.F., Evett, S.R., Colaizzi, P.D., and Howell, T.A. (2015). Assessing application uniformity of a variable rate irrigation system in a windy location. Journal Applied engineering in agriculture. Vol. 29(4): 497-510

DOI: 10.13031/aea.29.9931
Ortiz J.N., de Juan J.A., Tarjuelo J.M. (2010). Analysis of water application uniformity in a Center pivot and its effect on sugar beet (Beta vulgaris L.) yield. Biosyst Eng. 105. 367 - 379.
Playa´n, E.; Salvador, R.; Faci, J. M.; Zapata, N.; Martı´nez-Cob, A. and Sanchez, I. (2005). Day and night wind drift and evaporation losses in sprinkler solid-sets and Moving laterals. Agricultural Water Management, 76(3), pp.139-159.
Rinders, F. B. (2001). Performance of irrigation systems and the impact on water use 0127, Efficiency, ARC- Institute for Agricultural Engineering, private Bag X519 Silverton, South Africa.
Rogers, D. H, Aguilar, J. Kisseka, I. and Lamm, F. R. (2017). Center Pivot Irrigation System Losses and Efficiency. Annual Central Plains Irrigation Conference, Burlington, colarado.
Ruffino, L., (2009). Irrigation system: water conservation technical brief. http://www.saiplatform.org/. Accessed 02 January 2012.
Sabah, A., Jennifer, J. and Steve, M. (2011). Field evaluation of center pivot sprinkler Irrigation system. Department of Bio systems & Agricultural Engineering, Michigan State University
Sadeghi, S., Peters, T.R., Amini, M.Z., Malone, S.L., and Loescher, H.W., (2015). Novel Approach to evaluate the dynamic variation of wind drift and evaporation losses under Moving irrigation systems. Journal of Bio system engineering.v.35.4-53
Salih, S.A., (2013). Evaluation of Speed Effect on Center Pivot Irrigation System on Civil and Performance at Waha Project under Sudan North State Conditions. International Conference Architecture Engineering (ICCAE'2013) May 6-7, 2013 Kuala Lumpur (Malaysia).
Salmerón M, Urrego Y..F, Isla R, Cavero J. (2012). Effect of non-uniform sprinkler irrigation and plant density on simulated maize yield. Agricultural Water Management 113:1–9.
Singh, A. (2018). Performance Evaluation of Surface Irrigation Method under Cotton-Wheat Rotation. Journal of Current Microbiological Applied Science. 7(5): 1014-1026.
Shaughness, S.A., Urrego, Y.F., Evett, S.R., Colaizzi, P.D. and Howell, T.A. (2015). Assessing application uniformity of a variable rate irrigation system in a windy location.

Journal of Applied engineering in agriculture. DOI: 10.13031/aea.29.9931.

Scherer, T. (1998). Selecting a sprinkler irrigation system. North Dokota state university, NDSV, Extension service.

Smajstrla, A.G., Boman, B.J., Clark, G.A., Haman, D.Z., Harrison, D.S., Izuno, F.T., Pitts, D.J., Zazueta, F.S., (2002). Efficiencies of Florida agricultural irrigation systems. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, BUL247.

Smajstrla, A.G., Zazueta, F.S., (2003). Evaporation loss during sprinkler irrigation. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. BUL290.

Wang, J., Li, J. and Guan, H., (2017). Evaluation of Drip Irrigation System Uniformity on Cotton Yield in an Arid Region using a Two-Dimensional Soil Water Transport and Crop Growth Coupling Model. Journal of Irrigation and Drainage. DOI: 10.1002/ird.2105

Wang J, Zhu D, Zhang L and Ames D. P. (2015). Economic analysis approach for identifying Optimal micro irrigation uniformity. Journal of Irrigation and Drainage Engineering. 10.1061/(ASCE) IR. 1943-4774

Appendix 1 Climatic data

Appendix 1. 1. Average Rainfall Data,

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
January	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
February	4.4	0.1	0.0	0.0	0.3	0.0	0.0	1.4	1.1	0.0
March	2.9	1.3	1.6	2.1	3.9	0.1	0.4	1.8	0.2	0.5
April	1.0	1.9	1.1	1.8	0.1	0.0	4.7	0.6	10.3	4.5
May	3.7	1.5	0.6	0.7	3.3	4.0	3.7	4.9	1.2	2.1
June	3.6	3.9	0.7	2.4	0.1	3.0	4.0	0.8	4.3	3.8
July	6.8	4.7	14.4	12.9	5.3	2.3	14.6	8.1	6.8	9.4
August	9.5	7.8	6.4	3.9	4.4	2.6	3.7	5.9	7.3	4.4
September	3.8	6.5	5.0	4.6	5.0	2.3	3.4	3.8	2.3	8.8
October	0.0	0.0	0.1	1.0	2.7	0.3	0.0	0.3	0.0	1.1
November	0.2	1.7	0.0	0.5	0.7	1.1	0.9	0.1	1.2	1.7
December	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.5

Appendix 1. 2. Average Maximum Temperature

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
January	28.3	-	28.6	28.2	29.1	28.6	28.9	29.0	27.8	30.0
February	28.2	-	29.8	30.7	30.4	32.0	29.9	29.2	30.6	32.1
March	28.3	30.3	32.0	31.9	30.0	32.7	33.0	32.4	30.9	33.4
April	31.0	32.8	30.7	31.8	31.8	32.6	30.0	32.3	29.9	32.3
May	30.5	31.6	32.7	31.8	31.2	31.4	29.6	30.3	30.1	32.3
June	30.4	31.0	31.4	30.9	32.4	31.1	29.8	31.9	29.5	30.4
July	26.2	27.6	25.4	26.1	28.4	30.0	26.8	27.4	27.1	26.8
August	26.5	26.2	25.2	26.4	26.7	29.6	27.1	26.3	26.5	26.8
September	27.6	26.7	27.0	28.3	27.2	30.2	28.6	27.7	28.8	27.5
October	29.9	28.6	28.5	28.7	27.4	31.3	30.5	29.5	30.2	27.4
November	28.7	27.9	29.5	28.0	28.5	28.9	28.1	28.9	29.3	27.9
December	27.9	27.2	28.4	27.3	27.4	28.7	27.2	27.1	28.2	26.6

Appendix 1. 3. Average Minimum Temperature

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
January	12.5	-	10.1	10.1	11.6	8.8	15.3	6.2	8.8	9.3
February	15.1	-	9.9	11.7	15.6	13.0	13.4	15.4	13.4	15.2
March	15.6	11.1	13.4	15.9	15.6	15.5	17.6	15.6	15.8	17.0
April	16.1	10.7	16.1	16.2	16.1	15.1	17.3	16.0	16.3	16.8
May	17.3	11.0	15.1	17.1	16.5	16.5	16.1	16.7	15.9	16.0
June	17.5	11.5	17.4	17.3	16.8	17.5	16.5	18.0	17.1	17.4
July	16.5	10.3	16.1	16.0	17.0	16.9	16.2	16.6	16.2	16.6
August	17.0	8.5	17.0	15.0	16.0	16.5	15.5	16.0	17.5	16.0
September	15.2	8.8	15.3	14.7	14.9	16.4	15.6	16.0	14.3	16.1
October	11.0	4.5	10.0	12.2	12.5	15.5	12.0	13.2	13.1	12.5
November	10.8	6.7	9.5	11.4	11.4	13.7	11.8	11.0	13.0	13.4
December	5.6	7.1	10.9	7.7	9.1	13.7	10.0	6.0	10.9	11.4

Appendix1.4. Average Relative Humidity Data

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
January	45.58	48.22	45.85	55.25	45.35	54.19	57.74	41.2	45.61	42.88
February	54.5	37.75	46.29	45.39	50	49.35	50.25	55.60	48.71	45.14
March	52.67	35.61	41.90	50.34	50.54	45.67	44.83	46.12	44.35	46.80
April	55.23	38.1	51.45	54.92	45.96	41.23	62.53	46.16	59.73	56.86
May	58.87	47.03	47.27	53.47	50.83	55.33	64.16	60.09	57.35	54.5
June	55.86	51.7	50.65	58	47.23	56.27	60.5	51.96	59.7	62.4
July	68.48	64.35	73.58	73.45	63.06	61.64	72.04	68.90	68.96	68.96
August	69.51	70.45	76.85	69.93	67.03	63.16	69.1	71.51	71.09	71.39
September	68.06	70.66	74.42	64.9	73.46	60.53	66.6	69.5	63.83	70.57
October	45.54	40.77	50	53.90	59.74	48.22	51.3	55.06	50.24	60.91
November	50.26	53.43	50.13	52.1	48.5	53.6	49.66	47.94	51.7	58.41
December	46.90	45.70	52.32	44.03	42.83	56.87	52.45	45.32	49.64	38.19

Appendix 1.5 Average Sunshine Hours

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
January	9.2	9.8	9.9	9.0	9.7	9.9	8.1	10.3	9.5	10.3
February	6.4	10.1	9.8	9.9	8.8	10.4	9.5	9.4	8.7	9.7
March	7.8	8.6	9.2	8.5	8.2	9.4	9.5	9.5	8.7	9.7
April	7.4	8.8	7.3	8.3	9.0	8.6	7.1	9.9	7.4	9.1
May	7.5	8.0	8.9	8.1	8.5	8.0	8.4	8.5	8.1	9.2
June	8.3	8.1	7.5	7.8	9.2	7.9	8.0	8.9	8.0	7.9
July	6.3	7.2	5.9	7.4	6.5	8.9	6.7	6.5	7.3	6.7
August	6.3	6.5	5.5	6.8	7.2	8.3	7.0	6.6	7.1	6.4
September	7.3	6.6	7.0	7.7	5.9	8.2	7.3	7.5	8.5	6.1
October	9.9	10.0	8.9	7.9	8.9	8.7	9.8	9.1	9.3	8.6
November	9.1	8.5	10.2	8.8	9.2	9.0	9.3	10.2	9.0	8.4
December	8.8	10.1	9.7	10.2	10.1	9.0	9.7	10.1	9.9	9.0

Appendix 2 Effect of over watering by center pivot

Appendix 3 Alignment of catch can on the road while crop is on the field

Appendix 4 Wind drift during the Midday evaluation

Appendix 5 Evaluation during late afternoon

Appendix 6 Pressure gauge reading

Appendix 7 Recording the catch can data after pivot is passed over the installed can

Appendix 8 Reading Hour time and operating speed from the control panel during the evaluation

Appendix 9 Last tower ground speed measurement

Appendix 10 Reading volume applied from flow meter

Appendix 11 Automatic control station/Booster

Appendix 12 Center pivot (CP1) catch can data during morning (double row)

L1	V1	L2	V2	sumL1	sumL2	di1	di2	dmean1	dmean2
50	20	50	20	50	50	7.077141	7.077141	7.077141	7.077141
55	20	55	15	105	105	7.077141	5.307856	7.077141	6.150372
60	30	60	30	165	165	5.307856	8.846426	6.433764	7.130756
65	25	65	25	230	230	10.57148	7.032909	7.603119	7.103103
70	30	70	25	300	300	5.263623	5.263623	7.057236	6.673891
75	25	75	35	375	375	10.57148	10.57148	7.760085	7.453409
80	25	80	25	455	455	3.494338	7.032909	7.010064	7.379475
85	30	85	30	540	540	8.802194	8.802194	7.292158	7.603421
90	25	90	25	630	630	10.52725	10.52725	7.754314	8.021111
95	20	95	40	725	725	8.757962	8.757962	7.885826	8.117664
100	25	100	25	825	825	8.757962	8.757962	7.99154	8.195275
105	30	105	30	930	930	8.669498	5.130927	8.068083	7.849301
110	30	110	40	1040	1040	6.900212	10.43878	7.944558	8.123188
115	25	115	25	1155	1155	10.43878	10.43878	8.192901	8.353745
120	35	120	35	1275	1275	13.97735	13.97735	8.73732	8.883026
125	25	125	20	1400	1400	10.39455	13.93312	8.885287	9.333927
130	30	130	30	1530	1530	8.625265	8.625265	8.863194	9.273714
135	25	135	25	1665	1665	10.39455	10.39455	8.987358	9.364593
140	25	140	25	1805	1805	8.625265	10.39455	8.959273	9.444479
145	30	145	30	1950	1950	8.625265	8.625265	8.934437	9.383563
150	35	150	45	2100	2100	6.85598	6.85598	8.785975	9.203021
155	30	155	30	2255	2255	8.625265	8.625265	8.774929	9.163309
160	35	160	35	2415	2415	6.85598	8.625265	8.647794	9.127662
165	35	165	35	2580	2580	10.39455	10.39455	8.759505	9.208684
170	25	170	25	2750	2750	13.93312	13.93312	9.079328	9.50074
175	35	175	25	2925	2925	13.93312	10.39455	9.369726	9.554216
180	35	180	35	3105	3105	12.16384	10.39455	9.531704	9.602931
185	35	185	35	3290	3290	13.93312	12.16384	9.7792	9.746933
190	35	190	35	3480	3480	6.811748	6.811748	9.617184	9.586679
195	30	195	40	3675	3675	12.1196	12.1196	9.749965	9.721079
200	35	200	35	3875	3875	13.88889	13.88889	9.963587	9.936192
205	35	205	35	4080	4080	13.88889	8.581033	10.16081	9.868102
210	35	210	45	4290	4290	8.581033	8.581033	10.08348	9.805098
215	35	215	35	4505	4505	13.80042	13.80042	10.26087	9.995774
220	45	220	45	4725	4725	12.03114	12.03114	10.3433	10.09054
225	35	225	40	4950	4950	12.03114	13.80042	10.42002	10.25917
230	35	230	35	5180	5180	13.80042	13.80042	10.57011	10.41641
235	35	235	25	5415	5415	10.26185	10.26185	10.55674	10.4097
240	35	240	35	5655	5655	13.71196	13.71196	10.69064	10.54985
245	35	245	35	5900	5900	13.71196	11.94268	10.81611	10.60769

250	40	250	40	6150	6150	11.94268	11.94268	10.8619	10.66196
255	40	255	40	6405	6405	17.25053	20.7891	11.11625	11.06515
260	35	260	35	6665	6665	13.71196	13.71196	11.21751	11.1684
265	40	265	40	6930	6930	8.359873	10.12916	11.10823	11.12866
270	40	270	40	7200	7200	8.359873	8.359873	11.00517	11.02483
275	40	275	40	7475	7475	13.66773	13.66773	11.10312	11.12206
280	40	280	45	7755	7755	8.359873	10.12916	11.00408	11.08621
285	40	285	40	8040	8040	11.85421	11.85421	11.03421	11.11343
290	35	290	35	8330	8330	13.6235	13.6235	11.12435	11.20082
295	30	295	30	8625	8625	11.85421	11.85421	11.14932	11.22317
300	40	300	40	8925	8925	13.6235	13.6235	11.23248	11.30385
305	35	305	35	9230	9230	13.53503	11.76575	11.30857	11.31911
310	40	310	40	9540	9540	15.30432	15.30432	11.43841	11.44861
315	30	315	40	9855	9855	13.53503	13.53503	11.50543	11.5153
320	40	320	40	10175	10175	8.227176	8.227176	11.40233	11.41189
325	40	325	35	10500	10500	11.76575	11.76575	11.41357	11.42284
330	30	330	30	10830	10830	11.76575	11.76575	11.42431	11.43329
335	40	335	40	11165	11165	17.0736	17.0736	11.59381	11.60253
340	40	340	40	11505	11505	8.227176	8.227176	11.49432	11.50278
345	45	345	45	11850	11850	12.385	13.53503	11.52025	11.56194
350	40	350	30	12200	12200	8.138712	13.44657	11.42324	11.61601
355	40	355	40	12555	12555	13.44657	13.44657	11.48045	11.66777
360	35	360	35	12915	12915	13.44657	13.44657	11.53525	11.71735
365	30	365	30	13280	13280	11.58882	8.050248	11.53673	11.61656
370	40	370	45	13650	13650	15.12739	11.58882	11.63405	11.61581
375	45	375	45	14025	14025	16.89667	13.3581	11.77477	11.6624
380	40	380	40	14405	14405	11.50035	11.50035	11.76753	11.65812
385	40	385	30	14790	14790	15.03892	16.80821	11.85269	11.79218
390	50	390	50	15180	15180	11.50035	11.50035	11.84363	11.78469
395	40	395	40	15575	15575	14.90623	11.36766	11.9213	11.77411
400	45	400	45	15975	15975	13.13694	13.13694	11.95174	11.80823
405	40	405	40	16380	16380	14.90623	14.90623	12.02479	11.88483
410	40	410	35	16790	16790	12.96001	16.49858	12.04763	11.9975
415	40	415	40	17205	17205	14.7293	14.7293	12.11232	12.06339
420	40	420	45	17625	17625	11.0138	14.55237	12.08614	12.1227
425	40	425	40	18050	18050	18.09094	18.09094	12.22753	12.26323
430	40	430	40	18480	18480	16.32166	16.32166	12.32279	12.35766
435	40	435	40	18915	18915	14.46391	14.46391	12.37203	12.4061
440	40	440	40	19355	19355	16.23319	16.23319	12.45981	12.4931
445	50	445	50	19800	19800	18.00248	18.00248	12.58438	12.61692
450	40	450	50	20250	20250	23.31033	23.31033	12.82273	12.85456
455	45	455	45	20705	20705	12.56192	19.63907	12.817	13.00365
460	45	460	45	21165	21165	14.33121	14.33121	12.84991	13.0325

465	55	465	55	21630	21630	16.1005	16.1005	12.91979	13.09846
470	45	470	45	22100	22100	19.5506	19.5506	13.06081	13.23567
475	45	475	55	22575	22575	12.47346	12.47346	13.04845	13.21964
480	45	480	45	23055	23055	19.5506	19.5506	13.18382	13.35145
485	65	485	65	23540	23540	19.5506	26.62774	13.315	13.62498
490	70	490	60	24030	24030	21.31989	21.31989	13.47823	13.78189

Appendix 13 Evaporation from control collector during midday data Collection

	CP 1	CP 2	CP4	CP5
Initial volume of water	100 ml	100 ml	100 ml	100 ml
Time at the start	6:00	5:50	5:50	6:00
Final volume of water	90 ml	90 ml	90 ml	90 ml
Time at the end	6:40	6:30	6:35	6:40

Appendix 14 Meteorological and center pivot system parameters

Center pivots	Air Temperature (^{o}c)	Wind speed (m/s)	Relative Humidity (%)	Last tower travel speed (m/s)	Discharge (m^3/hr)
CP1	22.33	1.81	42	1.086	225
CP2	17.83	1.39	46.66	1.33	223
CP4	24.33	2.26	41.66	1.35	226
CP5	19.83	1.58	44.66	1.093	227.66