SUDAN UNIVERSITY OF SCIENCE & TECHNOLOGY

COLLEGE OF GRADUATE STUDIES

Technical Evaluation of performance of center pivot sprinkler Irrigation System at West Omdurman.Sudan

التقويم التقنى لآداء نظام الرى بالرش المحورى

(دراسة حالة غرب أمدرمان – السودان)

A thesis Submitted in Partial Fulfillment of the Requirement for the Master of Science in agriculture Engineering

PrePared by
eLfath hawait aLLah
SuperviSor

prof Dr. Hassan IbraHIm mOHammED aHmED

2015

Acknowledgement

Thanks to God for every success and uncountable mercies. I would like to express my deepest thanks and appreciation to my supervisor Prof. Dr. Hassan Ibrahim Mohammed Ahmed for his generous assistance, keen interest and his useful guidance throughout this study. Thanks are extended to the administration of West Omdurman project for giving me opportunity to carry out this study at their farm and also for their assistance. Thanks are due to my family for their helps and support. Thanks are also extended to my friends for their continuous encouragement. Thanks also extended to everyone who contributed in the preparation of this thesis.

Table of Contents

List of Figures:

List of tables:

List of Plates:

TECHNICAL EVALUATION OF PERFORMANCE OF CENTRE PIVOT SPRINKLER IRRIGATION SYSTEM AT WEST OMDURMAN-SUDAN

ABSTRACT

The main objective of this study was evaluating the technical performance of center pivot sprinkler irrigation during the growing season and when operating with different working speed. The evaluations entailed system and individual nozzle flow rates, travel speed, and depth and uniformity of applied water. Transects of catch cans extending radically from the pivot points are used to provide data on depth and uniformity. Both standard statistical methods (mean, standard deviation, and Christiansen coefficient of uniformity) and time-pace series statistics are employed to analyze the can data.

The evaluation activities were made at early, mid, and late in the crop growing season and with 50, 75, and 100 % speeds. From data of system performance it is found that: Cu varies from 86, 88, and 89 % for early, mid and late season respectively. Du values were 78. 81 and 83% for early, mid and late parts of the season respectively. Performance due to Ea is fair to good with values of 88, 84, and 85% for early, mid and late season respectively. Dependability of the system with reference to Ea, Cu, and Du is a round 93% irrespective of the stage of the season and can be rated as good for the system in use is new and free from breakdown. Impact of changing operating speeds on system performance reveals that the obtained Cu values are higher than those reported for Sudan They reach values of 87.6, 85.5 and 88.8 % for 50, 75, and 100% speed respectively. For Du the results obtained indicate poor levels for low (50%) and medium (75%)speeds, while a higher value of 83% is obtained with the maximum operating speed(100%). Results of evaluation due to Ea with respect of speed indicate low level of performance in general and the performance increases with increase of speed. This is due to the fact that with low speed evaporation losses increases

Key words: Technical performance, center pivot sprinkler, dependability. System efficiencies

الخلاصة

الهدف الرئيسي لهذه الدراسة هو التقييم الفني لأداء نظام الري بالرش المجوري خلال مراحل نمو المحصول عند تشغيل الجهاز عند سرعات تشغيل مختلفة.اشتملت التجربة علي قياس تصرف الرشاشات وسرعة دوران الجهاز وعمق الماء المضاف وانتظامية التوزيع للمياه بالحقل.تم استخدام علب تجمبع مياه وضعت في ثلاث صفوف تمتد في شكل وتدي من نفطة المجور للحصول علي العمق والانتظامية.تم تحليل البيانات المتحصل عليها من التجربة باستخدام الطرق الاحصائية القياسية والتي شملت المتوسط الحسابي والانحراف المعياري ومعامل الانتظامية لكرستنيانسن . تم اجراء التجربة بنفس الترتيب في مراحل النمو الثلاث(بداية ،منتصف،اواخرموسم النمو).

تم تقييم الجهاز فنيا اعتمادا علي قيم المؤشرات التي شملت قيم (Cu,Du,Ea,E) حيث وجد أن قيم Cu كانت 86%،88% ، 89% خلال مواسم النمو الثلاثة علي التوالي . قيم Du كانت 78%،81%،83% خلال مواسم النمو الثلاث علي التوالي. قيم Ea كانت بين مقبولة وجيدة للقيم 88%، 84% ،85%. اعتمادية الجهاز إعتماداً على قيم Cu, Du, Ea كانت حوالي 93% دون اعتبار لمواسم النمو كان التقييم جيد لأداء الجهاز وعزي ذالك الي ان الجهاز جديد وليست به اعطال. اثر تغيير سرعات التشغيل اوضحت بان قيم Cu اعلي من القيم التي وردت في التقارير المختلفة عن السودان حيث بلغت 87.5%، 85.5%، 88.8% عند سرعات التشغيل 50%، 75%، 100% على التوالي. قيم Du اوضحت بأنها ضعيفة المستوى عند السرعة 50% ومتوسطة عند السرعة 75% وعالية عند السرعة 100%. أما Ea أشارت الى مستوى منخفض لأداء الجهاز بصفة عامة مع إرتفاع مستوى الأداء مع إرتفاع السرعة وهذا عزي الى قيم E (معدل التبخر) حيث وجد أن فواقد التبخر تزيد عند السرعات البطيئة.

Chapter 1 : INTRODUCTION

1.1 Background

Irrigation plays a crucial role in addressing the main challenges caused by food insecurity and rainfall uncertainty. FAO (2002)estimated that 80% of the additional production required to meet the demands of the future will have to come from intensification and yield increase. The main objective of irrigation is to apply water to the crop root zone, the optimum amount of water that the crop needs for development and also that cannot be provided by rains. There are different methods of irrigation water applications, from these methods center pivot sprinkler irrigation method is one of the pressurized irrigation systems that takes water from a source and spray it to the atmosphere as droplets by means of an enclosed system and under pressure. The water is transmitted to the surface of the soil in equal distribution with the sprinkler irrigation system to obtain uniform distribution in the crop root zone (Keller and Bliesner, 1990). With rising fuel prices it is increasingly important that irrigation systems apply water uniformly in order to achieve maximum benefit from the water applied. When irrigation systems are used to apply fertilizers and pesticides, application uniformity becomes even more critical. Consequently, it is important for center pivot owners and operators to periodically check the uniformity of their systems(Rogers et al., 1994).

According to what documented by several authors and institutions, in many areas of the world irrigation projects perform far below their potential (Small and Svendsen, 1992) and, in most of the cases, unrealistic or out-dated designs, rigid water delivery schedules and operational problems are among the principal reasons for the poor performance (Plusquellec et al. 1994).

The assessment of actual performance and potential improvement of conveyance and distribution systems received greater attention in recent years, and this trend will most likely extend to the near future, given that public and private investments will be more addressed to modernization of ageing or poor-performing irrigation schemes rather than to development of new irrigated areas or to expansion of existing irrigation schemes. In the perspective of service-oriented management, existing irrigation systems should be periodically evaluated for their performance achievements relative to current and future objectives. This requires diagnostic methodologies to analyze system behavior, assess current performance, identify critical aspects and weaknesses, and to investigate potential improvements. In this domain, several authors (Small and Svendsen 1992; Murray-Rust and Snellen 1993; Burt and Styles 2004) reported a remarkable lack of analytical frameworks by means of which irrigation managers or professional auditors can assess current achievements and diagnose feasible ways to enhance performance in the future. On the other hand, as pointed out by Prajamwong et al. (1997), identifying and implementing improvement changes entail the collection of field measurements and the use of analytical tools for developing feasible alternative scenarios and for selecting the most effective measures with the greatest impact on system performance.

Bos et al. (2005) indicated that diagnostic assessments are usually made to gain an understanding of how irrigation functions, to diagnose causes of problems and to identify opportunities for enhancing performance so that actions can be taken to improve irrigation water management. The same authors reported that diagnostic assessments are to be carriedout when difficult problems are identified through routine monitoring, or when stakeholders are not satisfied with the existing levels of irrigation delivery services being provided, and desire changes in system operation.

The core component of diagnostic assessment is represented by performance indicators, as their selection and application aim at understanding functional relationships and at developing performance statements about irrigations. In the rationale of diagnostic assessment, irrigation managers or auditors need first to acquire a good understanding of system behavior under different operating conditions, prior to using simulation and management-support tools for appraising improvement options, and then take or recommend appropriate decisions.

In this view, a sound methodology for analysis of the existing irrigation schemes and of the management needs under current and future delivery scenarios is strongly required.

Both diagnosis, which is monitoring a set of variables that characterize the behavior of a complex system, and prognosis and simulation that indicate valuating the system response after alternative correcting measures represent the basic capabilities required to an analytical methodology for addressing modernization processes with accuracy. The diagnostic component should be usedto analyze different aspects of system management, such as assessment of water demand, management of water supply, and identification of current system management needs, evaluation of system design, capacity and performance. The simulation component should instead be capable of facilitating the appraisal of improvement options by evaluating the system response after modifications. Both the diagnosis and simulation phases should be based upon a set of properly-chosen performance indicators to account for the main variables effecting the system operation and for synthetically representing the state of thesystem with respect to defined management objectives.

In this perspective, the methodology proposed in this study enables to conduct diagnosticassessments, simulate alternative deliveries and operational scenarios, and evaluateperformance achievements in large-scale pressurized irrigation systems, thus constituting an analytical basis to address both operations of the systems and their modernization processes with greater accuracythan was done in the past.

1.2 Study Rationale

Minimizing energy costs for pumping irrigation water requires growers to assess the performance of their irrigation systems. A system evaluation, which describes the performance characteristics such as application rate and uniformity of applied water, can help identify problems in both system design and management that might contribute to energy costs, crop yield reductions, or both.

Center pivots are machines that continuously revolve around a pivot point, and the revolution time is controlled by the speed of the outermost support tower. A unique design characteristic of these systems is that the water application rate must increase along the lateral to apply a uniform depth of water, since the area irrigated per unit length of lateral increases along the lateral. This rate can be increased by using:

(1) A constant sprinkler spacing with a progressively increasing nozzle orifice diameter, or

(2) A constant nozzle diameter with progressively decreasing sprinkler spacing.

A large sprinkler, mounted at the end of the last lateral, called an end gun, is frequently used to increase the irrigated acreage. The evaluations entailed measuring pressures, system and individual nozzle flow rates, travel speed, and depth and uniformity of applied water. However, transects of catch cans extending radically from the pivot points provided data on depth and uniformity. Both standard statistical methods (mean, standard deviation, and coefficient of uniformity (Christiansen, 1942) and time space series statistics may be usedto analyze the can data. The former give a measure of uniformity that can be related to a standard; time space series statistics describe patterns of non-uniformity in the applied water.

Center pivot sprinkler irrigation systems are oftenth preferred type of sprinkler irrigation system byproducers due to their relatively high waterapplication uniformity and degree of automationwhich can substantially reduce labor costs compared to othertypes of sprinkler irrigation systems.

The operational characteristics of commercialcenter pivot sprinklers are well documented but few studies have beenconducted to evaluate the effects that operating characteristics of a particular sprinkler (working speed and application rate) have on infiltration, system reliability, and water satisfaction and distribution for specific soil types.

1.3 Problem Definition and Justifications

The number of center pivot sprinkler irrigation systems has increased rapidly in the last two decades in the Sudan as automatic and modern irrigation systems. In fact, in 2010 there were about 20,028 center pivots in the country, which mainly imported to irrigate wheat crop (Mohammed, 2010). The increased demand on the available water supply in the Sudan increases the need for better design and management of irrigation systems. This means that the irrigation systems must be properly designed, managed and maintained to apply the needed water at high irrigation efficiency. Unfortunately on many farms, maintenance of the irrigation systems is neglected. Particularly the small repair jobs such as closing small leakage in pipelines. When these are left they grow rapidly until it becomes a major job to close them. Pipes and sprinklers do not work because they are broken or rusted through lack of attention. Therefore, the improvement of irrigation water management is becoming critical to increase the efficiency of irrigation water use and to reduce irrigation water demands. The field evaluation of sprinkler irrigation systems and in particular center pivot irrigation systems is essentially required for standing the efficiency and performance of the system during operation. The evaluation data can be useful in indicating any defects regarding system operation, water distribution and water losses. Also, the evaluation of the system performance in the field will indicate both the location and magnitude of water losses that are occurring, and then determining how to improve the irrigation system and/or its operation. This problem has a great influence on water availability and conservation and hence on the water resources planning on local and national levels. This evaluation is essentially required for standing how much the System is efficient and suitable for application, where the performance criterion are considered the tools for standing the system condition, and workability.

1.4 Study Objectives

- **i-** To measure Center Pivot sprinkler Irrigation system field operational parameters: the Uniformity Coefficient, Distribution Uniformity, Dependability, and Potential Application Efficiency through the crop growing season (early, mid, and late conditions).
- **ii-** To evaluate performance of configurations of Center Pivotsprinkler operating conditions (Speed: 50%, 75%, 100%) that gives the best Coefficient (CU), Distribution Uniformity (DU),Application Efficiency (Ea),and operation losses (E) at Conditions of West Omdurman Project – Sudan.

Chapter 1 : LITERATURE REVIEW

2.1 Introduction

Center pivot irrigation systems are invented over 60 years ago to reduce labor requirements, enhance agricultural production, and optimize water use. A center pivot consists of a lateral` circulating around a fixed pivot point. The lateral is supported above the field by a series of A-frame towers, each tower having two driven wheels at the base.

Water is discharged under pressure from sprinklers or sprayers mounted on the laterals as it sweeps across the field or suspended by flexible hose over the crops. The lateral line is rotated slowly around a pivot point at the center of the field by electric motors at each tower.

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.

Three uniformity measurements are to be considered in the evaluation; Coefficient of Uniformity (CU) and Distribution Uniformity (DU) and Potential Application Efficiency of Low Quarter (PELQ).

A CU rating of 90%-95% is considered excellent and would only require regular maintenance. 85%-90%% is considered good and would not need major adjustments; regular maintenance and inspection are required. 80%-85% the system requires inspection and sprinkler package check. 80% or less the system requires an adjustment to the sprinkler package, change the default system, sprinkler pressure and conduct full maintenance for the whole system (Merriam, and Keller,1978)

The CU accounts for the increased area covered by each sprinkler as you move further from the pivot center. Sprinklers near the end gun cover greater acres than those close to the center pivot.

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. A value of 85% or greater is considered excellent, 80% is considered very good, 75% is considered good, 70% is considered fair, and 65% or less is considered poor and unacceptable(Merriam, et al, 1973)

Potential Application Efficiency of Low Quarter (PELQ is a measure of how well the system can apply water if management is optimal. PELQ is the ratio of the lowest 25% weighted average depth in the catch cans to the average applied rate that is obtained from the flow rate, revolution time, and wetted area. In this way deep percolation losses would be kept to minimum (Asough and Kiker, 2002) Low values indicate design or management problems.

PELQ should be determined in order to evaluate how effectively the system can utilize the water supply and what the total losses may be. It is, therefore, a measure ofthe best management practice and should be thought of as the full potential of the system.

2.2 Irrigation in Sudan

In Sudan, surface irrigation is a dominant method used almost in all of the major irrigated schemes in central clay plains.

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).

The irrigation methods used in most projects (Gezira, KhashmElgirba, Rahad, Suki ….etc) is a combination of border and short furrows. The Gezira and Rahad have conducted irrigation trials and studies on long furrows, which were used in Rahad experimental fields and Kenana fields (Siddig and Mohamed, 1997).

Water for crops grown under irrigation is applied through different forms of surface irrigation. In pump, irrigated schemes water is lifted to the ground surface by pumping and then conveyed to the field by the action of gravity, while in other irrigated schemes water is directly diverted from reservoirs of Dams, via network of canals to the field by gravity (Siddig and Mohamed, 1997).

The surface irrigation method is characterized by high losses in the .amount of irrigation water. There is now a growing awareness to introduce modern pressurized irrigation systems (sprinkler and trickle). These systems are characterized by a high overall efficiency, but with high energy costs and difficulty to adjust system water application rate with soil water intake rates.

According to (Siddig and Mohamed, 1997) sprinkler irrigation is the method of applying water to the surface of the soil in form of spray, somewhat as in ordinary rain. The method is used for almost all crops except rice, jute and on nearly all soils. Sprinkler includes many types like solid set system, semi-permanent and continuously moving systems.

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 (Mohamed, 2010). Over-irrigation will result if the system is operated at full capacity when the water demand of the crop is less than the maximum values. Excessive application will cause leaching of soluble plant food, low water-application efficiencies, reduction in quality and quantity of crops, and ultimately a drainage problem (Israelsen, 1967).

The center pivot irrigation is one of the modern irrigation method that has been entered in Northern state in Sudan because it is capable to improve climate, increase productivity and decrease operation costs of irrigation by reduce usable power(Mohamed,2010).

2.3 Sprinkler irrigation

Sprinkler irrigation systems are broadly categorized into set and continuous-move systems (Keller and Bliesner, 1990). In set systems, the sprinklers are stationary while irrigating, whereas sprinklers move, in either straight or circular paths, while irrigating in the case of continuous-move systems. The set-move or solid set system is sub-divided into portable and periodic-move systems. The portable systems are either hand-moved or tractor-moved (end-tow, side-row, side-move, gun and boom). In these systems, the sprinkler laterals are moved manually or mechanically between irrigation sets (Merkley and Allen, 2004). The periodic-move category, also called the self-propelled or ‘wheel lines’, are suitable for low to medium height crops.

In solid set systems, the sprinklers may be attached directly to the pipe lines in the case of low growing crops or attached to a riser for vegetables and taller crops such as citrus and grains. The fixed/permanent set systems consist of sprinklers attached to buried laterals which are installed to cover the entire field. Usually, a line/lateral or a block of laterals is irrigated at once and the next irrigation set is the adjacent lateral or block of laterals (Merkley and Allen, 2004). In both solid and permanent set systems, movement within set irrigation events is facilitated by valves which are strategically installed in the pipe network. Continuous-move systems include travelers, center pivot and linear move systems.

2.3.1 Advantages of sprinkler irrigation systems

Sprinkler irrigation has advantages according to Keller and Bliesner (1990) regarding:

- Adaptability to various land topographies, problem soils with intermixed textures, and the amount of water applied because of the wide ranges of sprinkler discharge available
- Labour requirements, which reduce relative to the system being employed; from hand-moved to fixed systems down to automated systems
- Achieving other special tasks such as modifying/ controlling extreme weather conditions, supplementing erratic rainfall and leaching of salts from saline soils
- Water savings for systems with high application efficiency.

2.3.2 Disadvantages of sprinkler irrigation systems

According to Keller and Bliesner (1990) Sprinkler irrigation disadvantages are:

- The system requires high initial capital and pumping cost compared to surface irrigation systems
- The quality of water has effect on both the quality of crops produced and the system itself. For instance saline water has the potential of corroding metal parts employed in many irrigation systems
- The sprinkler system is not well-suited to soils with intake rate (infiltration rate) less than 3 mm/h.
- The system is greatly affected by windy and excessively dry conditions, which cause low irrigation efficiencies and
- Field shapes other than rectangular are not suitable for the system, especially for mechanized sprinkler systems

2.3.3 Components of pressurized irrigation systems

Plate 1-1Series of A-frame Towers

The main components of all pressurized irrigation systems according to Phocaides (2000) are:

2.3.4 Control Head

This consists of a supply line (rigid PVC, or threaded galvanized steel) installed horizontally at a minimum height of 60 cm above ground. It is equipped with an air release valve, a check valve, and 50 mm hose outlets for connection with the fertilizer injector, a shut-off valve between the two outlets, a fertilizer injector and a filter. Where a gravel filter or a hydro cyclone sand separator is required, it is installed at the beginning of this unit complex. A pump is needed in a sprinkler system, at the control head, to deliver water against gravity.

2.3.5 Main pipeline

It is the largest diameter pipeline of the network, capable of conveying the flow of the system under favorable hydraulic conditions of flow velocity and friction losses. The pipes used are generally buried permanent assembly rigid PVC, black high density polyethylene (HDPE), lay flat hose, and quick coupling galvanized light steel/PVC pipes in sizes ranging from 50 to 150 mm depending on the area of the farm.

2.3.6 Sub-mains

These are smaller diameter pipelines which extend from the main lines and to which the system flow is diverted for distribution to the various plots. These pipes are the same type as the mains.

2.3.7 Off take hydrants

These are fitted on the sub mains or the mains and equipped with a 50-75mm shut-off valve. They deliver the whole or part of the flow to the manifolds (feeder lines). Furthermore, hydrants serve as controls for switching between sets and the isolation and/or correction of defective feeder lines.

2.3.8 Manifolds (feeder lines)

These are pipelines of a smaller diameter than the sub mains and are connected to the hydrants and laid, usually on the surface, along the plot edges to feed the laterals. They can be of any kind of pipe available in sizes of 50-75 mm.

2.3.9 Laterals (irrigating lines)

These are the smallest diameter pipelines of the system. They are fitted to the manifolds, perpendicular to them, at fixed positions, laid along the plant rows and equipped with water emitters at fixed frequent spacing.

2.3.10 Limitations of sprinkler irrigation systems

Irrigation systems have inherent application limitations that make field calibration critical for efficient use of water resources. Irrigation systems are normally designed to satisfy equipment specifications provided in manufacturers' charts. However, information presented in manufacturers' charts is obtained under controlled or still wind conditions and is based on average operating conditions for relatively new equipment. The discharge rates and precipitation rates, and therefore performance, change over time as equipment ages and components wear due to rust caused by the use of saline water sources. Sprinkler irrigation designs that neglect prevailing field/crop characteristics and environmental factors can lead to poor system performance. Consequently, equipment should be field calibrated regularly to ensure that application rates and uniformity are consistent with values used during the system design and those given in manufacturers' specifications. Moreover, sprinkler irrigation design and management rules are very site specific, change with the irrigation materials, and most often rely on unstructured experiments and life-long professional experience. Hence, regular evaluation of irrigation systems is of essence to the maintenance of the systems for optimal performance at the designed parameters (Ascough and Kiker, 2002).

2.3.11 Pressure measurement

The operating pressures of sprinklers are in the range of 150-250 kPa for low pressure sprinklers and 400-900 kPa for high pressure sprinklers. Most agricultural sprinklers, however, have hammer-driven slow-rotating or revolving mechanism and use low-medium operating pressures i.e. 200 – 350 kPa (Phocaides, 2000). Merkley and Allen (2004) also wrote that the medium pressure sprinklers operate between 200 and 410 kPa. For satisfactory sprinkling with impact rotating conventional sprinklers, the minimum operating pressure should be at least 200 kPa.

According to King et al. (2000), a Pitot tube attached to a pressure gauge can be used to check a pressure regulator's operation. There are three categories of pressure measurement, namely, absolute pressure, gauge pressure and differential pressure. Moreover, there are two types of fluid systems, which are static and dynamic systems. In dynamic systems, typical of flow through a nozzle, pressure is defined using three terms: static pressure, dynamic pressure and total pressure. The Pitot tube measures the total pressure, which is the sum of the static and dynamic pressures. The total pressure is obtained when the flowing fluid decelerates to zero in an isentropic (frictionless) process. Hence the energy of the fluid is converted to pressure in the Pitot tube and the magnitude is registered by the pressure gauge attached to the tube (Heeley, 2005).

2.3.12 Sprinkler precipitation profile

The extent of uniformity achievable by a set irrigation system is greatly affected by the water distribution pattern. Each type of sprinkler has its characteristic precipitation profile which varies with nozzle size and operating pressure. Under such conditions, the water from the nozzle concentrates in a ring a distance away from the sprinkler resulting in a poor precipitation profile. At satisfactory/optimum pressure range the precipitation is symmetrical around the sprinkler. At excessive pressure ranges, the water from the nozzle breaks into fine drops and settles around the sprinkler. The fineness of the droplets makes them susceptible to wind movement (Keller and Bliesner, 1990).

2.3.13 Wind

The performance of sprinkler irrigation systems is greatly affected by both the direction and magnitude of the prevailing wind. Wind is the chief modifier that reduces the diameter of throw and changes the profiles of sprinklers. Wind speed in combination with sprinkler spacing has significant impact on the uniformity of set-move sprinkler irrigation systems. The problem is pronounced especially when wind speed exceeds 8 km/h. The changes in wind speed and direction, however, tend to increase the cumulative irrigation uniformity calculated over multiple irrigation events. Another phenomenon associated with the wind condition is ‘wind skips’, which occurs when there is a large difference in wind speed and/or direction between adjacent irrigation sets. This creates temporary dry zones adjacent to the sprinkler laterals on the upwind side. It is, however, not cumulative and successive irrigations/moves correct this effect (King et al, 2000). Notwithstanding these limiting effects, Merkley and Allen (2004) wrote that occasionally, wind can help improve uniformity as the randomness of wind turbulence and gusts contribute to smoothening out the distribution pattern/profile.

2.3.14 Sprinkler spacing

There are three main types of sprinkler spacing patterns and a number of variations to adapt these patterns to special situations. These spacing are the square, rectangular and triangular patterns. The square pattern has equal distance running between the four sprinkler positions and it is suitable for irrigating square-shaped areas. The limitation of this pattern is the diagonal distance between sprinklers in the corners and this is usually susceptible to wind effects. To minimize wind effects, closer spacing is recommended depending on the severity of the wind. The rectangular sprinkler spacing has sprinkler positions forming a rectangle with the shorter side of the rectangle across the wind and the longer side with the wind, so as to obtain a good coverage. This pattern has the advantage of fighting windy situations and it is suitable for areas with defined straight boundaries and corners. In the triangular pattern, sprinklers are arranged in equilateral triangle formats so that the distance from each other is equal. This pattern allows for lengthy spacing and therefore requires fewer sprinklers compared to the square spacing, for a specified area. Furthermore, two of the above patterns can also be combined on the same site to achieve optimum sprinkler coverage (Phocaides, 2000).

2.3.15 Critical determinants of irrigation system performance

Four factors critical to achieving high levels of performance for any irrigation system are:

- Irrigation timing
- Depth of application
- Uniformity, and
- Water supply characteristics

Irrigation system design is to create the potential for high performance and it must result in an application system that farmers can use to irrigate uniformly, in the right amount and at the right time. The performance of an irrigation system is significantly affected by the interactions between the application system characteristics and water supply characteristics. Irrigation system design must take into account the water supply characteristics to ensure that farmers have sufficient flexibility to irrigate at the right time and apply the right amount of water (Lincoln Environmental, 2000).

2.3.16 Types and operation mechanisms of impact sprinkler heads

There are three types of impact sprinkler heads used in agricultural applications. These are the spoon-driven, wedge-driven and precision jet sprinkler heads. In operation, pressurized water jet from the body passes through the nozzle past the sloping vane, through the window and into the curve of the spoon. In the spoon, the reactionary force of the water exiting the spoon drives the arm out of the stream and away from the nozzle. The tension in the arm spring then restores the arm to its original position while impact on the bridge causes the sprinkler to turn. Wedge-driven sprinklers have the same mechanism as the spoon-driven but use a wedge instead of a spoon to force the arm into or out of the water stream. These sprinklers prevent excessive deposition of water just below the sprinklers.

Precision jet sprinklers have similar operation as the spoon-driven with a precision jet tube in place of the spoon. As the arm enters the stream, the water is directed through the tube. The reactionary force of water leaving the tube is along a line away from the fulcrum and thus the arm is kicked back out of the stream. The advantage of precision jet sprinkler is that the occurrence of side splash is eliminated (Rain Bird Int. Inc., 2000).

2.3.17Losses in sprinkler irrigation systems

There are much inefficiency associated with sprinkler irrigation systems including leakages in pipes, evaporation, wind drift, canopy interception, surface runoff and uneven/excessive application depths. These losses and their typical values are presented in Table 2.1.

Table 1-1 Losses in spray irrigation

Losses component	Range	Typical values
Leaking pipes	0 – 10%	0 – 1%
Evaporation in the air	0 – 10%	<3%
Wind drift	0 – 20%	<5%
Interception	0 – 10%	<5%
Surface runoff	0 – 10%	<2%
Uneven/excessive application depth and rates	5 – 80%	5 – 30%

(Source: Davoren, 1995)

It is therefore clear from Table 2.1 that, the greatest losses in sprinkler irrigation is as a result of uneven application, i.e. uniformity of application. Keller and Bliesner (1990) wrote that other losses encountered on field scale included evaporation from wet soil surfaces, transpiration from unwanted vegetation and field border losses. Thus studying the uniformity of a system is of vital importance to the effectiveness and efficiency of a sprinkler irrigation system.

2.4 Recent Research

The center pivot irrigation is one of the modern irrigation methods introduced in North State because it is capable to improve climate, increase productivity and decrease operation costs of irrigation by reduce the power used and this study aim to evaluate the efficiency of this modern method at different operation speeds.

The center pivot has at times been referred to as the most significant piece of technology to change the face of agriculture since the tractor. Its ability to irrigate “hilly” terrain and irregular shaped field has greatly influenced the development of land environment and climates and increased the ability to produce, even in dry years (ASAE 2011).

The center pivot was named because of its radial rotation around center pivot; the center point is called the pivot. This self-propelled sprinkler system rotates around pivot point and has the lowest labor requirements of the system considered. It is constructed using a span of pipe connected to movable towers. It irrigates approximately 125.5 hectares (299fed) out of square quarter section.

Sprinkler packages are available for low to high operation. Center 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 operation 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; the water application amount is controlled by the speed of rotation (Scherer, 1998). .

James (1988)reported that the depth of water applied by center pivot system is determined by the speed at which the lateral rotates around the field. The maximum hours per revolution to prevent run off can be estimated by the following equation:

$$Sr \leq 24Dm/DDIR \quad \text{--} \quad (2.1)$$

Where,

Sr = Rotational speed of center pivot lateral (h / revolution)

Dm = Amount that can be applied per irrigation without run off (mm/day).

DDIR = Design daily irrigation requirement (mm/ day).

Center pivots are adaptable for any crop heights and are particularly suited to lighter soils. They are generally not recommended for heavy soils with low infiltration rates.

Deep wheel tracks can be a problem on some soils, but there are a number of management methods available to control this problem. Electric drive pivots are the most popular due to flexibility of operation. 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.

Corner attachment systems are available, which allow irrigation of most corner areas missed by a conventional center pivot systems. Depending on the method of corner irrigation, pivot system with corner attachments will irrigate 124 to 172.5 feddan out of 193.6 Feddan quarter section. The most common method of corner irrigation has additional span, complete with tower, attached to the end of center pivot system main line, which swings out in the corners. As it swing out, sprinklers are turned on to irrigate the corner. The movement of the moving span is controlled either by a buried wire on mechanical switch (Scherer, 1998).

Another type of corner system uses several guns mounted on the end of center pivot system main line. The guns are activated in sequence form smaller to largest and back again on machine moves past the corner (Scherer, 1998).

System performance: Distribution uniformity (DU) or pattern efficiency. These methods sort all data point in the overlap area.

2.5Measuring Performance of Sprinkler Systems

It has been demonstrated that the water application uniformityis becoming increasingly important as energy and water costs rise andthe water conservation is emphasized. A necessary step for calculatingapplied water distribution parameter is the accurate measurement ofapplied water from sprinklers using catch cans or collectors (Fischerand Wallender, 1988). Many investigators have been developed methodsto evaluate the efficiency for the sprinkler systems (Heermann and Hein, 1968, Thooyamani andNorum, 1987 Chriatiansen,1942. Recently there has been a movetowards better and more efficient methods of irrigation. Many systemsdesigned today must be able to apply adequate water to crops as well as minimize energy costs, water loss, and soil erosion. Numerousof investigators and institutes stated the guidelines for sprinkler waterdistribution testing, e.g. Merriam and Keller (1978); Seginer et al.(1992) and ASAE standard S436 (1994).

Traditionally, center pivot irrigation systems are evaluated byplacing a transact of catch cans, uniformly spaced and radially outwardfrom the pivot point along the lateral. As the machine travelsacross the transact. The water is caught in the cans, and then the systemperformance is evaluated from the measured water caught in thecans. Non-uniformity in the center pivot system is assumed to occur more along the lateral than in the direction of travel (Hanson andWallender, 1986 and Al-Ghobari, 1996). The uniformity of water applicationcould be influenced by many factors. These factors includeimproper sprinkler nozzling and spacing, wear of sprinklers and pipes, variation in pressure distribution along the lateral, and wind speed anddirection during irrigation. Also, the evaluation entailed measuringpressures, system and nozzles flow rates and travel speed of the endower.

Water application uniformity is an important performancecriterion for the design and evaluation of sprinklerirrigation systems (Derrel and Ronald, 2007). It alsoaffects the profitability of crops (López-Mata et al., 2010). The most commonly used term for placing anumerical value on uniformity of application foragricultural irrigation systems is Christiansen's coefficientof uniformity expressed as a percent (Christiansen,1942). It is based on the absolute deviation of individual amounts from the mean amount. Another parameter thatis also widely used is the distribution uniformity. The DUis defined as the ratio of the mean depth caught on thequarter of the field receiving the least amount, divided bythe mean depth caught on the entire field, and multipliedby 100 to express this as a percent. The magnitude ofcoefficient ofuniformity (CU) is usually greater than that of DU, but thisis not the case for all data sets (Lin and Merkley, 2011).

The impact of pressure variation (within themanufacturer-recommended ranges) on applicationuniformity is less than that of the sprinkler spacing (Lin etal., 2011). A generalized catch weighting factor should beused for calculating the CU and DU for center-pivot catchdata from a radial leg of containers with non-uniformcontainer spacing (Marjang et al., 2011).

Most of the effort to evaluate sprinkler irrigation systemuniformity and efficiency is done with “can” (catchcontainer) tests and the uniformity and efficiency iscalculated from catch-can data (ASAE S398.1 R2007).However, catch-can testing is very time-consuming and inmost cases water depth data can only be collected alonga limited number of radial lines around a sprinkler head. Therefore, the uniformity under any sprinkler spacing canbe determined by overlapping the catch-can test data of asingle sprinkler. Data interpolation is required to calculate
a certain point's data associated with the overlap. Catchcandata interpolation is also used to build water applicationdepth distribution maps. Maps identify actual fieldlocations receiving given amounts of water, and nutrientinput if the irrigation system is also used for chemigation.

2.5.1 Irrigation efficiency:

Irrigation efficiency can be defined in many ways, with over 30 definitions currently in use (Landwise Inc., 2006; Dalton and Raine, 1999). For example, Dalton and Raine (1999) defined efficiency as the ratio of useful work done to the energy expended. This is due to the numerous water management sub-systems existing on most irrigated farms. These sub-systems include supply systems, on-farm storage systems, on-farm distribution systems, application systems and recycling systems (Dalton and Raine, 1999). Efficient on-farm irrigation depends on water use, energy use, labor, capital investments and how these aspects relate to production and profitability, and there is no single definition that covers all aspects of irrigation efficiency. Although there are variant definitions of irrigation efficiency, they can be grouped into three main categories: irrigation efficiency, application efficiency and distribution efficiency (Landwise Inc., 2006). Irrigation efficiency relates to the fraction of water applied to a field that is really utilized beneficially by the crop. The measurement of ‘beneficial use’, however, is only attainable on long term basis rather than a single event. So in defining ‘beneficial use’ the boundary area is very critical (Burt and Styles, 2004 as in Landwise Inc., 2006). Beneficial uses of irrigation include replacing crop evapotranspiration (ET) (the primary reason for irrigating), crop cooling, frost protection, crop germination and metabolism, leaching requirement and pest control. Although, frost protection results in the highest peak use in terms of liters per second per hectare, meeting crop ET requires the highest volumetric use over an irrigation season (Landwise Inc., 2006).

2.5.2 Coefficient of uniformity (Cu):

Irrigation uniformity is how evenly water is distributed to different areas of the field. Solomon (1990) wrote that irrigation uniformity actually refers to the variation, or non-uniformity in the amounts of water applied to locations within the irrigated area. Therefore, Kelley (2004) asserts that irrigation uniformity is a concept that all areas within an irrigated field received the same amount of water. Solomon (1990) stated that specific quantitative study of sprinkler irrigation uniformity started with the work of Christiansen in 1942. High irrigation uniformity connotes water being applied adequately with little excess and low uniformity indicates that some portions of the field would be deprived of water while other locations will become over-irrigated. Unfortunately, no irrigation system or even Mother Nature, applies water in a perfectly uniform way, so wet and dry spots always occur (Solomon, 1990).

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. Keller and Bliesner (1990) linked the performance of sprinkler irrigation systems to the sprinkler physical characteristics (i.e. jet angle, number and shape of nozzles and mode of operation), nozzle size and pressure. It was recommended that the CU values used for the final design of a system should be based on actual field or test facility data. Hachum (2006) wrote that the principal indices for evaluating the performance of farm irrigation systems are:

- Uniformity of water distribution (the key index in the evaluation)
- Adequacy of irrigation, and
- Efficiency of irrigation.

According to Dalton and Raine (1999), an important component of the evaluation of in-field irrigation system performance is the assessment of irrigation uniformity. Irrigation uniformity is thus an important management factor necessary for achieving high irrigation efficiency.

King et al. (2000) also stated that to maximize production efficiency, two irrigation management issues required attention, that is, irrigation scheduling and uniformity. The evaluation of sprinkler systems typically involves an assessment of the volumetric discharge rate and the uniformity of the discharge (Dalton and Raine, 1999). Huck (2004) also wrote that for existing irrigation systems, irrigation audit or catch-can test is a good method for evaluating sprinkler system efficiency. It has been found that raising the irrigation uniformity from 70% to 90% allows half as much area to be irrigated adequately with a given volume of water (Davoren, 1995). Irrigation uniformity is thus affected by the sprinkler characteristics and layout, operating pressure, environmental conditions and management practices. Assessing irrigation system uniformity is therefore pivotal to the design of an effective irrigation system.

2.5.3 Methods of determination of sprinkler water distribution

The procedures for determining water distribution and hence sprinkler uniformity is:

- Applying the catch can grid to the existing irrigation system according to Merriam and Keller (1978) as in Keller and Bliesner (1990).
- Placing a catch can grid around a single sprinkler head in no-wind conditions and establishing the corresponding overlapping for any sprinkler spacing (Solomon, 1990 as in Montero et al., 2002).
- Reducing the catch cans grid to a single-leg in a radial pattern, in no-wind and with high relative humidity conditions. The application rate can be calculated by rotating the radial pattern around the sprinkler (Vories and von Bernuth, 1986 as in Montero et al., 2002).

2.5.4 Agronomic significance of irrigation uniformity and performance

Irrigation uniformity is linked to crop yield through the effects of under or over irrigation. Inadequate water results in high soil moisture tension, plant stress and reduced crop yields, whilst excess water may also reduce crop yield through mechanisms such as leaching of plant nutrients, increased disease incidence or hindered growth of commercially valuable parts of crops (Solomon, 1990). The uniformity and performance of an irrigation system are inherently associated with the manner in which agricultural resources are utilized. So, that non-uniformity and under performance result in excess pumping costs and fertilizer loss either through fertigation or leaching by the excess water. Capital losses are also incurred due to the extra capacity put into the irrigation and drainage systems to convey the excess water from the field (Solomon, 1990).

2.5.5 Irrigation uniformity and water requirement :

To conserve water resources, the performance of irrigation systems needs serious attention. This demands the evaluation of systems on regular basis and the implementation of corrective measures to keep the system operating according to design.

2.5.6 Coefficient of uniformity

Coefficient of uniformity is a measure of non-uniformity of water application for a given sprinkler head, nozzle type, operating pressure and sprinkler spacing combination. It is thus an index of irrigation uniformity. The main stream agricultural industry has long used a calculated coefficient of uniformity to measure the non-uniformity of water application (Solomon, 1990).

The uniformity of water application could be computed by dividing thelowest values caught in quarter of the cans (low quartet) by the averagedepth caught in all cans (Ali, 2002).

2.5.7 Quantitative measures of irrigation uniformity

i- Christiansen’s coefficient of uniformity (CU)

Dalton and Raine (1999) found CU as the most commonly used quantitative measure of irrigation uniformity. This coefficient measures the average deviation from the mean application depth. Hence, for a perfectly uniform application the CU is 100%, which is impossible to achieve on a field scale due to equipment deficiencies and limiting environmental factors. CU values of 80-90% is attainable for set-move systems, which are properly designed and maintained, operating under moderate wind speeds less than 16km/h. 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). Sprinkler uniformity is generally affected by the combination of wind speed/direction, operating pressure and sprinkler spacing, in the case of set-move sprinkler system. Dalton and Raine (1999) found that a wide range of irrigation uniformity coefficients are used when evaluating performance of irrigation systems and that one of the basic measures of any irrigation system’s performance is Christiansen’s uniformity coefficient (CU). Dalton and Raine (1999) indicated that the uniformity of application is acceptable for CU values greater than 0.84 or 84%. Keller and Bliesner (1990) also wrote that in general CU of at least 85% is recommended for delicate and shallow-rooted crops such as potatoes and most other vegetables, whilst values between 75% and 83% is acceptable for deep-rooted crops like alfalfa, corn, cotton and sugar beets. In cases where chemicals are applied through the irrigation water, the CU should be at least 80%.

ii- Pattern efficiency (PE)/distribution uniformity (DU)

Distribution uniformity is usually defined as a ratio of the smallest accumulated depths in the distribution to the average depths of the whole distribution (Ascough and Kiker, 2002). This uniformity measure is also called low-quarter distribution uniformity and it is often used to quantify irrigation uniformity of surface systems (King et al., 2000). The DU coefficient takes into account the variation of can readings from the mean but concentrates on the lowest 25% of readings. A commonly used fraction is the lower quarter, which has been used by the USDA since the 1940s (Ascough and Kiker, 2002).

Du = M25/M * 100 -- (2.2)

Where M is the mean of all the can readings and M25 is the lowest 25% of all the can readings. Wilson and Zoldoske (1997) 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.

Cu = 100 $\left[1-\frac{\sum x}{mn}\right]$--(2.3)

Where:

Cu = Coefficient uniformity (percent)

X = Deviation of individual observation from the mean (mm)

n = Number of observation

m = Mean value of observation (mm)

,Du = 100 – 159 (100 - Cu) --- (2.4)

Ea % = $\frac{Dw}{Dg}$ * 100 -- (2.5)

,Dependability:

a- For Du (Distribution Uniformity):-

Dependability =$\frac{1}{R}\sum_{T=1}^{T=n} CVt * Du$--

(2.6)

b- For Cu (Coefficient of Uniformity):-

Dependability= $\frac{1}{R}\sum_{R=1}^{R=n} CVt * Cu$--- (2.7)

c- For Ea (Application Efficiency):-

d- Dependability= $\frac{1}{R}\sum_{T=1}^{T=n} CVt * Ea$-- (2.8)

Where:-

CVt=Coefficient of variation.

R= Crop growth stage.

2.5.8 Factors affecting Sprinkler irrigation uniformity

Sprinkler irrigation uniformity is affected significantly by:

- Equipment and design factors such as sprinkler characteristics (that is number of nozzles, size and shape), operating pressure and sprinkler spacing

- Environmental factors such as humidity and more importantly wind condition and
- Management factors such as length of irrigation time, time of day irrigation is performed, practicing of offsetting laterals (alternate sets) and irrigating blocks of several adjacent laterals at once (Solomon, 1990).

2.5.9 Operating pressure

The pressure of the irrigation system is the maximum water pressure required for normal operation and it includes the friction losses in the piping network from the control station to the distal end of the system, the difference in elevation and the pressure required at the emitter/sprinkler. Operating pressure used in this work refers to the pressure measured at the emitter, in this case the sprinklers. Sprinkler irrigation systems can be classified by the operating pressure as follows (Phocaides, 2000):

Low pressure systems, where the pressure required is 200-350 kPa;
Medium pressure, where the pressure required is 350-500 kPa;
High pressure, where the pressure required exceeds 500 kPa.

The operating pressure of sprinklers has significant impact on irrigation uniformity and the overall performance of the irrigation systems. The optimum operating pressure of impact sprinklers, with standard straight bore nozzle is 310.5 kPa to 414 kPa (45 to 60 psi). Armstrong et al. (2001) give the common operating pressure range for overhead impact sprinklers as 240 – 400 kPa. Under low pressures less than 276 kPa (40 psi), the water jet leaving the nozzle does not break up adequately and this results in concentrated water application. Conversely, pressures above 483 kPa (70 psi) break the jet excessively (misting) resulting in concentrated water application near the sprinklers (King et al, 2000). This also creates fine mist in the sprinkling zone resulting in excessive wind drift and evaporation. The operating pressure controls the wetted diameter and the mean water droplet size (Kranzet al., 2005).

To achieve acceptable uniformity, the pressure variation along a lateral is not to exceed 20% of the design pressure. Excessive pressure variation, however, is prevalent on undulating or sloping topographies and this problem is best rectified with the use of pressure compensating nozzles or pressure regulators. With rocketing energy cost, the tendency has been to reduce the operating pressure so as to make savings on fuel. To achieve this, special nozzles (with non-circular orifices) which use mechanical means to provide extra breakup of the water jet at low pressures are utilized. Such nozzles operate at pressures that are 1 bar lower than the traditional nozzles (Solomon, 1990).

Chapter 2 : MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Study Location:

The study area is a plain surface gently sloping towards the White and river Niles, generally elevated between 400 to 380 m above mean sea level (a.m.s.l.).The study area is located about 80 km² North West ofOmdurman province at latitudes 15°: 25 to 15°: 30 North and longitudes32°: 12 to 32°: 18 East and altitude of 420 meters above the mean sea level. The experiments were conducted in December, 2013 to December, 2014.

3.1.2 Topography:

The area is devoted of hilly or high ridges topographic features except Merkhyite hills and Jebel Aulia at the extreme north and extreme south of the area respectively The drainage system is dominated by the lower most reaches of the White Nile, River Nile and local systems of ephemeral streams (e.g. Wadis and Khors),which trend mostly east-west.

3.1.3 Soils and Natural Vegetation:

Acacia species(Acacia tortilissub. Sppraddiana (seyal), sub spp, Spirocarpa (samor), Bosciasenegalensis(mokhate), Acacia nubica (laoot), and Acacia mellifera (kitir) and rangeplants such as Covolvolusspp (Tabar) and Ipomeaspp(hantout))are predominant as the desert and semi-desert vegetation types. The area is regarded as semi-arid zone, which is characterized by its scanty vegetation that can be increased along seasonal drainage pattern and river banks . According to El Hag et al, (1994), the natural vegetation is replaced in the cultivated sites by some cereals e.g. Sorghum and few Legumes.

3.1.4 Climate:

According to Adam (2015), the semi-desert climate prevails on state. It is dry, hot in summer with average temperature of 32^{o}C during March\ June. Rainy during June \ September with average rainfall of 157 mm. In winter the temperature ranges between 27 and 30.8c during October\February. Water resources are surface water and underground water (El Hag et al, 1994). The White and Blue

Niles represent the main sources of surface water. The Nubian sandstone and Gazira formation reservoirs represent the underground water.

3.2 crop grown:-AlfaAlfa crop

According to FAO (2013) Alfalfa (Medicago sativa) is believed to have originated in Mediterranean region. It is grown as the forage crop,either for fresh produce or for hay . Thecrop is grown under a wide range of climates where average daily temperature during the growing period is above 5^0C. The optimum temperature for growth is about 25C and growth decreases sharbly when temperature are above 30C and below 10C . In warm climates the production is higher under dry as compared to humid conditions . Alfalfa can be used as an important break crop in the rotation and most crops can follow alfalfa with the exception of certain root crops such as sugar beet, because of the high amount of root residue left in the soil. Alfalfa is a perennial crop and produces its highest yields during the second year of growth. In climates with mild winters, alfalfa is grown for 3 to 4 years continuously, but in continental climates with cold winters it is grown for 6 to 9 years, with a dormant period in winter. The crop is also grown as a short season annual crop. Foll0wing seeding, the crop takes about 3 months to establish. Number of cuts varies with climate and ranges between 2 and 12 per growing season. Also, yield per cut for a given location varies over the year due to climatic differences.

Water use by the crop in relation to its production is high when compared to other forage crops such as forage maize, and when economic conditions permit alfalfa is replaced by maize as a forage crop.

Alfalfa is successfully grown on a wide variety of soils, with deep, medium textured and well-drained soils being preferred. Fertilizer requirements vary with production level and are 55 to 65 kg/ha P and 75 to 100 kg/ha K. (Fertilizer requirements (kg nutrient/ha) of high-producing varieties under irrigation; accurate amounts are to be obtained from local research results or to be determined by experiments, soil testing and plant analysis and evaluation of economic conditions. Conversion: 1 kg P = 2.4 kg P2O51 kg K = 1.2 kg K2O.) Alfalfa is capable of fixing atmospheric nitrogen which meets its requirements for high yields. However, a starter of approximately 40 kg N is beneficial for good, early growth.

The crop is moderately sensitive to soil salinity. Yield decrease related to electrical conductivity (ECe of extraction saturated paste in mmhos/cm) is: 0% at ECe 2.0 mmhos/cm, 10% at 3.4, 25% at 5.4, 50% at 8.8, and 100% at ECe 15.5 mmhos/cm.

Water Requirements

Crop water requirements (ETm) are between 800 and 1600 mm/growing period depending on climate and length of growing period. The variation in water requirements in each cutting interval for alfalfa is similar to that during the total growing period from sowing to harvest for other crops. The kc value is about 0.4 just after cutting, increasing to 1.05 to l.2 just prior to the next cutting with a mean value of 0.85 to 1.05. For seed production, the kc value is equal to 1.05 to 1.2 during full cover until the middle of flowering, after which the kc value is reduced

Sharply

To stimulate root growth, the young stand should be irrigated frequently because root development is adversely affected by dryness. During each cutting interval the amount of total green matter produced increases to a maximum at the start of flowering when the quality for hay production is also at its best. To enhance growth, irrigation is normally applied just after cutting. When irrigation is applied just before cutting the top soil may still be wet at the time of cutting, hampering cutting and causing the cut material to mould more easily.

Excess irrigation may cause reduced soil aeration which is particularly harmful to the crop. During winter, when the crop i s dormant or growing very slowly, the crop will tolerate short periods of flooding without causing much damage to the later growth of the crop.

The relationship between relative yield decrease (1 - Ya/Ym) and relative evapotranspiration deficit (1 - ETa/ETm) is given in Figure 6. Within a certain range of relative evapotranspiration deficit (0 to 0.4), the yield response factor (ky) for both fresh and dry yield is smaller than one. This implies that water utilization efficiency (Ey) (kg of produce/m3 of water) increases in this range of relative water deficit. Under conditions of limited water supply, overall production is increased by extending the area under irrigation rather than by meeting full crop water requirements over a limited area. Also, the effect of a reduced water supply on yield of alfalfa is less pronounced than that of many other crops that have ky values greater than one during the period of water shortage. Where cropping of several crops is involved, the irrigation supply to alfalfa may be reduced in favors of more sensitive crops.

To reduce peak demands for water during the hot summer months, a dormancy period during these months is sometimes practiced in North Africa. Water savings are utilized during spring and autumn when climatic conditions allow high yields with relatively lower water requirements. Where the crop is grown for seed, effective water savings may be made by timing the seed production during the period when normal water demands of a forage crop would be high.

The 'drought tolerance' of alfalfa, sometimes claimed during periods of low water requirements, appears to be due to its extensive rooting system which enables the crop to draw water from a large soil volume.

Water Uptake

Alfalfa has a deep rooting system extending up to 3 m in deep soils. The maximum root depth is reached after the first year. The crop can draw water from great soil depth and little response to irrigation has been shown with groundwater tables at 2 m or higher. Normally, when the crop is fully grown, 100 percent of the water is extracted from the first 1 to 2 m soil depth (D = 1-2 m). When maximum evapotranspiration (ETm) is 5 to 6 mm/day, about 50 percent of the total available soil water can be depleted before the uptake of water from the soil affects crop evapotranspiration (or p = 0. 5). After cutting full cover is reached in 12 to 20 days depending on temperature, and peak ETm is reached soon after.

Irrigation Methods

Surface irrigation is commonly used in alfalfa production. The most common method is border irrigation. Contour irrigation and wild flooding are sometimes practiced. Where water is scarce or the soil permeability is high, water is supplied by overhead sprinkling.

Yield

Crop yield varies with climate and length of total growing period. Good yields after the first year are in the range of 2 to 2. 5 tons/ha per cut (hay with 10 to 15 per cent moisture) of about 25 to 30 day cutting interval. For example, Hofuf, Saudi Arabia, 28 ton/ha of hay over 310 days involving 12 cuts; Davis, California, under experimental conditions, 22 ton/ha of hay over 200 day growing period involving 7 cuts. The water utilization efficiency for harvested yield (Ey) of hay with 10 to 15 percent moisture is 1. 5 to 2.0 kg/ m3after the first year. The moisture content of fresh green matter is about 80 percent. From 18 to 20 percent of the dry weight is protein.

3.3 Data Collection

3.3.1 System description:

A center pivot machine consists of a lateral circulating around a fixed pivot point. The lateral is supported above the field by a series of A-frame towers, each having two driven wheels at the base. Depending on field layout, the pivot may complete a full circle or only part segments. Water is discharged under pressure from sprinklers or sprayers mounted on the lateral as it sweeps across the field. As such, the evenness of application at points along the lateral, and the evenness of application as the lateral passes across the field both contribute to overall irrigation distribution uniformity.

Plate 2-1Center Pivot Under Test

Plate 2-2Control panel

3.3.2 Catch Cans data:

The detailed procedures given by Merriam and Keller (1978) Keller and Blister (1990), ASAE standards (ASAE 1994), and Merkley and Allen (2003) for collecting and analyzing sprinkler catch-can data is adopted in this study.

Uniformity tests were conducted following the ASAE S436.1 standard for center pivots. Under the standard, catch cups are spaced 3m (10ft) apart in 1 or more rows extending from the pivot center straight out to the circle edge. When the pivot is started, no water wereentering the cups until the unit is at full pressure and speed.

Relevant standards are:

- ANSI/ASAE S436.1994 DEC01 Test procedure for determining the uniformity of water distribution of center pivot and lateral move irrigation machines equipped with spray or sprinkler nozzles (ANSI).

- ISO 11545: 2001 Agricultural irrigation equipment – Centre-pivot and moving lateral irrigationmachines with sprayer or sprinkler nozzles – Determination of uniformity of water distribution (ISO).
- ISO 8224/1 – 1985 Traveler irrigation machines – Part 1: Laboratory and field test methods.
- ISO 7749-2: 1990 Irrigation equipment – Rotating sprinklers – Part 2: Uniformity of distribution and test methods.

Field catch-cans arrangement: In the field catch-cans were arranged in radial “legs” of cans. In this case, the data values are used as-is in calculations which are specific to the configuration of a center pivot. The rotation rate and effective radius of the center pivot machine were also recorded.

Radial legs: Each of the radial legs begins at the location of a single operating sprinkler under field or laboratory test conditions; that is, the sprinkler is the center of a circle from whichall of the radial legs emanate.

Flow rate: This is the sprinkler discharge, which was measured just before and or after a test. The value entered here is multiplied by the test duration to estimate the effective portion of the applied water.

Pressure: This is the operating pressure at the sprinkler head, which was measured just before and or after a test. The value entered here is only for purposes of documenting the test conditions; it is not used in any calculations for evaluation.

Test date and time: The date of the sprinkler test and the start time (the duration of the test and the end time) were noted.

Can opening: the catch-can opening (at the top of the container, and in a plane parallel to the ground surface) is measured by measuring its diameter using vernier instrument.

Can spacing: the distance between each adjacent catch-can along the radial distance was noted. In practice, the spacing of catch-cans is taken equal along the radial distance. Typical spacing’s for the grid are 61 m.

.

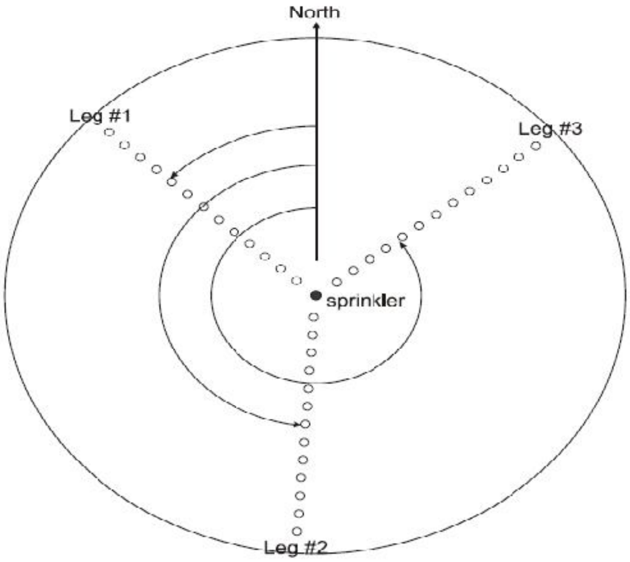

Figure 2-1 Three radial legs of catch cans at different azimuth values

Water quality: The water used for the test is the same as that normally used for irrigation unmodified for the purpose of the test by any additional filtration, or injection of chemicals.

Pressure and machine speed: Standard tests are made to run at the normal operating pressure, and at the planned three speeds of (50 %, 75%. 100%) It is ensured that the pressure is maintained during the test. To maintain constant pressure; the system is not affected by other significant system draw-offs.

The machine speed selected for the test was made with minimum effect of stop-start effects on distribution patterns from any one-off test, and to apply and obtain sufficient volume for reliable measurements to be obtained.

Experimental Design: The center pivot sprinkler installed in the experimental area is consisting of 7 towers, with 50 m between towers and 7m between cans within each tower, togive a total of 50 cans. The diameter of each cans is7cm with a height of 10 cm.

Weather data: The ten year temperature, humidity, sunshine hours, wind speed, rainfall and other necessary data were collected from Metrological Station. The data were used to estimate average values for wind speed and others.

Discharge rates along the lateral:-

The unique and critical feature of a center pivot machine is how it moves across the field. The center pivot lateral moves at increasing ground-speed with distance for the center, so the application rate must increase further out along the lateral to give the same application depthAny point-measurement, such as a collector (catch-can) volume, is representative of a much larger area of the entire field. Under a center pivot, the measurements at the outer end represent a very much larger area of the field than do those near the center.

Stop-start operation:

The speed of rotation of a center pivot is generally controlled by varying the average speed of the end tower. For electric machines, this is achieved by cycling the power on and off using a percentage timer mounted at the pivot end. Typically the cycle time is one minute. Irrigator alignment is maintained by operating inner towers for proportionally shorter times, so the forward movement of these machines is unsteady. This stop-start operation can result in non-uniform application along the travel path, especially for single irrigation events. Because the stopping points are effectively random, this is mostly mitigated by subsequent irrigation cycles (CPD).

Field evaluation should attempt to minimize effects of single event stop-start effects on distribution measurements which otherwise lead to underestimates of distribution uniformity.

For a single radial test this may require operating the machine at 100% speed to minimize the number and duration of stop-starts. Alternatively, multiple radial measurements can be used.

Hydraulically powered center pivot machines should run more smoothly but assessors are advised to still pay attention to the possibility of erratic movement and potential effects on uniformity.

3.3.3 Equipment Used:

The following equipment was used to measure sprinkler coverage:

i. Catchcans

ii. Weights to prevent catchcans blowing away

iii. A shovel to smooth catchcan area, and where necessary for partially burying the cans

iv. A measuring cylinder or jug with graduations in milliliters

v. A 30-metre measuring tape; and possibly a short ruler

vi. Pegs or markers

vii. A calculator, a pen and evaluation sheets (you may need extra copies of the data sheets)

viii. Manufacturer's sprinkler performance charts

1- Equipment was used to measure flow:

i- A container of known volume (10 L bucket)

ii- Stop watch

2- Equipment used to measure pressure:

i- An accurate pressure gauge with an appropriate scale so it works midrange at normal pressures (say 0 to 400 kPa) to 1000 kPa

ii- Tees and fittings to install above pressure regulators.

Field Evaluation Method:

Out of more than 20 centre pivots atWest Omdurman, four centre pivot Systems named (A,B,C,D) were selected to evaluate water distribution during three stages of the season(Early, Mid and late).

For assessment of the performance of center pivot irrigation system, we measured: the pressure at various points in the system, its operating speed and the output of the emitters using catch cans. To do this, work is made though the following procedure.

1. Record of wind speed and direction: Field tests are in reality done in zero wind conditions.
2. Data sheet with details about the crop; soils and the center pivot were filled.
3. The length of each span and the distance from the center to the outer wheel track and travel speed were measured.

Water output measurement:

a-Catch canswere placed across the pathway of the center pivot. The locations were flat and level, and far enough ahead of the boom so that no water enters the catch cans before they are all set up.. However, the catchcan position under the span was noted and the catch volume wasrecorded.

b-The catch cans were set out no more than 7meters apart

c- The cans are placed in a straight line.

d- When the machine has completely passed over all of the catch cans, the water volumes in each container was measured and recorded. Each volume was written in the correct space on the field record sheet.

Speed measurement: The pivot was made to move with constant(selected) speed throughout the test, so that the difference in flow rates between the inboard and outboard sprinklers will not give incorrect results.

1. Record the control panel settings/readings.
2. Measure the pivot's speed by staking out a measured distance (say 10 m) around the outer wheel track and recording the time required for the end drive unit to travel between the stakes.

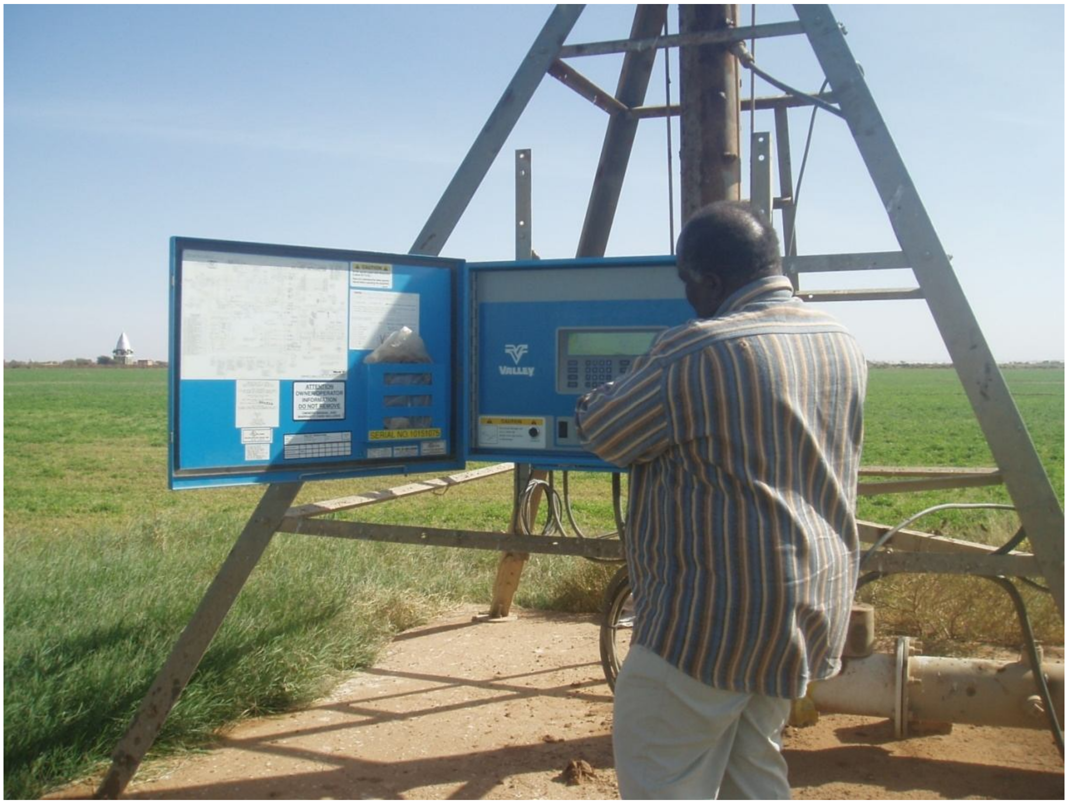

Plate 2-3Adjusting speeds of Center pivot

Calculating the results:

After taking all measurements the calculationswere made in accordance with Al Algobari (2007). As the calculations for a center pivot are quite complex, it is put into a computer spreadsheet (Appendix A). The calculation procedure is detailed in following notes:-.

a- Ranking of the volumes starting with the lowest amount,(in descending order).

b-Calculation of the “weighted catch” by multiplying the volume collected in the catchcan by the position number of that catchcan.

c- Calculation of the Average Application Depth per pass of the system using the Average Application Depth Table

d- Calculation the Distribution Uniformity (DU) of the system using the DU Formulae.

e- Record of the results in the Application Results table.

3.4 Data Analysis

3.4.1 Statistical Analysis:

Several statistical values were calculated based on the catch data. These values can help you interpret your data, as well as provide comparative indicators between data sets and test cases. You may not need all of the statistical analysis results, so you might want to select just a few which would be used in practice, as required.

In the following, X denotes a single catch value, X-bar represents the mean catch value, and n is the number of catch values (including those which are equal to zero).

Average Net Depth: This is the average net depth (cm or inches) collected in the catch cans during the sprinkler evaluation test. It is based on the total number of catch cans (even those that had a zero depth):

$$\text{Avg net depth} = \frac{1}{n}\sum_{i=1}^{n} X_i \text{--} (3.1)$$

Average Gross Depth: The average gross depth (cm or inches) is determined based on the sprinkler flow rate and the area covered by the catch cans. This area is determined as the number of cans multiplied by the row and column spacing values in a rectangular grid of catch cans:

$$\text{Avg. gross depth} = \frac{q_a t}{n\,S_x S_y} \text{--} (3.2)$$

Where q_a is the average sprinkler discharge during the test; t is the elapsed time; and $S_x$and $S_y$are the spacing between adjacent catch cans in a rectangular grid. In this case, it is assumed that each catch can represents an area of$S_x \times S_y$. For radial legs of data, and for center ivots, the value is determined as follows:

Avg. gross depth= $\frac{q_a t}{\pi R^2}$-- (3.3)

Where, R is the effective radius of the sprinkler or center pivot machine. Of course, the necessary unit's conversions are done in Catch3D so that the average gross depth is shown correctly in cm or inches.

Average Net Application: This is the application rate (cm/hr or inches/hr) during the sprinkler test. It is equal to the average net depth divided by the test duration:

Avg. net application = $\frac{1}{t}\left[\frac{1}{n}\sum_{i=1}^{n} X_i\right]$-- (3.4)

The necessary units' conversions are done in Catch3D so that the average net application rate is shown correctly in cm/hr or inches/hr.

Volume of Water Applied: This is simply the average sprinkler discharge multiplied by the duration of the test:

Volume applied = $q_a t$-- (3.5)

The volume of water applied should always be greater than or equal to the volume caught. If the volume of water applied is shown in the program to be greater than the volume of water caught, it was raining during the field test, or else there was an error in the data collection. In the latter case, the sprinkler discharge might have been underestimated, multiple sprinklers were operating and contributing to the catch data, the duration of the test was underestimated, or perhaps the catch data had errors.

3.4.2 Determination of Application Rate

To measure the application rate and time of application, a weighting-type recording rain gage was first used. However since the system passed over a point about 100 m away from the pivot in less than one hour and the recording pen movedover only a small distance on the graph during the same time, no appreciable results were obtained from this measurement. This could be corrected by changing. the timing gears of the gage, but since only one recording rain gage was availablefor the project and measurements had to be taken at several locations at different distances from the pivot point, amore suitable method using the cans Wasemployed. Six groups of catch cans were placed at different pointsalong the lateral about 30 m apart. The time when the spraystarted falling in the cans at each of the observed points, was noted and the volume of water collected in any one canat each position was measured in convenient time intervalsranging from 5 to 15 minutes with the graduated cylindersas described earlier. These measurements were taken at onlysix locations along the lateral due to constraints of irrigationtime and labour.

Volume of water applied and caught: The volume of water applied by the system will be compared to the volume of water caught in the catch cans. Finding the difference between the two will show the amount of water lost to system malfunction or environmental condition.

The ultra-sonic flow meter is used to measure the accurate flow rate in the system. The device can be used horizontally or vertically for measuring the flow rate in the lateral pipe with 2-3% accuracy. Calculating the volume applied was done by multiply the reading of the flow rate (gpm) by the time required to complete one full revolution. This result is the total volume of water that exits the irrigation system.

$$Q \times T = V_{sys} \text{ -- } (3.6)$$

Where:

Q = Flow Rate (gpm).

T = Time for full Revolution (min).

= Volume Pumped to System (gallons).

Time of revolution is taken from the farmer or from the information book of the manufactures, which is an approximate time. Plus or minus fifteen minutes in the estimation time will affect the total water volume applied through the system by 2% differences. The total volume of water caught by the cups is calculated by multiplying the area covered by each cup times the corresponding water depth.

$$A \times d \times \frac{(43560 \times 7.481)}{12} = V_{cc} \text{ -- } (3.7)$$

Where:

A = Area covered by each catch can (acres).,

d= depth of water caught (in.).
V cc = Total Volume caught in Catch Cans (gallons).

3.4.3 Measurement of Speed of the System

The actual speed of a center-pivoted system can bedetermined by measuring either the angle or the circulardistance travelled by the unit with time. In most of theobservations, the speed was calculated by measuring thelength of the arc with a measuring tape. A number of woodensticks were fixed at a distance of about 2 m in the track ofthe first tower for a better measurement of the length ofthe arc- The time interval was measured with a wrist watch.

3.4.4 Pressure Measurement

Pressure at the pivot was measured by a standard pressuregage, installed on the laterat three m from the pivot. The gage was precise to measure 6.g kpa (r psi). Pressurewas checked at frequent time intervals during each experiment.

3.4.5 Flow Measurement

Flow into center-pivot systems can be measured by variousflow-measuring devices and methods such as inferential flowmeters' which give the best results, orifice plates or bymeasuring the pressure at the pivot (Ring and. HeermannLg).In this project, the pressure gage method was used.. However, an attempt was made to double check the flow rates with an orifice meter manufactured in the Agricultural Engineering Department. An orifices plate was installed in a one cm diameter irrigation pipe which was then included into thesupply pipeline. Because of practicaldifficulties the firstmeasurement i,/as taken only at the end of the growingseason- The results of this measurement, however, wereunsatisfactory and subsequent tests were impossible due topoor weather. Therefore, flow had to be determined from themanufacturer's manual on the basis of pressures measured at the pivot.

3.3.9 Evaporation Losses (E):-

The evaporation losses can be calculated as given by Al Elgobari (2007) with the following formula:-

$$E = \frac{D_g - D_w}{D_g} \text{------------------------------------} (3.8)$$

Where:

E = evaporation losses (percent)
D_g = gross application depth
Dw = average weighted depth

Dependability:-

Quality of irrigation service conceptually addresses physical system capability and operation to deliver water per schedule and design .As given by (Molden and Snellen 1993).Seasonal dependability of the system can be obtained by using the following relation:-

f- For Du (Distribution Uniformity):-

Dependability=$\frac{1}{R}\sum_{T=1}^{T=n} CVt * Du$ -- (3.9)

g- For Cu (Coefficient of Uniformity):-

Dependability= $\frac{1}{R}\sum_{R=1}^{R=n} CVt * Cu$---(3.10)

h- For Ea (Application Efficiency):-

i- Dependability= $\frac{1}{R}\sum_{T=1}^{T=n} CVt * Ea$---(3.11)

Where:-
CVt=Coefficient of variation.
R= Crop growth stage.

Chapter 3 : RESULTS AND DISCUSSIONS

4.1 Evaluating System Performance

4.1.1 Coefficient of Uniformity (CU)

Results from the field evaluation and calculated using Christiansen Coefficient of Uniformity (CU) was 86, 88, and 89 % for early, mid, and late season respectively. The descriptive statistics for CU is given in Table 4.1:

Table 3-1General Descriptive statistics for CU

Mean	88.01
Standard Error	0.83
Standard Deviation	1.44
Range	2.85
Minimum	86.47
Maximum	89.33
Confidence Level(95.0%)	3.58

Table (4.1) indicates a mean value of 88 %; with standard error of 0.831.According to Allen (1993), the Christiansen Coefficient of Uniformity (CU) ranked is very good. This very good Christiansen Coefficient of Uniformity (CU) might have been observed due to the fact that the system was new (one year old while the study was made). Regardless of the irrigation method, some parts of a field infiltrate more water than other areas. More drainage below the root zone implies higher non uniformity and differences in infiltrated water throughout the field. These values are higher than those obtained by Ali (2012) for evaluating early season conditions.According to Table 4.1, the obtained CU values are more better than those reported by Ali (2012) for Arab Company for Agricultural Production (79%) , El Bashir Jordanian Company(79%) , Tala Company (85%) and Ras Al Wadi Alakhdar Project (78%). However, Mandoor (2010) reported average CU values of 75.5 % for Center pivot in Nile State. In contrast Saeed (2001) gave arrange of 81.5 to 90.4 % foe CU for center pivot working also in Nile State.

Table 3-2 Changes of CU with time and results of Chi-squire test

Season Stage	CU % Obtained	CU % Recommended
Early Season	86.47127	90-100
Mid. Season	88.24131	80- 89
Late Season	89.32551	0.0 – 79
Chi sq.($P \leq 0.05$)	3.18 Calculated	5.1 Tabulated

As depicted in table 4.2 using Chi-squire test there is no significant difference between the observed CU and the recommended values of (90-100 good, 80-89 fair and 0-79 poor). Figure 4.1 indicate that there is a linear increase of CU values with time. This may be attributed to the increase of evaporation due to rise of wind speed from December (8mph) to March (10mph).

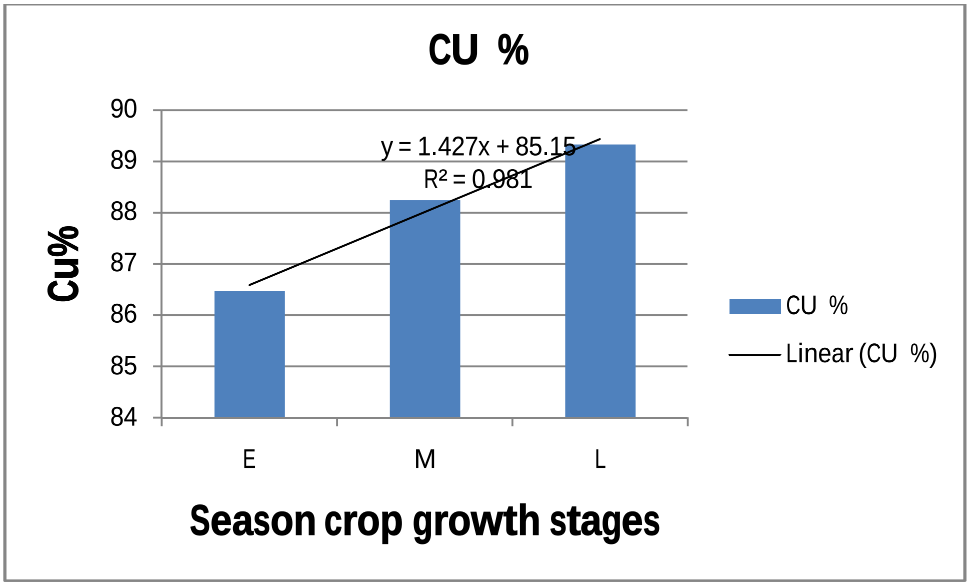

Figure 3-1Variation of CU with time (E=early season, M= mid. season, L= late season)

Likewise,theobtained results of Table 4.2are in agreement with Reuben, et al (2010) reported a center pivot model GP7 had average coefficient of uniformity (CU) of 96.91% while it was 86.28% for model BP5 at Kagera, Tanzania.

Distribution Uniformity (DU)

The descriptive statistics for DU is given in Table 4.3:

Table 3-3General Descriptive statistics for DU

Mean	80.94
Standard Error	1.32
Standard Deviation	2.29
Range	4.54
Minimum	78.49
Maximum	83.03
Confidence Level(95.0%)	5.69

Table (4.4) indicates a mean value of 81 %; with standard error of 1.322.As given in Figure 4.2 DU vary linearly with stage of the season, and shows DU values of 78 % for early season, 81 % for mid-season, a land 83 % for late season. The increase in DU values with season age is typical to that observed for CU results and same reasons given before may be considered as main cause.

These results are higher than those indicated by Salih (2013) who reported an average DU value of 77 % for center pivot working with different speeds and a value of 68 % for the one working at value 100 % and an odd value of 75.6 % recoded at 70%. He attributed the odd value to be due to speed might attributed to some factors such as different spacing between nozzles and wind drifting. The low values of DU can be attributed to clogging of nozzles caused by sedimentation, trashes and/or nozzle being worn out and inaccurate setup of the system. Reuben (2003) reported a value of 75 % for Du for Center pivot in Tanzania.

Ali (2012) evaluated performance of Centre Pivot irrigation Systems in River Nile State and obtained distribution uniformity values ranged from 68 to 78 %. Likewise Ali (2012) recorded that the uniformity of distribution was found to be 78% in El Bashair and Tala project, 71% in Arab company, 68% in Ras El Wadi Project in Sudan. Solomon (1990), Keller and Bliensner (1990) and and Rain Baird (2008) found that the uniformity of distribution ranged from 75 to 85%. Ali (2002) and El Badawi (2001) found uniformity of distribution of about 77%. Similarly, low average values of 65% for DU of Center pivot irrigation in River Nile State were found by Mandoor (2010).

Salih (2013) attributed the odd low DU values (less than 79 %) to be due to speed variations and may also be attributed to some factors such as different spacing between nozzles and wind drifting (Figure 4.2). However the low values of DU can be attributed to clogging of nozzles caused by sedimentation, trashes and/or nozzle being worn out and inaccurate setup of the system.

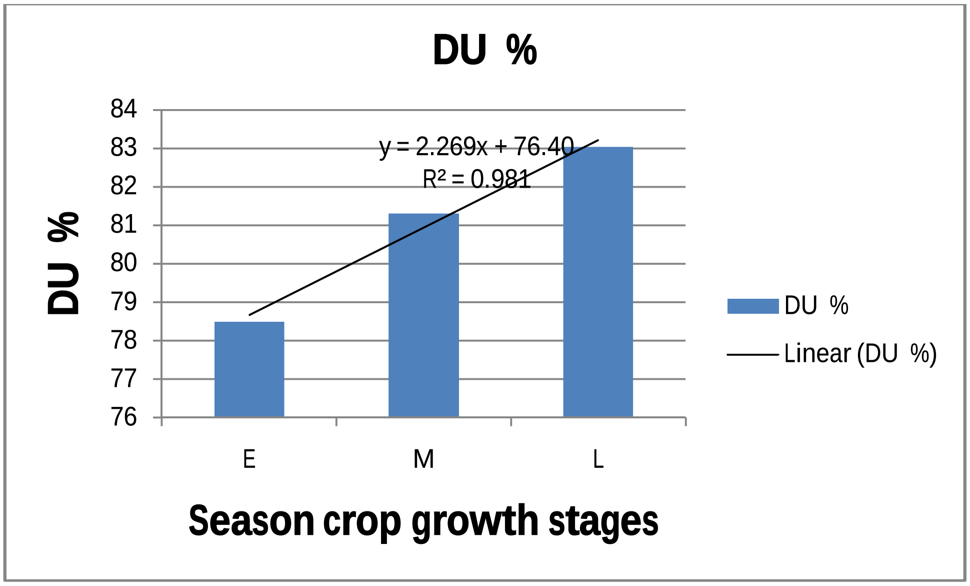

Figure 3-2Variation of DU with time (E=early season, M= mid-season, L= late season)

Data of Table 4.4 shows that there are no significant differences according to chi-squire analysis between the recommended values and those calculated from the experiment.

Table 3-4Changes of DU with time and results of Chi-squire test

Season Stage	DU% Obtained	DU% Recommended
Early Season	78	90-100
Mid-Season	81	80- 89
Late Season	83	0.0 – 79
Chi sq	5.5 Calculated	5.1 Tabulated

4.1.2 Potential Application Efficiency(Ea)

As shown in Table 4.5 the mean value of Ea was found to be 86 %; with standard error of 1.119. From

Table 3-5General Descriptive statistics for Ea

Mean	85.77
Standard Error	1.12
Median	84.98
Standard Deviation	1.94
Range	3.63
Minimum	84.34
Maximum	87.97
Confidence Level(95.0%)	4.82

Figure 4.3 it is clear that no specific trend may be observed for the seasonal variations of application efficiency. It seems that the results are in consistent with those found for either CU or DU.

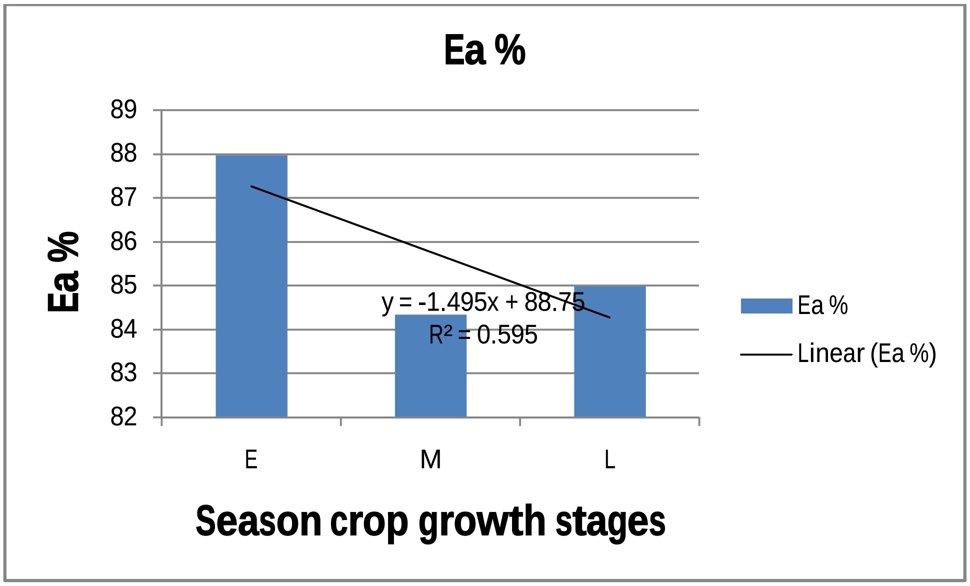

Figure 3-3Variation of Ea with time (E=early season, M= mid-season, L= late season)

Table 4.6: shows changes of Ea with seasonal time and results of Chi-squire test. The results indicate that obtained are in the range of fair to good according to published scale (El Gobari, 2004)

Table 3-6Changes of Ea with time and results of Chi-squire

Season Stage	Ea % Obtained	Ea % Recommended
Early Season	88	90-100
Mid-Season	84	80- 89
Late Season	85	0.0 – 79
Chi sq	2.1 Calculated	5.1 Tabulated

4.1.3 Seasonal Dependability

i- Dependability According to Ea

In this study dependability was measured to diagnose the physical system while the various speeds were tested to evaluate operation mode.

Table 4.7 shows descriptive statistics for coefficient of dependability according to Ea. It indicates a mean value of(93% +1.229)for Ea%

Table 3-7Descriptive statistics for coefficient of dependability according to Ea

Mean	92.98
Standard Error	1.23
Standard Deviation	2.13
Range	4.08
Minimum	91.30
Maximum	95.38
Sum	278.95
Count	3.00
Confidence Level(95.0%)	5.29

According to table 4.8 dependability coefficients for Ea is almost constant irrespective of seasonal variations(93 %), and can be evaluated as good according to scale of Molden - Gates (1990). El Gobari (2004) stated that performance of center pivot with time is direct function of level of maintenance. The obtained results support this claim for the system tested is new and expected to be reliable in its first season.

Table 3-8Dependability Coefficient According to Ea at season various time stages

Season Stage	% Ea mean	Dependability	
		(Dp. of Ea) obtained	Scale of Evaluation
Early	88	92	90-100 Good
Mid	84	91	80-89 Fair
Late	85	95	0 - 79 Poor

ii- Dependability According to CU

Table 4.9 shows descriptive statistics for coefficient of dependability according to CU. It indicates a mean value of 93% with standard error of 1.048 for CU%.

Table 3-9Descriptive statistics for coefficient of dependability according to CU

Column1	
Mean	92.89
Standard Error	1.05
Standard Deviation	1.82
Range	3.63
Minimum	91.03
Maximum	94.66
Confidence Level(95.0%)	4.51

According to Figure 4.4 dependability coefficients for CU is almost constant irrespective of seasonal variations (93 %), and can be evaluated as good according to scale of Molden - Gates (1990). This result is in line with that obtained for dependability coefficient of Ea. The high value of this coefficient may also be due to the fact that the machines used are new (El Gobari, 2004). This result is in agreement with the performance data for CU given in section4.1.1.

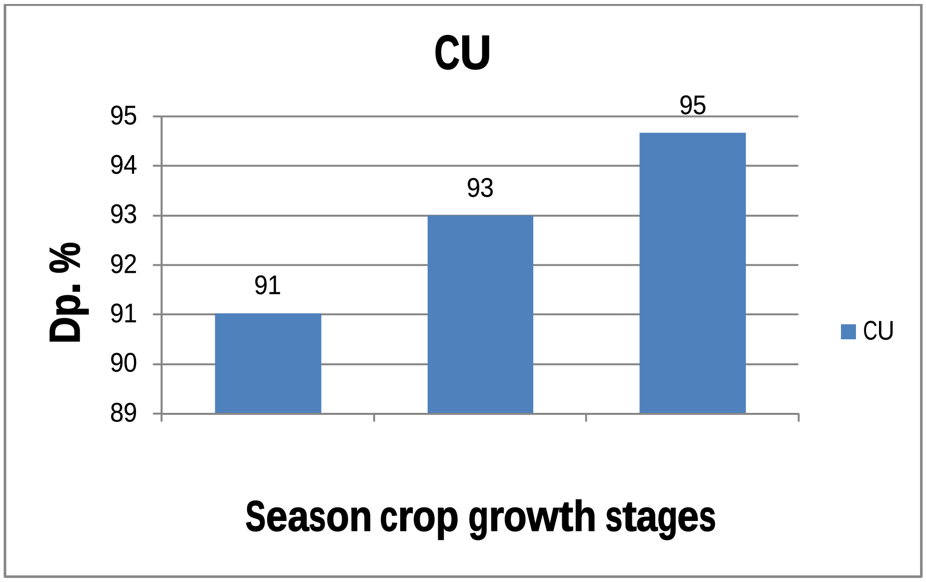

Figure 3.4Dependability Coefficient According to CU at season various time stages

iii- Dependability According to DU

According to table 4.10 the mean coefficient of dependability according to DU is 87 % with Standard Error of 1.849.

Table 3-10Descriptive statistics for coefficient of dependability according to DU

Mean	87.34
Standard Error	1.85
Standard Deviation	3.20
Range	5.77
Minimum	85.26
Maximum	91.03
Confidence Level(95.0%)	7.96

As depicted in table 4.11 the coefficient of dependability according to DU is almost stagnant around fair value in early-mid stages and then increases to good status at season end. However, this result is in line with the general performance of the system reported in section 4.1.2 for DU.

Table 3-11Dependability Coefficient According to DU at season various time stages

Season Stage	%DU mean	Dependability	
		DU obtained	Scale of Evaluation
Early	78	86	90-100 Good
Mid	88	85	80-89 Fair
Late	83	91	0 - 79 Poor

4.2 Impacts of Changing sprinkler operating Speed (50%, 75%, 100%) on system performance

According to Cisneros (1999) the DU is important parameter that combines the concept of efficiency and spatial distribution in a direct manner so it needs to be considered in any evaluation exercise.

4.2.1 Effects of operating Speed (50%, 75%, 100%) on Distribution Uniformity (DU)

Table 4.12 depicts the DU obtained by operating speeds of 50%, 75%, 100% in relation to expected values (Miriam and Killer, 1978). The table indicates that the average Distribution Uniformity is Poor for 75 and 50 % speeds and fair for 100% speed and results of DU is in the range of 73 to 83 %.The Du values estimated by Mandoor (2010) for 60%, 70%, 80% and 100% speed are 55.9, 75.6, 61.9 and 68 % respectively which indicate a range typical to that found in this study.

Table 3-12Variation of DU with Different operating Speed and Scale of Evaluation.

Replication	DU %			Scale of Evaluation	
	100.00	75.00	50.00	Expected	Class
1.00	64.84	71.02	77.62	100.00	Good
2.00	83.00	75.00	83.00	90.00	Fair
3.00	81.00	72.00	86.00	80.00	Poor
Mean	82.21	73.25	74.16		
Evaluation	Fair	Poor	Poor	Overall= Not Satisfactory	

However, according to ANOVAs single factor analysis (Table-4.13) there is no significant differences in the results calculated for DU of various speeds. This result is confirmed by Mandoor (2010) who reported that DU values obtained with different operating speeds (60%, 70%, 80% and 100%) are considered low as compared to standard values under ideal conditions. The results obtained are similar to those obtained by El Badawi (2001), who found the uniformity of distribution about 70% at Umdom project. These low values are attributed by different authors to be due to some factors such as the inaccurate setup of the system (Evan et al., 1996), different spacing between nozzles and wind drift. The low value of distribution uniformity obtained under different system speeds can also be attributed to clogging of nozzles caused by sedimentation, trashes and/or nozzles being worn out (Evan et al., 1996; Mandoor ,2010 and El Badawi , 2001).

The obtained results for DU do not agree with Salih (2013) who found that there was a significant difference at ($P = 0.05$) between treatments. He found that Speed 70% showed exceptionally higher value followed by 100%, 80% and 60% and their values were 75.6%, 68%, 61.9% and 55.9% respectively. He described the results of 75 % as odd result and attributed it to some factors such as different spacing between nozzles and wind drifting. He also suggested that the cause of the low values of DU in the low range of 55.9% to75.6% to be due to clogging of nozzles caused by sedimentation, trashes and/or nozzle being worn out and inaccurate setup of the system.

Table 3-13ANOVAs Single Factor Analysis for DU with different speeds

Speed	average	Variance	source of Variation	Df	F	P-value	F-critical
100%	76.28	99.12	Between Groups	2	1.71	0.25	5.14
75%	72.67	4.3	Within Groups	6	1.7 <5.14		
50%	82.2	18					

*indicate no significant difference

4.2.2 Effects of operating Speed (50%, 75%, 100%) on Application Efficiency (Ea)

As given in Table 4.14 themean Ea obtained by operating speeds of 50%, 75%, 100% are 54, 58, and 79 % respectively. In relation to expected values recommended by Miriam and Killer (1978) they can be evaluated as poor.

Table 3-14Variation of Ea with Different operating Speed and Scale of Evaluation.

Replication	Ea			Scale of Evaluation	
	100.00	75.00	50.00	Expected	Class
1.00	37.90	52.74	88.20	100.00	Good
2.00	39.00	53.00	89.00	90.00	Fair
3.00	39.00	53.00	88.00	80.00	Poor
Mean	53.98	58.44	78.80		
Evaluation	Poor	Poor	Poor	Overall= Not Satisfactory	

According to Table4.15 Single Factor Analysis for Ea with different speeds indicate that the F-value is 8386<5.1, the Null Hypothesis is rejected at 5% significant leveland therefore, we reject the null hypothesis H0: there are significant differences between the different speeds at the 5% significant level.That is we accept the alternative hypothesis H1: there is clear differences between operation speeds and Ea is negatively related to the tested speeds. However, the low Ea values indicate that some water is lost due to seepage and deep percolation in light soils of the study area.

Table 3-15ANOVAs Single Factor Analysis for Ea with different speeds

Speed	average	Variance	source of Variation	df.	F	P- value	F- critical
						4.143	
100%	4	0.40	Between Groups	2	83856	-11	5.14
75%	4	0.02	Within Groups	6			
50%	1	1		8			

*indicate significant difference

4.2.3 Effects of operating Speed (50%, 75%, 100%) on Coefficient of Uniformity (CU)

Table 3-16Variation of CU with Different operating Speed and Scale of Evaluation

CU					
Replication	Speed %			Scale of Evaluation	
	100.00	75.00	50.00	Expected	Class
1.00	84.73	85.51	89.54	100.00	Good
2.00	90.00	85.00	88.00	90.00	Fair
3.00	88.00	86.00	89.00	80.00	Poor
Mean	90.68	82.88	79.14		
Evaluation	Good	Fair	Poor	Overall= Satisfactory	

As given in Table 4.17for ANOVAs Single Factor Analysis for CU with different speeds there is no significant difference at ($p<0.05$) between treatments. According to table 4.16, results obtained are comparable to results reported by someinvestigators in Sudan.Of these research workers Osama (2002) found DU values of 84% and 81% forspeeds 100% and 50% respectively. Likewise, Saeed (2001) obtained CU ranges from 81.5% to 90.4% for center pivot tested under variable wind velocities. The results given in table 4.16 areagrees with those obtained by El Badawi (2001) who found the uniformity coefficient of 85% at Umdom Project. Ayman, (2008) claimed that (CU) values are normally lower than the 85%, for sprinkler systems in Sudan. Heattributed the results to some factors such as different spacing between nozzles and wind drift. According to Evan et al., (1996) and Mandoor (2010)the low value of uniformity coefficients obtained under different system speeds can also be attributed to clogging of nozzles caused by sedimentation, trashes and/or nozzles being worn out.

Table 3-17ANOVAs Single Factor Analysis for CU with different speeds

Speed	average	Variance	source of Variation	df	F	P-value	F-critical
						0.111	
100%	87.57	7.06	Between Groups	2	3.23	3	5.14
75%	85.50	0.25	Within Groups	6			
50%	88.84	0.61		8			

*indicate no significant difference

4.2.4 Effects of operating Speed (50%, 75%, 100%) on Evaporation (E)

Table 4.18: shows variation of E with Different operating Speed and Scale of Evaluation (Merriam and Killer, 1978). The results indicate poor level of performance due to presence of high evaporation which is expected due to the arid nature of the climate of the study area. The low values may also be attributed to presence of high wind drift since there is no shelter belt or any fence to act as wind breaker. This result is in line with the results obtained for Ea.

Table 3-18Variation of E with Different operating Speed and Scale of Evaluation

E					
Replication	Speed %			Scale of Evaluation	
	100.00	75.00	50.00	Expected	Class
1.00	62.10	47.26	11.80	100.00	Good
2.00	61.00	47.00	11.00	90.00	Fair
3.00	61.00	47.00	12.00	80.00	Poor
Mean	71.02	54.06	21.20		
Evaluation	Poor	Poor	Poor	Overall= not Satisfactory	

Single Factor Analysis for E with different speeds given in Table 4.19: indicate significant difference in evaporation with increase in operating speed

Table 3-19ANOVAs Single Factor Analysis for E with different speeds

Speed	Average	Variance	source of Variation	df	F	P-value	F-critical
						4.57	
100%	61.3	0.40	Between Groups	2	3.23	11	5.14
75%	47.08	0.02	Within Groups	6			
50%	11.60	0.28		8			

*indicate significant difference

Chapter 4 : SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1Summary and Conclusions

The main objective of irrigation is to apply to the crop root zone the optimum, amount of water that the crop needs for development and also that cannot be provided by rains. With rising fuel prices it is increasingly important that irrigation systems apply water uniformly in order to achieve maximum benefit from the water applied. When irrigation systems are used to apply fertilizers and pesticides, application uniformity becomes even more critical. Consequently, it is important for center pivot owners and operators to periodically check the uniformity of their systems. In recent year CP irrigation is introduced rapidly in many farms in Khartoum and Nile States of Sudan. However, these systems are installed and operated as per dealer specifications without any adaptation to local conditions in most cases as reported in the literature. In some cases attempts were made to modify system operating speed on basis of experience. Accordingly this study is directed to quantify the actual performance of these newly introduced systems and at the same case avail technical evaluation procedures for producers to use and also give them a technique to test the dependability of their system. To achieve these objectives a case study of a farm in West Omdorman is taken as example.

The result of evaluation exercise reveals the followings:

Evaluation of performance using Cu, Du, Ea, and dependability of these parameters

- i- For Cu and Du performance of CP system does not vary with season significantly and vales are increase linearly with season.
- ii- Ea performance is in the range of fair to good for this new CP system irrespective of crop growth stage.
- iii- Dependability with respect to Ea, Cu, and Du is found to be fair to good according to Molden-Gate scale. This is accepted for using new machines.

1- Impact of changing operating speeds on system performance:

i- Effects of variation of speed on Cu reveals that the obtained Cu values are higher than those reported for Sudan They reach values of 87.6, 85.5 and 88.8 % for 50, 75, and 100% speed respectively.

ii- For Du the results obtained indicate poor levels for low (50%)and medium (75%)speeds, while a higher value of 83% is obtained with the maximum operating speed(100%).

iii- Results of evaluation due to Ea with respect of speed indicate low level of performance in general and the performance increases with increase of speed. This is due to the results of evaluating E where it is found that with low speed evaporation losses increases

5.2 Recommendations

The recommendations drawn from this research are:

1- Although the system tested is new the overall technical performance of the system is fair to good. Hence, periodical evaluation runs are needed more when the system getting older. Thereby the adopted evaluation procedures need to be followed In particular evaluation exercise should be in accordance with crop growth stages.

2- Due to low performance of application efficiency with low speed it is advised not to slow down the system movement in such arid hot climate and it is recommended to install shelter belt to cut down losses by evaporation and wind movement.

3- To improve Du, Ea, and E it is recommended to conduct more studies to select the suitable application rate rather than using blindly dealers recommendations.

References

Adam Hussein S. (2015). Climate Change and Irrigation in Sudan. Sudan Academy of Sciences Journal-Special Issue (Climate Change), Vol. 11, 2015, 115-117 ISSN 1816-8272

Al-Ghobari, H.M. (1996). The Effect of Travel Speed on Spray Losses from Center Pivot Systems. J. of King Saud Univ., vol. 8,Agic. Sciences (1): 111-123.

Al-Ghobari, H.M.(2004). The real distribution of applied water above and below soilk surface under center pivot sprinkler irrigation system. J. of the Saudi Society of Agric. Sciences, vol.2 (2):207-221.

Al Algobari, H.M.(2007). Practical guide for design of sprinkler irrigation systems. King Saud Univ. Scientific Printing and Publications. P.520.

Ali, O., O. (2002) Evaluation of the Performance of Center Pivot Irrigation

Ali O. O. (2012) Performance of Centre Pivot irrigation Systems in River Nile State Nature and Science 2012; 10(12) http://www.sciencepub.net/nature http://www.sciencepub.net/nature naturesciencej@gm 184 ail.com

Allen, R.G,(1993). Irrigation Engineering Principles. Department of Biological and Irrigation Engineering,UtahStateUniversity,Logan,Utah.

ANSI/ASAE S436.1, "Test Procedure for Determining the Uniformity of Water Distribution of Center Pivot and Lateral Move Irrigation Machines Equipped with Spray or Sprinkler Nozzles", Jun1996 (R2007).

Armstrong, D., O'Donell, D., Thompson C. (2001). Irrigation Equipment and Techniques, Module Notes, Irrigation Systems, Department of Primary Industries, Parks, Water and Environment, Australia. Accessed on 15th December 2007 from www.dpiw.tas.gov.au/inter.nsf/Attachments/JMUY-5FLVYP/$FILE/3%20Irrigation%20Systems%20V3.pdf

ASABE Standards S398.1 (MAR1985 (R2006)). Procedure for Sprinkler Testing and Performance Reporting, ASABE, USA. Accessed on 27th July 2007 from http://asabe.org, 933-935

ASAE Standards, ASAE S436, (1994.) Test performance for determining the uniformity of water distribution of center pivot, corner pivot and moving lateral irrigation machines equipped with spray or sprinkler nozzles. pp 546-547, ASAE, St. Joseph, MI 49085.

ASAE.35(5): 1465-1472.. ogers,D.H.,F.R.Lamm,W.Spurgeon.1994b Trans. of the ASAE, vol. 31(2): 538-542 Lin Z, Merkley GP (2011). Relationships between common irrigation application uniformity indicators. Irrig. Sci. Online First™, 27 January 2011.

Ascough, G. W. and Kiker, G. A. (2002). The effect of irrigation uniformity on irrigation water requirements. Africa Journal of Agricultural Research 28: 378 - 473

Ayman, H., (2008) Performance of a Semi Portable Solid Set Sprinkler

Bos MG, Burton MA, Molden DJ (2005) Irrigation and drainage performance assessment. Practical Guidelines. CABI Publishing, Cambridge, MA. ISBN 0851999670.

Burt CM, Styles SW (2004) Conceptualizing Irrigation Project Modernization Through Benchmarking and the Rapid Appraisal Process. In: "Irrigation and Drainage" ©2004 of the International Commission on Irrigation and Drainage (ICID), John

Cisneros, F., Torres, P., and Feyen, J. (1999, June). Quantitative analysis of theperformance of sprinkler irrigation in the southern sierra of Ecuador on slopes steeper than 12%. In Proceeding of the inter-American conference on water resources management, II water meeting (pp. 15-18).

Christiansen, J. E. Irrigation by Sprinkling. California Agricultural Experiment Station, Bulletin 670, 1942.

Dalton, P. and Raine, S. (1999). Measures of Irrigation Performance and Water Use Efficiency, Department of Environmental and Resource Management, Australia. Accessed on 17thAugust 2007.

Davoren, A. (1995). Spray Irrigation: Is Your System up to Scratch, Schools of Isolated and Distance Education (SIDE), New Zealand. Accessed on 13th

December 2007 from http://www.side.org.nz/IM_Custom/ContentStore/Assets/7/39/136a843f72640ce0d71bd44ad0595ff1/Is%20your%20irrigation%20system%20up%20to%20scratch.pdf, 1-3

Derrel LM, Ronald LE (2007). Design and Operation of Farm Irrigation Systems (2 Edition). American Society of Agricultural and Biological Engineers, Michigan

Doorenbos, J., and A. H. Kassam. "Yield response to water." Irrigation and drainage paper 33 (1979): 257.

El Hag, M. M.; El Hiraika, A. A.; El Hadi, S. A. and Saad, S. A. (1994). Characterization of El Rawakeeb Soil. Annual Scientific Report

El Badawi, A.,M. (2001) Center Pivot Performance at Omdoum a Case Study M.Sc., (Agric) thesis, university of Khartoum

Evans, R. G., Han, S., Kroeger, M. W., and S. M. Schneider. (1996). Precision center pivot irrigation for efficient use of water and nitrogen. Proceedings of the 3rd international conf. on precision agriculture. ASA-CSSA-SSSA; Madison, WI, USA, pp. 75-

FAO (2002): FAO (Food and Agricultural Organization), 2002. Deficit irrigation practices. FAO Water Report No. 22. Rome, Italy.

Fischer, G.R. and Wallender,W.W. (1988). Collector Size and Test Durationeffects on Sprinkler Water Distribution Measurement.

Hachum, A. (2006). Performance Evaluation of Sprinkler Irrigation Systems: Symposium on Irrigation Modernization, International Programme for Technology and Research in Irrigation and Drainage, Syria. Accessed on 28th June 2007 from http://dotproject.fao.org/syria/hachum.pdf, pp. 1-24 smith, R.E. 1976. Approximations for vertical infiltration rate patterns. Trans. ASAE 19: (3) 505-509.

Hanson, B.R. and Wallender, W.W. (1986). Bi-directional Uniformity of Water Applied by Continuous-Move Machines. Trans. Of the ASAE,vol.29(4): 1047-1053

Heeley, D. (2005). Understanding Pressure and Pressure Measurement, Application Note, Free scale Semiconductor Inc., USA. Accessed on 28th August 2007.

Heermann, D.F. and Hein, P.R. (1968). Performance Characteristics of Self-Propelled Center Pivot Sprinkler Irrigation Systems. Trans. of the ASAE, vol. 11(1):11-15.

Huck, M. (2004). Irrigation Uniformity, Turfgrass Information Center, USA. Accessedon 27July2007 from http://turf.msu.edu/docs/74th_Conference/Huck_Water_Irrigation.pdf, pp.1-4.

Israelsen, W., Vaughn, E., Hansen, and Oroson, (1967). Irrigation Principles and Practices, Third Edition, New York, USA.

James, G.L. (1988). Principle of Farm Irrigation System Design.

Keller, J., and Bliesner, R.D. (1990). Sprinkle and trickle irrigation. Van Nostrand Reinhold, New York, NY. 652 pp.

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 28th June 2007 from http://info.ag.uidaho.edu/pdf/BUL/BUL0824.pdf, 1-11

Kranz, B., Yonts, D. and Martin, D. (2005). Operating Characteristics of Center Pivot Sprinklers, University of Nebraska-Lincoln Extension, USA. Accessed on 27th March 2007 from www.ianrpubs.unl.edu/epublic/live/g1532/build/g1532.pdf, 1-4

Landwise Inc. (2006). Evaluating Irrigation Efficiency, Hawkes Bay Regional Council, New Zealand. Accessed on 28th June 2007.

Lin Z, Merkley, GP, Pinthong K (2011). Assessing whole-field sprinkler irrigation application uniformity. Irrig Sci. Online First™, 7 July 2011

Lincoln Environmental, (2000). Designing Effective and Efficient Irrigation Systems, Ministry of Agriculture and Forestry, New Zealand. Accessed on 12th December 2007 from http://www.maf.govt.nz/mafnet/rural-nz/sustainable-resource-use/irrigation/designing-irrigation-systems/finalwater09checked.pdf, 1-30

López-Mata E, Tarjuelo JM, de Juan JA (2010). Effect of irrigation uniformity on the profitability of crops. Agric. Water Manage. 98(1):190-198.

Mandor(2010) Evaluation of operation Speed Effect on Center Pivot Irrigation system performance . Acase of study of El Waha and ELZahra Project in northern State(Sudan)

Marjang N., Merkley GP, Shaban M (2011). Center-pivot uniformity analysis with variable container spacing. Irrig Sci. Online First™, 3March 2011.

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

Merkley, G.P., and Allen, R.G.(2003). Sprinkle and trickle irrigation lecture notes (BIE 5110/6110). Dept. of Biological and Irrig. Engrg., Utah State Univ., Logan, UT. 249 pp.

Merriam, J.L., and Keller, J. (1978). Farm irrigation system evaluation: a guide for management. Dept. of Biological and Irrig. Engrg., Utah State Univ., Logan, UT. 271 pp.

Merriam, John L., and Jack Keller,(1973). “Irrigation System Evaluation and Improvement” Utah State University, Logan, Utah, (1973)

Mohamed M. T. (2010) Evaluation of Operation Speed Effect on Center Pivot Irrigation System Performance. A Case Study of El Waha and El Zahra Project in Northern State (Sudan) MSc. Thesis Dept. of Agriculture EngineeringCollege of Agricultural StudiesSudan University of Science And Technology.

Molden, D. J., and T. K. Gates. (1990). Performance measures for evaluation of irrigation water delivery systems. Journal of Irrigation and Drainage Engineering, ASCE 116(6):804–823

Montero, J.; Tarjuelo, J.M. and Ortega, J.F. (2002). Heterogeneity Analysis of the Irrigation in Fields with Medium Size Sprinklers, CIGR, USA. accessed on 27thJuly 2007 from http://cigr-journal.tamu.edu/submissions/volume2/CIGRLW00 _0002/Sprinklers.pdf, 1-11

Murray-Rust DH, Snellen WB (1993) Irrigation system performance assessment and diagnosis (Joint publication of IIMI, ILRI and IHE). Colombo, Sri Lanka:

Phocaides, A. (2000). Technical Handbook on Pressurized Irrigation Techniques, FAO, USA. Accessed on 6http://www.fao.org/waicent/faoinfo/agricult/aglw/ies, 101-112 th August 2007.

Plusquellec HL, Burt CM, Wolter HW (1994) Modern water control in irrigation. Concepts, issues, and applications. World Bank Technical Paper 246. Irrigation and Drainage series. World Bank.

Prajamwong S, Merkley GP, Allen RG (1997) Decision Support Model for Irrigation Water Management. J Irrig Drain Eng 123 (2), 106-113

Rain Bird International, Inc. (2000). Maintenance Guide for Impact Sprinklers, Rain Bird Corporation, USA. Accessed on 20thJune 2007 from http://www.rainbird.com/pdf/ag/imp.pdf, 1-4

Reuben, P. M.1, Mahoo, H.1, Thadei, S.Y.1 & Ernest, E.1 ... Morogoro, Tanzania. Corresponding author: reupal (2003)@yahoo.co.uk

Reuben, P. M.1, Mahoo, H.1, Thadei, S.Y.1 and Ernest, E.1 (2010) Evaluation of the performance of Centre Pivot Sprinkler irrigation system and its effects on crop yield at Kagera, Tanzania Second RUFORUM Biennial Meeting 20 - 24 September 2010, Entebbe, Uganda

Ring, L., and D.F. Heermann. (1978). Determining center pivot sprinkler uniformities. ASAE paper io. 7B-2OOI.

Rogers,D.H.,F.R.Lamm,W.Spurgeon.(1994) b.LEPA Irrigation Management for center pivot. Kansas State University Cooperative Extension, Irrigation Management Series. Kansas State university,Manhattan,Kansas.

Saeed, M., M. (2001) Probable Impact of the Hamadab Dam M.Sc., (Agric). Thesis University of Khartoum. Wiley & Sons, Inc.nternational Irrigation Management Institute.

Salah, A. R., (2013). Evaluation of Speed Effect on Center Pivot Irrigation System Performance at Waha Project under Sudan North State Conditions. International Conference on Civil and Architecture Engineering (ICCAE'2013) May 6-7, 2013 Kuala Lumpur (Malaysia).

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

Seginer, I..; Kanetsu, D; Nir,D.andVonBernuth, R.D. (1992). Indoor measurements of single-radius sprinkler patterns. Trans. of the ASAE, vol. 35(2): 523-533.

Siddig, A.A. and Mohamed, A.E. (1997). Regional study Presented to Arab Organization for Agriculture Development, Khartoum, Sudan (In Arabic).

Small LE, Svendsen M (1992) A framework for assessing irrigation performance. Working Papers on Irrigation Performance No. 1. Washinghton, D.C., International Food Policy Research Institute.

Solomon, K.H. (1990). Sprinkler Irrigation Uniformity, Center for Irrigation Technology, USA. Accessed on 11thMay 2007 from cati.csufresno.edu/CIT/rese/90/900803/index.html

Thooyamani,K. P. and Norum, D.I. (1987). Performance of low pressure center-pivot sprinkler irrigation systems in Saskatchewan. Canadian Agricultural Engineering, 29(2):143-148.Vol.18, No. 5, September/October, 2011.

Vories, E. D., and R. D. von Bernuth. (1986). Single nozzle sprinkler performance in wind. Trans. ASAE 35(4): 1185–1189 Willey and Sons, Inc. New York, USA.

Wilson,T. P. and D. F. Zoldoske, (1997). Evaluating Sprinkler Irrigation Uniformity. http://. wateright. org/site/publications/970703.html.

Appendix A:

Samples of Catch Cane Data Analysis

1	2	3	4	5	6
Span No	Can No Wi	Volume V ml	Depth Xi Mm	Weight Depth Wi*	I (Xi/Dw)-1I
1	1	52000	76.92	76.92	0.64
	2	42333	62.62	125.24	0.33
	3	37667	55.72	167.16	0.19
2	4	42667	63.11	252.44	0.34
	5	36333	53.74	268.70	0.14
	6	39667	14.30	85.80	0.70
	7	42333	62.62	438.34	0.33
3	8	51667	76.42	611.36	0.63
	9	10000	14.79	133.11	0.69
	10	39333	43.39	433.90	0.08
	11	34667	51.28	564.08	0.09
	12	39000	57.69	692.28	0.23
4	13	36000	53.25	692.25	0.13
	14	22333	33.03	462.42	0.30
	15	34333	50.78	761.70	0.08
	16	34667	51.28	820.48	0.09
	17	35333	52.26	888.42	0.11
4	18	36667	54.24	976.32	0.15
	19	27000	39.94	758.86	0.15
	20	30333	44.87	897.40	0.05
	21	31667	46.84	983.64	0.00
	22	33000	48.81	1073.82	0.04
6	23	27000	39.94	918.62	0.15
	24	26000	38.46	923.04	0.18
	25	29333	43.39	1084.75	0.08
	26	32667	48.32	1256.32	0.03
	27	34000	50.29	1357.83	0.07
	28	31667	46.84	1311.52	0.00
7	29	31667	46.84	1358.36	0.00
	30	32667	48.32	1449.60	0.03
	31	32333	47.83	1482.73	0.02
Sum	496	1066333.27	1518.13	23307.41	6.042
			Dw	46.99	

Appendix B:
Samples of Catch Cane Data Analysis

7	8	9	10	11	12	
Wi * I (Xi/Dw)-1I	Sorted Depth Xi mm	Can No	Weight Depth Sort	Sum Can No	Sum Weight Depth	124
						128
0.64	14.30	6	85.80	6	85.80	1
0.67	14.79	9	133.11	15	218.91	1
0.56	33.03	14	462.42	29	681.33	1
1.37	38.46	24	923.04	53	1604.37	1
0.72	39.94	19	758.86	72	2363.23	1
4.17	39.94	23	918.62	95	3281.85	1
2.33	42.90	33	1415.70	128	4697.55	0
5.01	43.39	10	433.90	138	5131.45	0
6.17	43.39	25	1084.75	163	6216.20	0
0.77	44.87	20	897.40	183	7113.60	0
1.00	46.84	21	983.64	204	8097.24	0
2.73	46.84	28	1311.52	232	9408.76	0
1.73	46.84	29	1358.36	261	10767.12	0
4.16	47.83	31	1482.73	292	12249.85	0
1.21	47.83	32	1530.56	324	13780.41	0
1.46	48.32	26	1256.32	350	15036.73	0
1.91	48.32	30	1449.60	380	16486.33	0
2.78	48.81	22	1073.82	402	17560.15	0
2.85	50.29	27	1357.83	429	18917.98	0
0.90	50.78	15	761.70	444	19679.68	0
0.07	51.28	11	564.08	455	20243.76	0
0.85	51.28	16	820.48	471	21064.24	0
3.45	52.26	17	888.42	488	21952.66	0
4.36	53.25	13	692.25	501	22644.91	0
1.92	53.74	5	268.70	506	22913.61	0
0.74	54.24	18	976.32	524	23889.93	0
1.90	55.72	3	167.16	527	24057.09	0
0.09	57.69	12	692.28	539	24749.37	0
0.09	62.62	2	125.24	541	24874.61	0
0.85	62.62	7	438.34	548	25312.95	0
0.55	63.11	4	252.44	552	25565.39	0
57.988	1455.5	552	25565.39	9852	430647.1	6