APPLICATION AND DISTRIBUTION OF IRRIGATION WATER UNDER VARIOUS SIZES OF CENTER PIVOT SPRINKLER SYSTEMS

Zafar Islam*, Abdul Ghafoor Mangrio*, Muhammad Munir Ahmad*, Ghani Akber*, Sher Muhammad**, Muhammad Umair*** and Yaskina****

ABSTRACT:- The field study was carried out to evaluate the comparative efficiency of three low pressure central pivot sprinkler irrigation systems for their water distribution, uniformity and tendency to recommend changes in system maintenance or repair. The main objective of this study was to evaluate existing central pivot sprinkler irrigation systems under field conditions at different locations in the country. The study was carried out to evaluate water distribution under central pivot irrigation systems at three locations; National Agricultural Research Center (NARC), Islamabad, Arid Zone Research Institute, Bahawalpur (AZRI, BWP) and Thana Boula Khan (TBK, Sindh) in Pakistan. Water distribution coefficients used in the evaluation were: Christiansen's coefficient of uniformity (CU %), distribution uniformity (DU %) and scheduling coefficient (Sc %). The results showed that overall mean values for the coefficient of uniformity ranged from 87 to 92%, distribution uniformity ranged from 90 to 93% and scheduling coefficient ranged from 1.07 to 1.12.

The results showed that overall mean value of Christiansen Coefficient of Uniformity (CU) was 87%, 91% and 92% and Distribution Uniformity (DU) was 93%, 92% and 90% of NARC, BWP and TBK locations, respectively. According to review the DU and CU for all center pivot sprinkler systems should be in the range of 85% or greater and 90-95%, respectively, for excellent ratings. Scheduling coefficient of NARC, BWP and TBK locations were obtained 1.09, 1.07 and 1.12, respectively. Also the calculated linear relationship between values of CU and DU in the all sprinkler systems tested in this study is as follows:

$$CU = 100-0.8(100-DU) \quad R2=0.697$$

Key Words: Center Pivot Irrigation, Uniformity Coefficient, Distribution Uniformity, Scheduling Coefficient

INTRODUCTION

Adequate freshwater resources are crucial to human health and environmental integrity, as well as economic growth. Agriculture has been recognized as an engine of economic development of Pakistan and depends fully on the Indus river basin for its survival and sustenance (Bhatti et al. 2009). Pakistan's reliance on a single river system puts it at high risk of water insecurity. The flow pattern of Indus River System is highly uncertain and irregular. The average annual flow of Indus River System is approximately 172 Billion Cubic Meter (BCM) of which presently

* *Climate Change Alternate Energy and Water Resources Institute, National Agricultural Research Center, Islamabad*
** *National Institute of Organic Agriculture, National Agricultural Research Center, Islamabad*
*** *PMAS-Arid Agriculture University, Rawalpindi*
**** *SSRI, National Agricultural Research Center, Islamabad*
Corresponding author: shermuhammadnioa@yahoo.com

119.5 BCM is being diverted for irrigation and the balance outflows into the sea (Bhatti et al. 2009). Kharif (June–October) and Rabi (November–April) are the two principal agricultural seasons in Pakistan. Annually, out of total available water for irrigation, about 84 percent flows during Kharif season and only 16 percent flows during rabi season. Nearly 81 % of river flows and 65% of precipitation occurs during the June to September monsoon. Irrigation plays a key role in addressing the main challenges caused by food insecurity and rainfall uncertainty. The main issues are inadequate availability of water at the critical time of crop growth. About 80% of the cropped area (18.09 million ha) of Pakistan is irrigated and 90% of the agricultural output comes from irrigated land. The net irrigated area is providing about 90 percent of food and fiber requirements of the nation. Irrigated agriculture in Pakistan is not efficient and overall system efficiency is about 45-50% (Bhatti et al. 2009).

Sprinkler irrigation is one of the most common methods used to achieve high application efficiencies of 80-90% as compared to surface irrigation (Mclen et al, 2000). This translated a significant water use reduction of 75% throughout the growing season when utilizing a center pivot compared to surface irrigation (Werner and Krautschun, 2003). A center pivot consists of a lateral circulating around a fixed pivot point. The lateral span is supported above the field by a series of A-frame towers, each tower having two driven wheels at the base. Water is pumped from a well or nearby water source to the center of the pivot and discharged under pressure from sprinklers/ 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.

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., 1994b). Center pivots have proven to be very flexible and can accommodate a variety of crops, soils, and topography with minimal modification. Pivot irrigation systems are invented over 60 years ago to reduce labor requirements, enhance agricultural production, and optimize water use. The number of center pivot sprinkler irrigation systems has increased rapidly in the last decade in Pakistan as automatic and modern irrigation systems. In fact, there were about 66 imported center pivots of different size at private farms in the country as reported unofficially by the company office record. The demand of these systems increased due to shortage in water supply and on the other hand the system's performance efficiency. Without good uniformity, it is impossible to irrigate adequately and efficiently; parts of the field will be either over-irrigated or under-irrigated.

The field evaluation of sprinkler irrigation systems and in particular center pivot irrigation systems is essentially required for efficiency and performance improvement of the system during operation. The evaluation of 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. Therefore, the study was conducted to determine irrigation water distribution and uniformities under each span of the center pivot irrigation system.

MATERIALS AND METHOD

The PARC researchers of Climate Change, Alternate Energy Water Resources Research Institute (CAEWRI) followed a standard evaluation technique (ASAE S436.1) at all three locations in the country after the installation of the systems. The objective of this study was to apply an exact amount of water to the crop by using the respective CU and DU of the system avoiding under and over irrigation application. Therefore, this study was proposed and executed with the specific objective of evaluating the coefficient of uniformity for center pivot sprinkler irrigation in order to address the potential of uniform irrigation application using center pivot sprinkler irrigation.

The main objective was to evaluate the Uniformity Coefficient, Distribution Uniformity and Potential Application Efficiency of Low Quarter under field conditions providing necessary information for more effective water management.

Table 1. Details of CPSIS at each location

Description	Site a	Site b	Site c
Total system span length (m)	144.08	254.13	329.1
Total number of spans	2	4	5
Total area irrigated with end guns (acres)	19.63	50.0	91.89
Water pump capacity (m^3/hr)	59.54	50.72	223.09
Sprinkler system flow (liters/second)	16.54	14.09	14.09

Description of site and center pivot sprinkler irrigation systems (CPSIS)

The study was carried out during the period 2010 to 2012. Three sites of center pivot irrigation systems i.e. NARC, Islamabad (site a), Arid Zone Research Institute, Bahawalpur (site b) and Thana Boula Khan (T.B. Khan), Sindh (site c) were chosen to evaluate the performance of the center pivot irrigation system. These systems of site a, b and c covered an area of 50 acres, 91 acres and 19 acres at 100% timer in 6.59, 7.6 and 4 hours, respectively. The other information for each location is given in Table 1.

Water application and distribution measurement

The uniformity of each type of irrigation system is influenced by different factors. The factors that affect the uniformity of sprinkler systems are given by (Pereira, 1999):

$$DU = f(P, DP, S, dn, WDP, WS)$$

Where:

P = is the pressure at the sprinkler;

DP = is the variation in pressure in the operating set

S = is the sprinkler spacing; dn

is the nozzle diameter influencing discharge and wetted diameter

WDP = is the water distribution pattern, and WS is the wind speed and direction.

The most common procedure was used for the evaluation of center pivot uniformity to measure the application depth by using catch cans for the collection of water. The most common standards used internationally for evaluating the uniformity of center pivot irrigation systems was ASAE S346.1, (1999) and National Engineering Handbook, (1983). As recommended by the ASAE standard, two radial lines of catch cans were laid but not more than 50 m apart at the outer end. Both standards recommend calculating the uniformity with the Heermann and Hein (1968) modified equation for the Christiansen (1942) uniformity coefficient.

Uniformity coefficient, uniformity of distribution and scheduling coefficient were determined using catch cans for the collection of water from

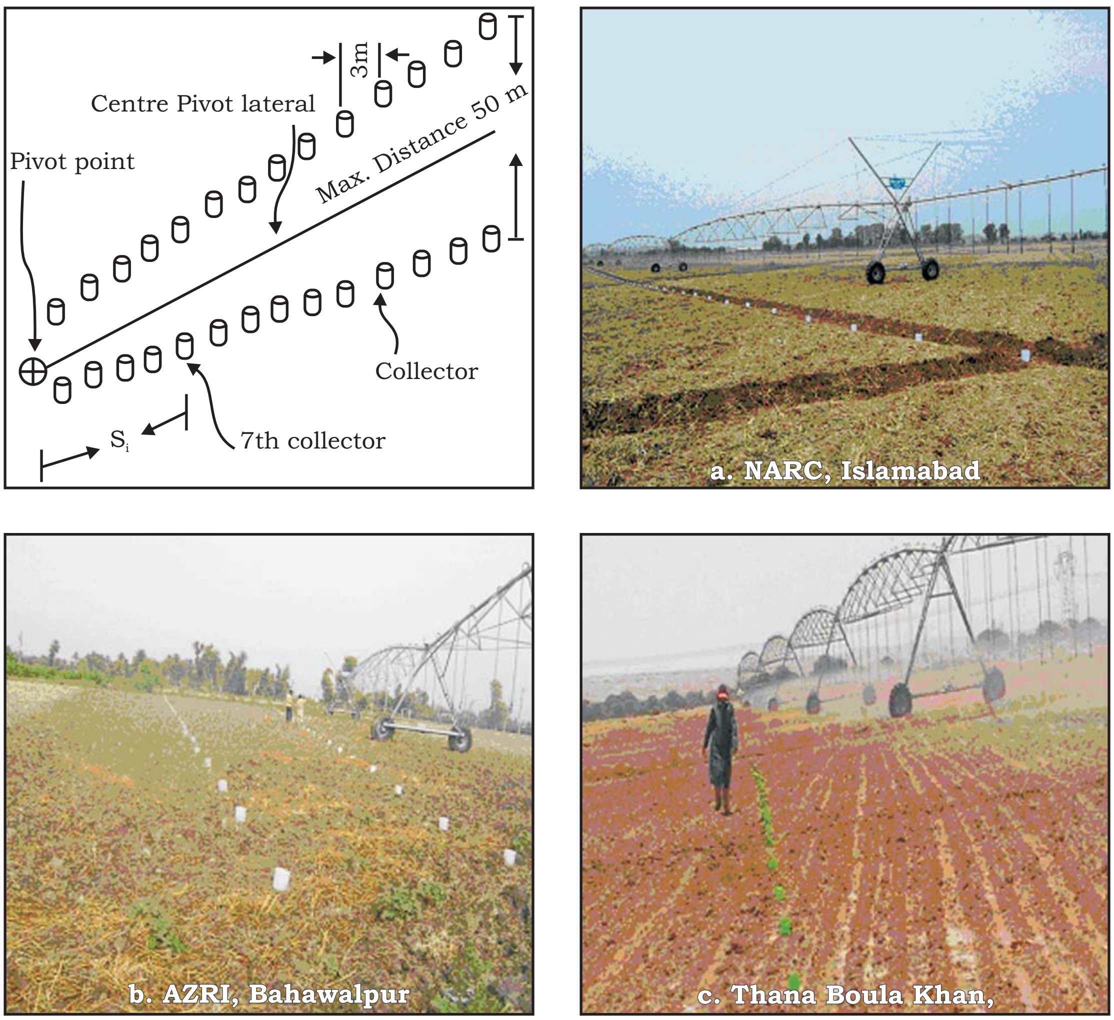

Figure 1. Placement of cans for water collection along span length at a, b and c sites

the sprayers. The cans were placed at 3 meters equal distance from the pivot point towards the outward direction as shown in Figure 1. The center pivot system was allowed to pass over the cans and volumetric measurements with a graduated cylinder were made to measure the water caught in each can. To obtain the water depth in a can, the collected volume in that can was divided by the cross sectional area of the can.

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

Coefficient of uniformity (CU)

A measurable index of the degree of uniformity from any sprinkler operation is known as coefficient of uniformity. The measure most commonly used is Christiansen coefficient of uniformity and is expressed as percentage (%). 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. 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 (Zoldoske et al., 1994).

The coefficient as stated by Christiansen (1942) can be written as follows:

$$CU(\%) = \frac{100[1-\sum x]}{mn}$$

Where:

CU = Coefficient of uniformity (percent).

x = deviation of individual observation from the mean (mm).

n = number of observations.

m = mean value of observation (mm).

Distribution Uniformity (DU)

DU compares the lowest quarter of the water depth caught to the entire set of data from the catch cans. DU is useful as an indicator of the magnitude of the distribution problems. DU was calculated by dividing the weighted average of the lowest quarter of samples by the average of all samples. A DU 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).

The uniformity of distribution was computed by dividing the mean low quarter caught in the cans by the average depth caught in all cans (Ali, 2002).

$$Du(\%) = \frac{\text{average of the lowest quater of sample}}{\text{average of all samples}} \times 100$$

Scheduling Coefficient (Sc %)

Scheduling coefficient is determined to find the critical area in the water application pattern. This is the area receiving the least amount of water, which is divided by the average amount of water applied through the irrigation area (Solomon, 1988).

$$SC\ (\%) = \frac{1}{DU}$$

Where:

Sc = scheduling coefficient.

DU = uniformity of distribution (in decimal).

This method enables specific observation of the water distribution map and location of the field that receives the minimal water portion. The Sc measurement enables planning of the irrigation portion and the required extra irrigation, based on the field that receives the minimal portion. For example, scheduling coefficient 1.3 means that the minimal area receives 30% less than the average.

The Sc coefficient can help us to select a better solution than the CU values for different sprinklers or spacing. It is the best measure but in-field measurement is impractical. The critical difference between DU and Sc is that Sc uses adjoining area. This contiguous area is typically defined as 1%, 2% or 5% of the irrigated area.

RESULTS AND DISCUSSION

Irrigation Water Depth Under Various Spans

The objective of the work was to study the performance of the center pivot sprinkler system as it was practically applied. The approach was considered to give an evaluation based on actual application more than the potentialities of the design. Figure 2 shows application depth of irrigation water of all three sites (a, b and c) along the span length from the pivot.

From Figure 2 it can be noted that there is sudden drop in irrigation depth near the end of site c. this is because sprayer was installed instead of end gun at the center pivot installed at site c. The application rate of water of sprayer is less compare to the end gun, therefore, it shown drop in application depth for site c. Catch cans placed in the twenty percent of the system length closest to the center pivot point were ignored, deleted catch can data from the outer edge of the wetted area when the volume was less seventy percent of the average and three percent of the data points removed due to an ex-treme deviation from the average (Lyndon, 2007). This was done after removing the outer edge data to define the effective irrigated area and removing up to 20 percent of the inner area data. A few catch cans collected extreme data that was not repre-sentative of the system area, like water running from a trust rod or brace rod directly to the cup were not considered.

The following table presents guide lines for the systems uniformity acceptable by the American Society of Agricultural & Biological Engineers. Although slightly lower uniformity ranges may be acceptable in humid

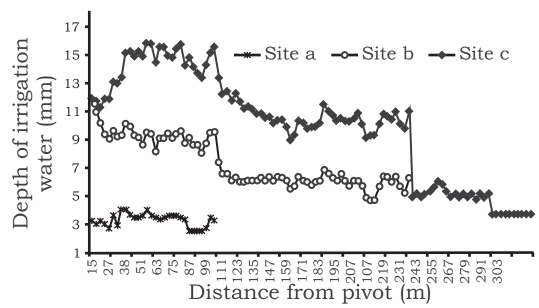

Figure 2. Water application depths from pivot point along span of a, b and c sites

Table 2. Uniformity acceptance ranges.

CU	Guidelines	DU	Guidelines
>95%	Excellent	>90%	Excellent
85-90%	Very Good	80-90	Good
80-85%	Good	70-80	Adequate
75-80%	Fair	60-70	Fair
<75%	Poor	<60%	Poor

Table 3. Average performance coefficients of center pivot systems at various sites

Location	Coefficient of Uniformity (%)	Distribution Uniformity (%)	Scheduling Coefficient (%)
a; NARC, Islamabad	87 (very good)	93 (Excellent)	1.07 (Acceptable)
b; AZRI, Bahawalpur	90 (Excellent)	92 (Excellent)	1.09 (Acceptable)
c; TB Khan, Sindh	92 (Excellent)	90 (Excellent)	1.12 (Acceptable)

areas, as 80% is the minimum acceptable uniformity when fertilizers are applied through the system. Coefficient of uniformity of 100% is an ideal one but not possible. The other level of acceptance of CU is shown in Table 2.

A CU of 91 to 95% is very good to excellent and 85 to 90% is good to very good. If CU is less than 85%, it can easily be improve by checking sprinklers for plugged or enlarged nozzles or the wrong nozzle size for the location on the irrigation system. A DU above 90% lies in the system excellent performance range but 81 to 90% is a good performance range of the system.

The calculated values of coefficient of uniformity, distribution uniformity and scheduling coefficient for the three sites of evaluation are shown in Table 3.

An 87% CU of the system at site a, indicates that some areas of the field are receiving 13% less water and some areas are receiving 13% more than the average applied. Similarly, 93% DU of the same location indicates that some areas in the field in which 7% less water is distributed from the average applied.

Table 4 shows the coefficient of uniformity (CU), distribution uniformity (DU) and scheduling coefficient (Sc) of each span of the system at each site whereas Table 3 shows the average of the system performance values

Table 4. Coefficient of uniformity (CU), distribution uniformity (DU) and scheduling coefficient under various spans

Span no.	Site a; NARC			Site b; BWP			Site c; TBK		
	CU (%)	DU (%)	Sc (%)	CU (%)	DU (%)	Sc (%)	CU (%)	DU (%)	Sc (%)
1	69.17	99.49	1.01	87.16	88.46	1.13	80.39	74.05	1.35
2	92.41	94.8	1.05	92.63	94.28	1.06	95.12	96.23	1.04
3	94.8	95.74	1.04	92.27	93.65	1.07	88	90.34	1.11
4	91.08	88.83	1.13	-	-	-	95.58	94.4	1.06
5	-	-	-	-	-	-	93.4	92.78	1.08
Overhang	89.45	88.4	1.13	-	-	-	100	94.4	1.06
Average	87.38	93.45	1.07	90.69	92.13	1.09	92.08	90.37	1.12

along the span. Table 4 shows that CU and DU of all the systems are in the range of very good to excellent whereas CU and DU of site a and c of the first span is in poor and adequate range, respectively.

Center Pivot Performance Coefficients

a) *Coefficient of uniformity;* Water application uniformity is an important performance criterion for the design and evaluation of center pivot irrigation systems. System uniformity coefficient is a numeric judgment of the overall performance of an irrigation system's ability to evenly apply water to the field. However, the water application depth of a center pivot irrigation system is not usually uniform across a field as it depends on the sprinkler package, field topography, movement of the machine, and many other factors. In addition to that wind distortion of sprinkler distribution patterns is a major dynamic factor (Evans, 2001). The uniformity coefficient for the systems of the study was found to be 87% in NARC, 90% in AZRI (BWP) and 92% in TB Khan. The results of all locations were obtained in a range of 87 to 92%. According to Zoldoske et al. (1994), CU of AZRI (BWP) and TB Khan system lies in a range of excellent and only requires regular maintenance. Although the CU of NARC system is considered as good and does not need major adjustments but regular maintenance and inspection are required. Therefore, CU of all the systems is in good and excellent range.

b) *Distribution uniformity*; The uniformity of distribution was found to be 93% in NARC, 92% in AZRI (BWP) and 92% in TB Khan. Solomon (1988), Keller and Bliensner (1990) and Jorge, Pereira, (2002) and Rain Baird (2008) found uniformity of distribution in different projects which were ranged from 75 to 85% and declared as satisfactory. However, A DU of 85% or greater is considered excellent and 80% is considered very well (Merriam et al. 1973). Therefore, DU of all the systems lies in an excellent range.

c) *Scheduling coefficient;* Irrigations should be scheduled based on soil water levels to avoid undesirable levels of crop stress. This is compounded by the light frequent water applications, shallow rooting and cultural operations such as fertigation, spraying of chemicals and tillage programs (Evans, 2001). This test allows to provide a time adjustment factor to ensure that the dry or under watered areas receive adequate depth of application. To assess the performance of the center pivot system, there is a need to measure the pressure and flow at various points in the system, the operating speed at the far end, and the output of the sprinklers using catch cans.

If Sc= 1	No deviation, the entire field is uniform.
Sc = 1-1.5	Scope of results is reasonable.
Sc > .0	Bad results, not recommended.

SC was used because it depends on DU determination. Connellan (2002) and Abdelrahaman (2006) mentioned that an efficient irrigation system should aim to achieve an SC of less than 1.3.

The scheduling coefficient (SC) is found 1.09 in NARC, 1.07 in AZRI (BWP) and 1.12 in TBK systems, respectively. Values obtained at the three locations are below the limit i.e. 1.3 which indicates the scope of results is reasonable.

Recommendations

- Regular system maintenance including repair, adjustment or modification is necessary to keep the system operated efficiently.
- To save operation costs and conserve water, it is suggested that CUs are measured periodically (at least once a year). When coefficients fall below the desired values, system repairs and adjustments needs to be scheduled.
- Water pressure should be tested at the sprinkler outlet to ensure that each sprinkler operates at the design pressure which affects the overall DU and CU which gives low or high volume caught in catch cups.
- Low uniformities in the center pivot system have compounding negative effects when fertilizer is applied. Therefore, any major leaks and poor end gun performance need to be fixed or adjusted to insure the highest uniformity possible.
- The system should be operated when wind velocity is in the recommended range.
- Operating of the pressure regulation for all spray sprinklers should be checked and replaced when needed.

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AUTHORSHIP AND CONTRIBUTION DECLARATION

S. No	Name	Contribution to the paper
1	Mr. Zafar Islam	Conceived the idea, Abstract, introduction, Data Collection, results and discussion
2.	Mr. Abdul Ghafoor Mangrio	Technical input, references
3.	Dr. Muhammad Munir Ahmad	Overall management of the article
4.	Dr. Ghani Akber	Methodology, analysis
5.	Dr. Sher Muhammad	Technical input at every step
6.	Dr. Muhammad Umair	Wrote abstract, conclusion
7.	Ms. Yaskina	Data collection

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