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EFFECTS OF CENTRE PIVOT SYSTEM SPEED CONFIGURATION ON WATER APPLICATION EFFICIENCY AT KUKOBILA NASIA FARMS LIMITED IN THE SAVELUGU MUNICIPALITY, NORTYHERN REGION OF GHANA.

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Abstract

The study was carried out during the period February-April, 2018 at Kukobila Nasia Farms Limited, to evaluate performance of the centre pivot irrigation systems (pivot one and two) at six (6) different operating speed levels (43 m/h, 68 m/h, 85 m/h, 102 m/h, 136 m/h and 170 m/h) to ascertain the speed which gives best uniformity and efficiency of water application. The study revealed that CU obtained from centre pivot one and two ranged from 80.3-86.9 % and 75.6-84.4 % respectively. Similarly, DU computed from pivot one ranged from 60.2-68.5 % whereas pivot two had DU ranging from 65.3-73.2 %. DU increased as the speed of operation of centre pivot increased as general trend. The lower values recorded for pivot one at 170 m/h and 102 m/h operating speed levels and that of pivot two at 136 m/h operating speed were attributed to wind drift. The SC obtained from pivot one and two were above the lower acceptable limits and ranged from 1.46-1.66 and 1.37-1.53 respectively. **Ea** of pivot one ranged from 80.3-98 % except at 170 m/h operating speed which recorded **Ea** of 56 %. Similarly, pivot two had **Ea** ranging from 51-89 % with **Ea** from operating speeds of 102 m/h and 43 m/h meeting SABI norms. The values of PELQ were low and unacceptable as they ranged from 35-73 % and 38-61 % for pivot one and two respectively. The values of AELQ were also low as they ranged from 34-64 % for centre pivot one and 35-56 % for center pivot two. Wind distortions of sprinkling uniformity and standardisation of pivot operating speed to match with crop water requirement were major constraints to attaining high application efficiency. Periodic inspection, cleaning and replacement of clogged and or worn-out nozzles and night irrigation during windy periods should be done.

Keywords: Coefficient of Uniformity, Distribution Uniformity, Scheduling Coefficient, Application Efficiency, Potential Application Efficiency of Low quarter and Actual Application Efficiency of Low quarter.

1.0 Introduction

The global population is forecast to grow by over 2.3 billion people between 2009 and 2050. Almost all of this growth is prefigured to come to pass in the developing countries, of which the sub-Saharan Africa's population would grow the fastest at a rate of 114 % (FOA, 2009).

In Ghana, where agriculture is the pivot of the nation's economy, population is expected to rise to about 33 million (Statistics of the World, 2012) and as a result, the demand for food will increase (FOA, 2009). In numerous parts of the world, rainfall distribution and intensity are not adequate to meet the moisture requirement of crops necessary to produce sufficient grain and fiber to meet the need of people (Michael, 1978). It is largely recognised that irrigation is one of the cultural practices that stabilizes yields and enhances productivity in any agricultural development (Teeluck, 1997).

Irrigation is the application of water artificially to the soil for crop production (Rogers and Wilson, 2000). Irrigation systems are mechanisms that permit water to be turn aside from its primary source and applied to agricultural fields with the objective of adding on moisture for crops growing. The main irrigation system practiced in Ghana is the surface irrigation system. The labour requirement for this system is higher than modern irrigation systems such as sprinkler and drip irrigation systems, which have high efficiency, low water losses and low labour demands (Ali, 2002).

Centre pivot irrigation systems were recently introduced into Ghana through Kukobila Nasia Farms Limited, Integrated Water and Agriculture Development (IWAD), Cassi Farms, Vivacity Farms, Sakfos Farms, among others as supported by Ghana Commercial Agriculture Project (GCAP). A centre pivot consist of numerous segments of pipes joined together and supported by trusses mounted on wheeled towers with sprinklers positioned at equal intervals along its length (Mader, 2010). The centre pivot moves round when operated and is supplied with water from the pivot at the centre of the circle. Typically, centre pivots are less than 500m in length with most common size being 400m long (Gene, 2008). The longer the main lateral, the quicker the end drive unit travels and the bigger the area irrigated by the end section. Thus the discharge rate of water must increase progressively from the pivot to the overhang to secure a uniform application (Abdelrahman, 2006). Presently, there is no or little information available about performance of the system in the irrigation projects that have adopted centre pivot irrigation system in Ghana. There were two Zimmatic Centre Pivots in operation at the study area with each of them covering 20 ha of land. The systems were installed in 2015 and since operation till date; the centre pivots have not been evaluated for system performance to ascertain whether the performance of the system was efficient or needed improvement. Meanwhile, the centre pivots have been suffering from operational defects such as pipe leakages, tower tyre deflation and wind drift effects which affect efficient and reliable water delivery and distribution on the field. Owners are using available general operating guidelines from the manufacturer for the operation and management of system. Factors such as efficiency of system, rates of application and uniformity of application are unknown. The study evaluated field operational performance of the centre pivot irrigation system at Kukobila Nasia Farms Limited in the Savelugu Municipality, Northern Region of Ghana with the aim of determining the effects of centre pivot speed configuration on water application uniformity and efficiency.

Materials and Methods

2.1 Description of Study Area

The study was carried out during the period February - April, 2018 at Kukobila Nasia Farms Limited in the Savelugu Municipality, Northern Region of Ghana. The project area can be accessed through a trunk of road about 4 km westwards of Kukobila township on the Tamale-Bolgatanga road. It lies approximately around latitude 10.10802^o north and longitude 000.81926^o west of the equator.

2.2. Materials

Materials used to carry out the study were: Double ring infiltrometer, Global positioning system (Garmin eTrex), 80 catch cans (11 cm height and 8.2 cm width), two graduated cylinders (14 ml and 100 ml), tape measure (50 m), rule (30 cm), wooden pegs, 10 liter container, stop watch, soil auger, hydro sensors and pressure gauge.

2.3. Measurement of Soil Infiltration Rates

A double ring infiltration was used to conduct infiltration tests on the soil at various pivot sites (plate 2.1). The circular irrigable area of each pivot was divided into four (4) quadrants, namely; North-East, North-West, South-East and South-West with infiltration test conducted on each quadrant of the pivot. The infiltrometer was hit into the desired depth and a 30 cm rule placed firmly in the centre to stand upright.

The infiltrometer was filled with water (both the inner and outer ring) to the same height. Readings were taken by recording the time taken for the water to infiltrate into the soil.

Infiltration rates at various quadrants of the pivot were computed using Kostiakov equation (1932).

$i = a\,(t)^{b}$

Where:

i = infiltration depth, cm

t = time taken, min

a and b = empirical constants.

Plate 2.1: Infiltration Test Conducted on Soil at Each Sector of the Pivots (Field Work, 2018)

2.4. Measurement of System Performance

Uniformity of Distribution (UD), Uniformity Coefficient (UC), Scheduling Coefficient (SC), Application Efficiency (AE), Potential Application Efficiency of low quarter (PELQ) and Actual Application Efficiency of low quarter (AELQ) were determined using spray cans (plate 2.2) as described by Peter (2010) and ASAE (1993). The catch cans were placed at 3 m apart in a straight line from the pivot point towards the end drive unit and the overhang. The centre pivot was allowed to pass over the catch cans and volumetric measurements with a graduated cylinder were carried out to measure the water caught in each can. To determine the depth of water in a can, the collected volume in the catch can was divided by the cross sectional area of the catch can.

Plate 2.2: Field Measurement of Water Application using Catch Containers (Field Work, 2018)

2.4.1 Coefficient of Uniformity (CU)

CU describes the uniformity of flow of emitters along the span of the centre pivot system under a given condition. It is thus an index of irrigation uniformity (Solomon and Jorgensen, 1992). One of the standard quantitative measures of irrigation uniformity is the Christiansen Uniformity Coefficient (CU) expressed as percentage. The coefficient of uniformity as given by Christiansen (1942) can be written as follows:

$$CU = 100\left[1 - \frac{\Sigma X}{mn}\right] \qquad \textit{Equation 2.1}$$

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)

2.4.2 Distribution Uniformity (DU)

The distribution uniformity was determined by the dividing the mean lower quarter caught in the catch cans by the average depth caught in all cans (Ali, 2002).

$$DU\% = \frac{mean\ low\ quater\ caught\ in\ the\ cans}{average\ depth\ caught\ in\ all\ the\ cans} \qquad \textit{Eqn 2.2}$$

2.4.3 Scheduling Coefficient (SC)

Scheduling coefficient is ascertained to discover the critical area in the water application pattern. This is the area experiencing the smallest amount of water applied through the entire area irrigated (Solomon, 1988).

$$SC = \frac{1}{DU} \qquad \textit{Equation 2.3}$$

Where:

SC= Scheduling coefficient

DU= Distribution uniformity (decimal)

2.4.4 Application Efficiency (Ea)

Application Efficiency (Ea) according to Merriam et al. (1983) is computed as:

$$\mathbf{Ea} = \frac{Average\ \ Depth\ of\ Catch\ Receive}{Avereage\ Depth\ of\ Water\ Applied\ at\ Nozzles} \times 100 \qquad \textit{Equation 2.4}$$

2.4.5 Potential Application Efficiency of Low Quarter (PELQ)

As given by Merriam et al. (1983), Potential Application Efficiency of Low-quarter (PELQ) is determined using the equation:

$$PELQ = \frac{Average\ Low{-}quarter\ Depth\ of\ water\ Received}{Averege\ Depth\ of\ water\ Applied\ at\ Nozzles} \times 100 \qquad \textit{Equation 2.5}$$

2.4.5 Actual Application Efficiency of Low Quarter (AELQ)

As given by Merriam et al. (1983), AELQ

is determined using the equation:

$$\text{AELQ} = \frac{\text{Average Depth of Water Infiltrated and Stored at Root Zone Depth}}{\text{Average Depth Applied at Nozzles}} \times 100 \qquad \textit{Equation 2.6}$$

3.0 Results and Discussion

3.1 Soil Infiltration Rates Measurements

The soil physico-chemical analyses carried out suggested that the main soil textural class in the irrigable area where both centre pivots operate is sandy loam. The average application rate through the entire centre pivots (pivot one and two) was computed to be 78.22 mm/h and 109.63 mm/h respectively; compared to the average infiltration rate of 61.32 mm/h for centre pivot one and 105.14 mm/h for soil at centre pivot two. However, the average application

rates of the overhang for centre pivot one and two were 118.52 mm/h and 242.96 mm/h respectively; compared to average infiltration rate of 61.32 mm/h for pivot one

and 105.14 mm/h for pivot two. These values (average application rates of water at centre pivot including overhang) are higher than the average infiltration rates and could lead to surface ponding, run-off and non-uniformity of distribution of applied water at both centre pivots especially when operated at low speed level. This can be attributed to nozzles being worn out and or nozzles with smaller wetted diameter being installed at the overhang.

3.2 Field Operational Performance Calculated values for Coefficient of Uniformity (CU), Distribution Uniformity (DU), Scheduling coefficient (SC), Application Efficiency (**Ea)**, Potential Application Efficiency of low quarter (PELQ), Actual Application Efficiency of low quarter (AELQ), Average Application Depth (AAD) and Volumetric Water Content (VWC) for both centre pivot one and two are tabulated in Table 3.1.

Table 3.1: Results of Uniformity, Application Efficiency and Depth of Application for Centre Pivot One and Two

Operating speed (m/h)	Centre pivot	CU (%)**	DU (%) **	SC**	Ea (%) **	AELQ (%)**	PELQ (%)**	AAD (mm) **	VWC (%)*
170 (100 %)	Pivot one	80.3	61.4	1.63	56	34	35	1.69	10.4
	Pivot two	77.2	73.2	1.37	51	35	38	1.89	10.3
136 (80 %)	Pivot one	85.3	68.5	1.46	90	57	62	3.26	10.6
	Pivot two	75.6	65.3	1.53	69	44	45	3.11	10.8
102 (60 %)	Pivot one	82.8	60.2	1.66	94	50	56	4.29	11.4
	Pivot two	81.2	71.5	1.39	85	53	61	4.83	11.5
85 (50 %)	Pivot one	84.2	68.1	1.47	87	54	59	4.86	13.1
	Pivot two	84.4	70.2	1.43	83	51	58	5.71	13.0
68 (40 %)	Pivot one	86.9	64.8	1.54	92	56	60	6.54	14.8
	Pivot two	75.7	69.2	1.45	70	46	48	6.13	14.4
43 (25 %)	Pivot one	85.9	63.4	1.58	98	64	73	12.59	22.6
	Pivot two	79.5	67.9	1.47	89	56	60	11.98	20.2

Source: * - Field Measurements, 2018 and ** - Desk Computation, 2018.

3.2.1 Coefficient Uniformity (CU)

The CU obtained from centre pivot one and two at various operating speed levels are outlined in Table 3.1. The CU obtained in centre pivot one and two raged from 80.3-86.9 % and 75.6-84.4 % respectively. Henggeler and Vories (2009) stated that a CU greater than 90 % is excellent, CU of 85-90 % is good, CU of 80-85 % is fair and CU below 80 % is poor. CU obtained for centre pivot one operating at 136 m/h, 68 m/h and 43 m/h speed levels were good as suggested by Henggeler and Vories (2009) while CU from operating speeds of 170 m/h, 102 m/h and 85 m/h were fair as earmarked by Henggeler and Vories (2009). For centre pivot two, CU obtained from the operating speed levels of 102 m/h and 85 m/h were fair as recommended by Henggeler and Vories (2009) while CU from the operating speeds of 170 m/h, 136 m/h, 68 m/h and 43 m/h were below the acceptable range. However, other authors had CU below the acceptable range – Ghorbani and Amini (2011) had CU ranging from 76-81 %. Mandor and El Sadig (2010) had CU of 75 % and Ali (2002) had CU ranging from 78-85 %.

3.2.2 Distribution Uniformity

The uniformity of distribution obtained from various speed levels for centre pivot one and two is tabulated in Table 3.1. DU obtained from both centre pivots (pivot one and two) ranged from 61.4-68.5 % and 65.3-73.2 % respectively. Salah (2013) had DU ranging from 55.9-75.6 %. The DU obtained at Kukobila Nasia Farms for centre pivot one and two were within the range reported by Salah (2013). In addition, DU increased as the speed of operation of the centre pivot increased as usual trend. Results obtained for centre pivot one at 170 m/h and 102 m/h operating speed levels and that of pivot two at 136 m/h operating speed did not correspond to the increasing trend as the speed was increased and this can be attributed to wind drift. The low values realised from both centre pivots can be attributed to clogging of nozzles as a result of sedimentation or trashes and inaccurate design of system (wide spacing of nozzles at span one, two and three of both pivots).

3.2.3 Scheduling Coefficient

The scheduling coefficient obtained from centre pivot one and two at various speed levels is tabulated in Table 3.1. Values of SC for centre pivot one and two ranged from 1.46-1.66 and 1.37-1.53 respectively. These high values arose as a result of low distribution uniformities (DUs) obtained from both pivots. According to Connellan (2002) and Abdelrahman (2006), an efficient irrigation system should aim to accomplish a SC of less than 1.3. Results obtained at Kukobila Nasia Farms centre pivot irrigation system were above the lower acceptable limit reported by Connellan (2002) and Abdelrahman (2006). This can be attributed to wind distortions which affect sprinkling uniformity and or inaccurate design of system.

3.2.3 Application Efficiency (Ea)

The application efficiency (**Ea**) obtained from centre pivot one and two at various speed levels are presented in Table 3.1. Values of **Ea** obtained for pivot one and two ranged from 56-98 % and 51-89 % respectively. Though centre pivot one exhibited low distribution uniformities, it

recorded higher efficiency of application. Pivot two also recorded low distribution uniformities but only **Ea** obtained from 102 m/h and 43 m/h operating speed levels were higher (85 % and 89 % respectively) and within the acceptable limit as earmarked by South African Irrigation Institute (SABI) (2000). The application efficiencies were high because the average depths emitted from the sprinklers compared to the mean depths received on the ground were almost similar.

3.2.4 Actual Application Efficiency of Low Quarter (AELQ)

The actual application efficiency of low-quarter (AELQ) for centre pivot one and two at various operating speed levels are tabulated in Table 3.1. Values of AELQ obtained for centre pivot one range from 34-64 % while that of pivot two range from 35-56 %. These values are low and can be attributed to managerial gaps such as management inability to standardise centre pivot operation speed to match water application with crop water requirements and carry out periodic inspection, identification and cleaning of clogged nozzles and replacement of worn out nozzles. This is the only efficiency term that should be employed to compare systems or methods (Merriam et al., 1983).

3.2.5 Potential Application Efficiency of Low Quarter (PELQ)

The potential application efficiency of low quarter (PELQ) under given best management can be regarded as the potential of the system under the tested conditions. The values of PELQ obtained for centre pivot one and two ranged from 35-73 % and 38-61 % respectively as tabulated in Table 3.1. The values of PELQ are usually a bit lower than DU because the average water applied at nozzles (which is the denominator for PELQ) is bigger than the average water caught (which is the denominator for DU) (Samir et al., 1996). The results obtained for centre pivot one and two were low. The low DU realised earlier gives automatic indication of low PELQ values. These low values can be attributed to design constraints such as lack of pressure regulators at emitters, uneven sprinkler spacing and emitters with small wetted diameters installed at the overhang.

3.2.6 Pressure and Discharge Rate Measurements

The average pressure recorded for centre pivot one and two was 100 kPa compared to designed pressure of 103 kPa. The designed pressure through the system was higher than measured pressure which can be attributed to voltage drop at the time of evaluation. Weighted average discharge for centre pivot one and two was 20.17 l/s and 25.52 l/s respectively. Pivot one and two though recorded the same pressure (100 kPa) with centre pivot two slightly at gentle slope and centre pivot one at almost a flat topography, the discharge rates of sprinklers in centre pivot one was lower. This can be associated with clogging of the nozzles by sediments or

thrashes since centre pivot one has been put to use since 2015 to date while centre pivot two commenced operation in 2017. The discharge rates of each sprinkler at span four (4) for pivot one and two were 947 l/h and 1059 l/h respectively which were lower than discharge rates at span three (3) (1029 l/h and 1161 l/h for pivot one and two respectively). This can be attributed to the smaller nozzles with increased number installed at span four (span three had 12 sprinklers and span four with 23 sprinklers at a reduced spacing). The average operating pressure of a centre pivot lateral will vary significantly depending on whether the pipeline is going uphill or downhill. This can result in large variations in sprinkler discharge so that pressure regulators or flow control nozzles are often required on every sprinkler head (Evans, 2001). In the case of Kukobila Nasia Farms (KNF) where centre pivots have no pressure regulator and flow control nozzles, pressure and flow rate could not be adjusted. Table 4.4 presents flow rates through centre pivot one and two.

Table 4.4: Discharge Rates through Centre Pivots (10 Litre Containers Used)

Pivot Span	Centre Pivot	Time Taken (s)*	Discharge Rate (l/s)**	Average Discharge per Span (l/s)**	Discharge Rate (l/h)**	Weighted Average Discharge per Span (l/h)**
Span 1 (last nozzle ≠ 11)	Pivot one	65	0.15385	1.69235	554	6092.46
	Pivot two	67	0.14925	1.64175	537	5910.3
Span 2 (last nozzle ≠ 23)	Pivot one	40	0.25	3.0	900	10800
	Pivot two	37	0.27027	3.24324	973	11675.66
Span 3 (last nozzle ≠ 35)	Pivot one	35	0.28571	3.42852	1029	12342.67
	Pivot two	31	0.32258	3.87096	1161	13935.46
Span 4 (last nozzle ≠ 58)	Pivot one	38	0.26316	6.05268	947	21789.65
	Pivot two	34	0.29412	6.76476	1059	24353.14
Over hang (last nozzle ≠ 70)	Pivot one	20	0.50	6.0	1800	21600
	Pivot two	12	0.83333	9.99996	3000	35999.86
Weighted Average Discharge through Pivot	Pivot one			**20.17355**		**72624.78**
	Pivot two			**25.52067**		**91874.41**

Source: * - Field measurements, 2018 and ** - Desk computation, 2018.

3.2.7 Measurement of Speed Travel

The speed travelled (measured speed) for centre pivot one operating at 170 m/h, 136 m/h, 102 m/h, 85 m/h, 68 m/h and 43 m/h speed levels were 169m/h, 135.32 m/h, 101.41 m/h, 84.49 m/h, 67.64 m/h and 42.37 m/h respectively. Similarly, speed travelled for centre pivot two at the same operating speed levels were 169 m/h, 134.83 m/h, 100.84 m/h, 84.11 m/h, 67.29 m/h and 42.25 m/h respectively. As the speed of operation of the centre pivot increased, distribution uniformity (DU) increased while the average application depth (AAD) decreased. Standardisation of the centre pivot speed of operation to match water application with crop water requirement as well as infiltration rate of soil is critical in minimizing water application losses and increasing application efficiency (Ea). Table 4.5 presents the travel speed for centre pivot one and two.

Table 4.5: Centre Pivot Travel Speed

Pivot Operating Speed (m/h)	Centre Pivot	Time Taken (s)*	Speed (m/s)**	Speed (m/h)**	Time in one Revolution (h)**
170 (100 %)	Pivot one	213	0.04695	169.01	8.3
	Pivot two	213	0.04695	169.01	8.3
136 (80 %	Pivot one	266	0.03759	135.32	10.39
	Pivot two	267	0.03745	134.83	10.43
102 (60 %)	Pivot one	355	0.02817	101.41	13.87
	Pivot two	357	0.02801	100.84	13.95
85 (50%)	Pivot one	426	0.02347	84.49	16.63
	Pivot two	428	0.02337	84.11	16.73
68 (40 %)	Pivot one	532	0.01879	67.64	20.79
	Pivot two	535	0.01869	67.29	20.91
43 (25 %)	Pivot one	850	0.01177	42.37	33.12
	Pivot two	852	0.01174	42.25	33.29

Source: * - Field measurement, 2018 and ** - Desk Computation, 2018.

3.2.8 Constraints of Efficient Performance of the Centre Pivot System

Wind distortion of sprinkling uniformity, nozzles clogging and or worn out, voltage drop and thus lowering pressure rate and discharge rates exceeding infiltration rates of soil were constraints identified at the time of field evaluation.

4.0 Conclusions and Recommendations 4.1 Conclusions

The study revealed that:

- The average water application rates of the centre pivot irrigation system including the outer end (over hang) exceeded the average infiltration rates of soils, with an average water application rates of 118.52 mm/h and 242.96 mm/h for centre pivot one and two respectively and infiltration rates of 61.32 mm/h and 100.86 mm/h for soils in centre pivot one and two.
- The Coefficient of Uniformity obtained from centre pivot one at various operating speed levels were within the acceptable range as recommended by Henggeler and Vories (2009) whereas for centre pivot two, only Coefficient of Uniformity at 102 m/h and 85 m/h operating speed levels were within the acceptable range as recommended by Henggeler and Vories (2009).
- The Distribution Uniformity obtained from both centre pivots (pivot one and two) were low and unacceptable as values obtained ranged from 61.4 - 73.2 %.

- The Scheduling Coefficient computed from both centre pivots were above the lower acceptable limits of 1.3 as values ranged from 1.37 – 1.66.
- The water application efficiencies (**Ea**) obtained from centre pivot one at various speed levels were within the acceptable range as expected by SABI (2000) except **Ea** from operating speed of 170 m/h which was below the acceptable range while for centre pivot two, only values obtained at 102 m/h and 43m/h operating speeds were within the acceptable limits.
- The actual application efficiencies of low-quarter (AELQ) values for both centre pivots (one and two) were low as values recorded ranged from 34 - 64 %.
- The potential application efficiencies of low-quarter (PELQ) values for both centre pivots were low and therefore unacceptable as values recorded ranged from 35 - 73 %.
- The average pressure recorded through centre pivot one and two was slightly lower than design pressure as pressure obtained was 100 kPa and 103 kPa respectively.
- The average discharge rate through centre pivot irrigation system one (20.17 l/s) was lower than the average discharge rate through centre pivot irrigation system two (25.52 l/s).
- The speed of travel of centre pivot irrigation system one was slightly higher than centre pivot irrigation system two.
- Feedlot management was unable to match crop water requirements with water application rates of the centre pivot irrigation systems in order to minimize losses.

5.2 Recommendations

Based on the findings of the study, the following recommendations were made for management and future research.

- Periodic inspection, cleaning and replacement of worn out nozzles is required to enhance distribution uniformities as well as application efficiencies of water.
- Standardisation of centre pivot operation speed to match water application with crop water requirements is necessary at every stage of crop growth to minimize water losses.
- For optimum crop production, cultivated irrigable area of the centre pivot irrigation systems should match with the wetted diameter or limits of throw of the pivot's last nozzle.
- Routine inspection and gauging of centre pivot tyre pressures is required to prevent field operational stops.
- Performance evaluation of the centre pivot irrigation system using indicators which were not covered by this study should be done.

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