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Hydraulic Performance and Soil Moisture Distribution under central Pivot Irrigation System

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ABSTRACT

The Irrigation uniformity plays an important role in the performance of the sprinkler irrigation system and for good plant quality; however, sprinkler systems are typically gauged by the uniformity of water application above the crop canopy. The objectives of this study were to evaluate the hydraulic performance including: uniformity coefficients (CU %), distribution uniformity (DU %) and application efficiency (Ea %) and soil moisture distribution under center pivot. This study was conducted under central pivot irrigation systems (eight units) at the farms of Authority of Merowi Dam Area for Agricultural Development (AMDAD) in New Hamdab Scheme, Northern State, season 2016/17. Results showed that the volume of caught water ranged from 135.2 to 419.3 mm with an average of 5.05, 3.86 and 11.98 mm for central pivot 1, 5 and 8, respectively. However, the application efficiency (Ea %) of the central pivot irrigation system no. 1, 5 and 8 were 36.1, 27.6 and 85.6 %, respectively. The results showed that uniformity coefficients (CU%) of the center pivot irrigation system were 40.9% and 74.4% for center pivot no.1and 5, respectively which were generally below the recommended value while center pivot no. 8 (84.4 %) was in the range recommended. The water distribution uniformity (DU %) values were 57.4% and 77.5% for center pivot no.1and 5, respectively which were generally below the recommended value except center pivot no. 8 (84.3 %) was in the range recommended. The water distribution uniformity (DU %) values were 57.4% and 77.5% for center pivot no.1and 5, respectively which were generally below the recommended value except center pivot no. 8 (84.3 %). The results of soil moisture (MC%) were 3.47, 2.66 and 8.29% for center pivot no.1, 5 and 8 in depth 0-30cm, respectively they showed a clear variation between centers while the change didn't exceed 1% in depth 30-60cm. Results of soil moisture uniformity (SCU %) and soil moisture distribution (SDU %) in depth 0-30cm were below the recommended value for all centers, however, the irrigation requirement was not satisfied and, hence, resulted in low yield. Generally, among the three systems, both 1 and 5 showed lower performance than 8. Hence, the test of performance for a center pivot irrigation system should be carried out each season.

Keywords: sprinkler irrigation, uniformity, center pivot, distribution, soil moisture

1. Introduction

The art of irrigation can be achieved using watering cans, sprinklers, emitters, surface systems and many others. Irrigation is widely carried out through surface and pressurized systems characterized by the mode of transport of the water onto the point of application (Keller and Bliesner, 1990). Sprinklers are best suited to sandy soils with high infiltration rates. They are also adaptable to most soils and to any farmable slope, whether uniform or undulating (Brouwer, 1994). Many researchers proposed different criteria for the design and evaluation of on-farm water management systems. The most commonly used efficiency terms, are application efficiency, water requirement efficiency and Christiansen's coefficient of uniformity. The goal of any sprinkler irrigation system is to apply the desired amount of irrigation water to the crop's root zone as efficiently and uniformly as possible. The factors that determine sprinkler performance characteristics include wetted diameter (swath radius), droplet size, which is a function of the operating pressure, the flow rate or discharge, the application

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rate, and uniformity of water application among others (Ahaneku, 2010). A sprinkler water distribution pattern depends on the system design parameters such as: the sprinkler spacing, operating pressure, nozzle diameter, and environmental variables such as: wind speed and direction (Keller and Bliesner 1990). According to Harrison and Perry (2010), the basic interpretation of uniformity coefficients of center pivot irrigation systems is as follows: 90 to 100 % excellent; no changes required, 85 to 90% good; no changes required unless problem area is obvious, 80 to 85% fair; no improvement needed but system should be monitored closely and below 80% poor; where improvements needed. Generally, high uniformity is associated with the best crop growth conditions since each plant has equal opportunity to use applied water. Non-uniformity results in areas that either under watered or overwatered (Rogers and James, 2011). According to Huck (2000), any sprinkler irrigation system with distribution uniformity (DU%) of 85%, in the field, is excellent and acceptable. This means that even the best sprinkler irrigation system may begin with some 15% inefficiency. Poor distribution in center pivots can lead to leaching of agricultural chemicals into the groundwater, especially in sandy soils, which are porous and have small water-holding capacities (Henggeler and Vories, 2009). Eisa *et al.,* (2010) reported that uniformity depends on the design variables of the system (i.e. the sprinkler size, type of nozzle, pressure, sprinkler spacing, and the main uncontrollable variable, the wind speed). Also, Ebeidalla (2008) reported that the distribution of uniformity was found to be 80%. Generally, high uniformity is associated with the best crop growth conditions since each plant has equal opportunity to use applied water. Non-uniformity results in areas that are under watered or overwatered (Rogers and James 2011). Also, Mostafa and Alsayim (2016) reported that the distribution uniformity of a system must be as uniform as possible to ensure higher yields and efficient application of water. Soil moisture is an important factor across a range of environmental processes, including plant growth, soil biogeochemistry, land-atmosphere heat and water-exchange (Allen and Pereira, 2009). Therefore timely and accurate measurements of soil moisture are highly recommended for on farm irrigation water management. However monitoring of soil moisture distribution uniformity under center pivot irrigation system is highly required for understanding and modeling irrigation systems and maximizing on farm irrigation water unit net return (Yasser and Shalbi, 2016). El-Hagarey *et al.,* (2014) reported that soil moisture distribution helps for reducing water losses by evaporation, because water was saved at the root zone, and the vertical movement of water was more difficult than the horizontal movement of water under sprinkler irrigation, where the greatest saved quantity of irrigation water was at the first layer of the soil profile. According to Sanden *et al.,* (2003) there were a wide variety of technology for soil moisture monitoring has come onto the market in the last 5 to 10 years. The cost of these technologies and the bells and whistles they come with also vary widely.

2. Materials and Methods

Experiment was carried out during season 2016/2017 at the farm of Authority of Merowi Dam Area for Agricultural Development (AMDAD) in New Hamdab Scheme, Northern State, under desert climate condition. The soil under investigation belongs to El Multaga soil series. The texture is sandy loam to heavy sandy clay loam. It has slightly hard consistence when dry, friable when moist and sticky and plastic when wet.

2.1. Experimental:

Three sprinkler irrigation units (central pivot no. 1, 5 and 8 with same crop) from eight units were tested during winter season 2016/2017, where some performance indicators; such as uniformity coefficient (CU %), distribution uniformity (DU %), soil moisture content uniformity and distribution were evaluated. The test setup for central pivot irrigation systems was done by placing a row of spray collection cans at equal distances (5 m) at a straight line from pivot point to outward direction, 30° angle from the pivot point. All spray collection cans were of the same size and cross section, and were set up at the same height relative to the height of the sprinkler nozzle. The volumes of water collected during the test were read as soon as the system completely passes over the row of the spray collection cans. The following parameters were then determined:

2.2. Applied water or water caught (mm)

The volumes of water collected during the test and measured by a measuring cylinder and converted to millimeters (mm).

2.3. Wetting front (cm)

Wetting front measured by using steel rod along the central pivot 15m distance.

2.4. Moisture content (%)

The system efficiency could be evaluated by measuring the moisture distribution in the soil profile. For the subsurface water uniformity assessment, the **s**oil samples were taken by screw auger before and after irrigation process at three points from the beginning of mainline center pivot. The distance between samples is 15 m, and at two depths; 0–30 and 30- 60cm. The samples were labeled and weighed immediately and the wet weight (W_w) was determined and then oven dried at 105 ºC for 24 hours and re- weighed for the dry weight (D_w).

$\theta_g = 100 (W_w - D_w) / D_w$ …………………………………………………………………...................... (1)

θ_g = gravimetric moisture content (%)
W_w = wet weight
D_w= dry weight

2.5. Application efficiency (Ea %)

The application efficiency and water requirement efficiency were estimated according to the formula:

Ea%= 100* (Water stored in the soil root zone/ Water delivered to the field).……………………….……… (2)

2.6. Uniformity coefficient (CU %)

Uniformity of sprinkler pattern was estimated according to the formula suggested by Christiansen, 1941 :

CU = 100 [1 - (A/B)] …………………………………………….. (3)

Where:
CU is the Christiansen uniformity coefficient; A is the sum of the absolute value of the deviation of the average catch cup value from each individual catch cup data point, and B is the sum of the catch cup observations (Harrison and Perry, 2010).

2.7. Distribution uniformity or pattern efficiency (DU %)

Distribution uniformity is another index of application uniformity. It is the ratio, expressed in percent, of the average low–quarter amount of water caught to the average amount caught. DU compares the driest quarter of the field to the rest.

DU = $100 x l_Q / X$ …………………………………………………………………...................... (4)

Where:
l_Q = Low–quarter average–depth;
X= Average amount depth.

3. Results and Discussion

3.1. Depth of caught water (mm)

Water application uniformity is a measure of how evenly water is spread over the soil surface during irrigation under different field operating conditions. Water distribution profiles along the laterals of the tested center pivot systems are shown in Fig. 1 and 2 for central pivot 1, 5 and 8, respectively. Result showed that the volume of caught water ranged from 135.2 to 419.3 mm with an average of 5.05, 3.86 and 11.98 mm for central pivot 1, 5 and 8, respectively. Although the water distribution between central pivots was low and not uniform except in central no.8. The water distribution patterns of the tested center pivot systems above soil surface (catch cans) are shown in Fig. (1), the patterns present the average depth of water caught in each can along the lateral of the pivot. It can be seen from the figure that there were variations in the depth of water applied along the lateral from one system to another, and it can be said that the water distributed non-uniformly in some systems than the others along the lateral and in a whole center. Due to non-uniform nature of sprinkler irrigation, some areas in irrigated fields receive less while other parts receive more water (Darko *et al*., 2017). Also, Al-Ghobari (2014) reported that the lower depth values were attributed to lateral configurations changes made by farmers, bringing about pressure variations, improper nozzling, inaccurate water patterns and as well leakage along the laterals.

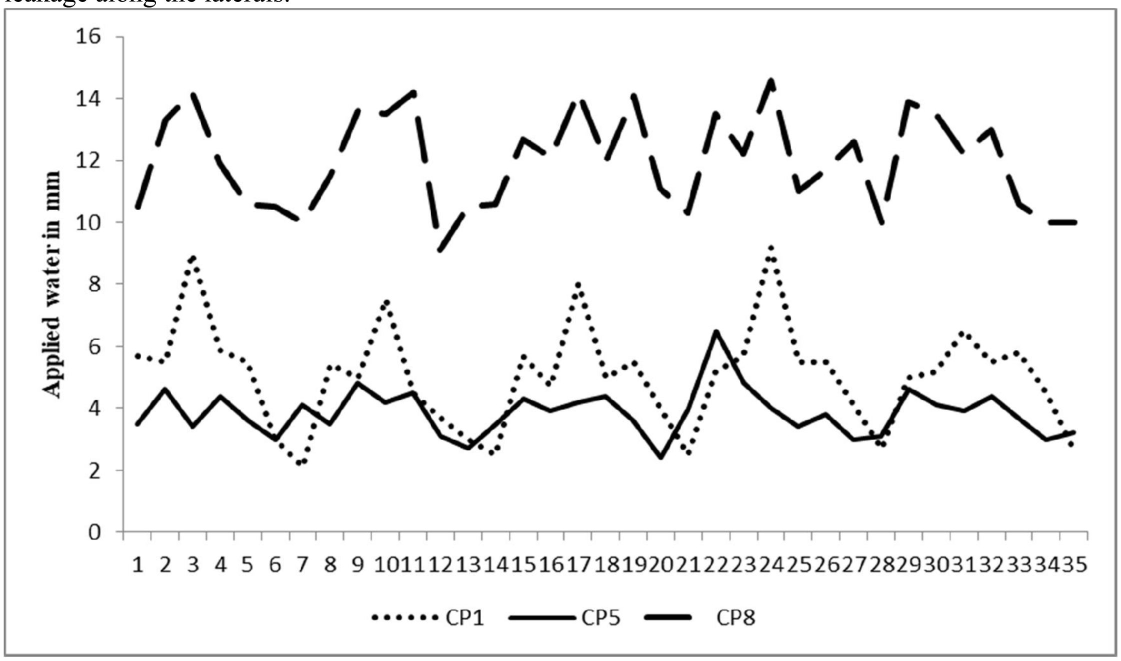

Fig. 1: Mean of caught water (mm) along each span

3.2. Wetting front (cm)

Fig. (2) shows that the wetting front ranged between 27 to 48 cm central pivot no. 1 and 8 have a similar trends wetting front along the pivot. Center pivot no. 5 has a highest wetting front in all spans (towers) this is due to soil characteristics under this center.

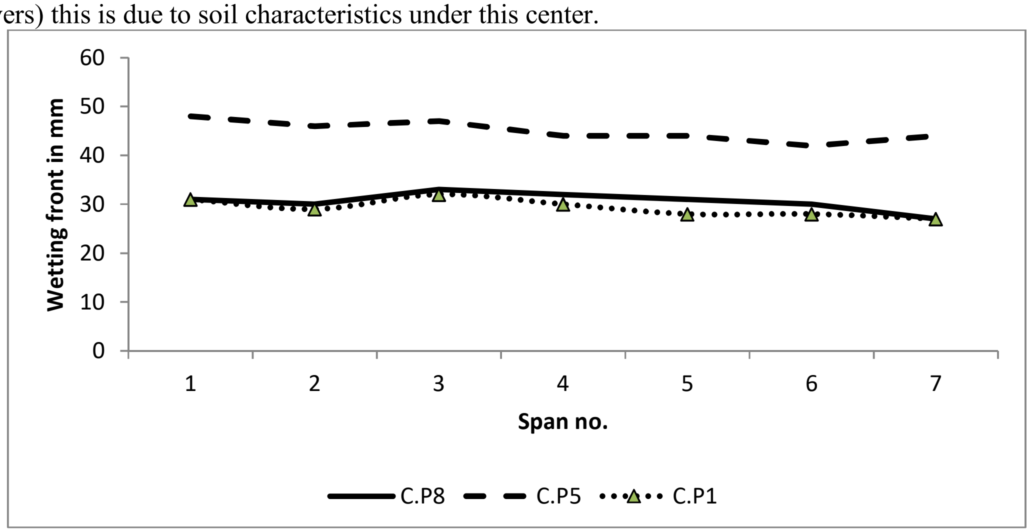

Fig. 2: Mean of soil wetting front (mm) in each center along each span

3.3. Soil moisture content (mm) in depth 0-30cm and 30-60cm

Fig. (3) represents the soil moisture content for the three center pivot systems. The results showed clear variation in soil moisture content between sprinkler systems. This variation can be clarified by the variation of application water (Fig. 1). On the other hand, the results of soil moisture content for system 8 showed slight variation in the soil moisture content along the sprinkler line (Fig. 3) as shown by the high values of the system performance indicators (CU=84.4 % and DU=84.3%).

The results showed a slight variation in soil moisture content in each center pivot (Fig. 3). This slight variation is due to the deep depth. These results were in agreement of Dukes *et al.,* (2006) who reported that soil moisture variability is less sensitive as depth increases and variation in application depths are dampened.

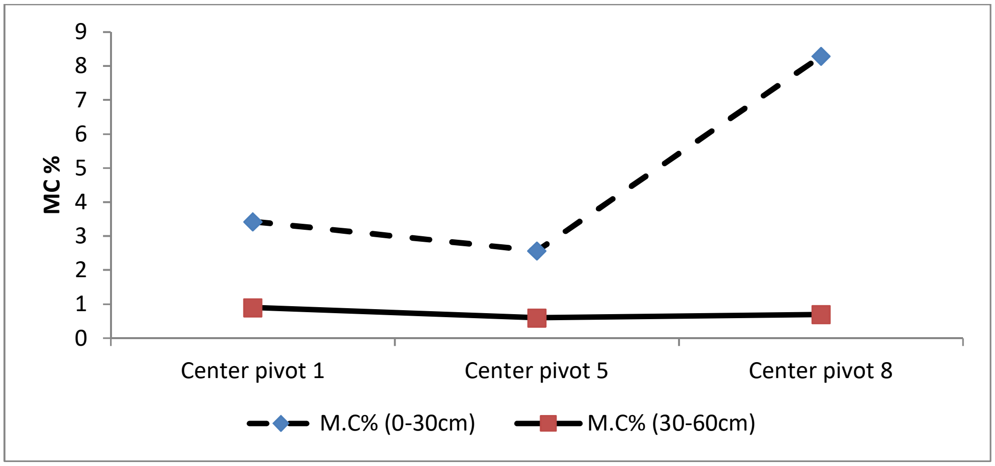

Fig. 3: Moisture content in 0-30 and 30-60 cm depth

3.4. Soil moisture uniformity (CU %) and distribution uniformity (DU %) coefficients

The values of the average soil moisture uniformity coefficient and distribution uniformity of soil moisture contents for depth (0-30cm) for each system were shown in Table (1) and Fig. (4). The highest value of uniformity coefficient were 76.8 % for center pivot no. 5, while the lowest value were recorded (66 %) under center pivot no. 1. Soil moisture content uniformity coefficients were distributing in low level of uniformity as compared to 80% value recommended by Harrison and Perry (2010). The highest values of soil moisture distribution uniformity were 81.7 % for center pivot no. 5 and the lowest value were 70.6 % in center pivot no. 1. Soil moisture content distribution uniformity were distributing in low level of uniformity except in center pivot no. 5.

3.5. Application efficiency (Ea %)

The results show that the value of application efficiency in each of the three center pivot (1, 5 and 8) was 36.1, 27.6 and 85.6 %, respectively which was very low except center pivot no. 8 compared to the normal expected value of (75-90%) obtained by Solomon (1988), Nezar (2008) under normal operating conditions.

3.6. Uniformity coefficient (CU %)

Table (1) shows the uniformity coefficients across center pivots and across season. The measured CU% were below the recommended values of Harrison and Perry (2007) who reported that the values below 80% were poor, except center pivot no. 8 (84.4%). The low values can be attributed to plugged, enlarged nozzles or wrong nozzle sizes for the location on the lateral system. This non-uniformity is attributed to the field operation factors, such as improper nozzling, leakage, and pressure variation along the lateral. However, the system operator justified that, the low uniformity coefficient values is due to unavailability of spare parts in time. The results obtained were below of El-Badawi (2001) who found the uniformity coefficient 85% at central Sudan. Also, Alsayim (2021) and Ebeidalla (2008) stated that the uniformity coefficient was 84.14% at Atbara farm. These values are lower than those obtained by Ali (2012) for Arab Company for Agricultural Production.

3.7. Distribution uniformity (DU %)

The values of the average depths and the average low quarter depths of application for each system were determined and shown in Table (1). Distribution uniformity values for the center pivot irrigation systems are considered low (57.4 and 77.5 %) except for center pivot no. 8 (84.3%). This low value of distribution uniformity can be attributed to clogging of nozzles caused by sedimentation, trashes and/or nozzle being worn out and inaccurate setup of the system. Similarly, low average values of DU (65%) of central pivot irrigation in River**.**

Nile State was found by Mandoor (2010) and Alsayim (2021). Mohammed (2011) attributed the low DU% values to be due to attributed to some factors such as high evaporation and wind drifting.

Table 1: Performance indicators for the three central pivot irrigation systems

Parameters	Center pivot 1	Center pivot 5	Center pivot 8
caught water (mm)	5.04	3.86	11.98
wetting front (mm)	29.28	45	30.75
M.C (0-30cm) in mm	3.43	2.57	8.29
M.C (30-60cm) in mm	0.9	0.6	0.7
CU of M.C% (0-30cm)	66	76.8	70
DU of M.C% (0-30cm)	70.6	81.7	78.7
Ea%	36.1	27.6	85.6
DU%	57.4	77.5	84.3
CU%	40.9	74.4	84.4

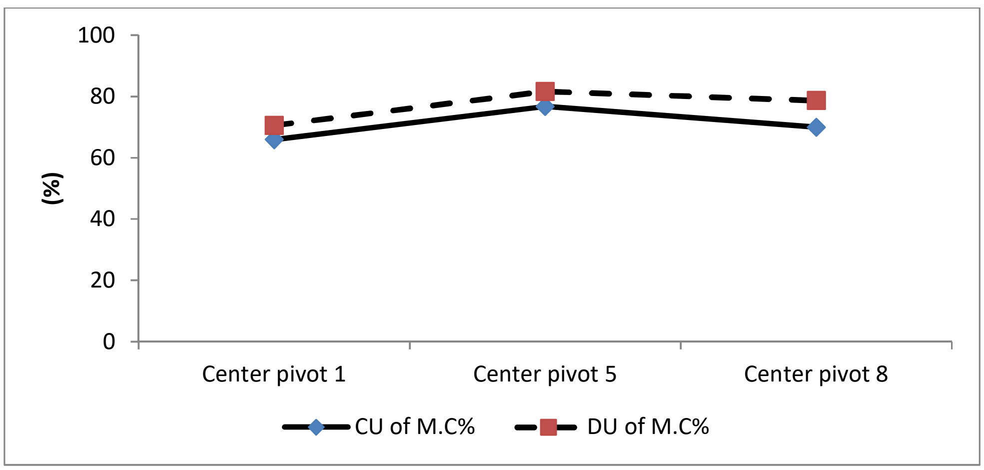

Fig. 4: Soil moisture uniformity and distribution coefficients

4. Conclusion

Water distribution of the center pivots was low and not uniform except in center no.8. Also, measured Ea %, CU%, DU% and SMC% values were considered below the recommended values except for center pivot no. (8). Generally, in Northern State the central pivot irrigation systems used were generally performing at or below the lower limits reported by researchers in this field. Further work is needed to determine the main contributing factors to this level of performance.

Recommendation

To improve CU %, DU% and Ea% it is recommended using flow meters to apply uniform and adequate water according to crop water requirements, also, sensors to measure soil water is to give a better understanding of how fast it is being depleted in the different areas of the field. Also, conduct more studies to select the suitable application rate rather than using blindly dealer's recommendations.

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