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Full Length Article

Impact of Center Pivot Sprinkler Speed and Water Regimes on Potato Crop Productivity

Abubaker B. Ali[1*], Li Hong[1], Nazar A. Elshaikh[2], Amir K. Basheer[3,4] and Yan Haofang[1]
[1]*Research Center of Fluid Machinery & Engineering, National Research Center of Pumps, Lab of Water Saving Irrigation, Jiangsu University, Zhenjiang, China, 212013*
[2]*State Key Laboratory of Efficient Irrigation-Drainage and Agricultural Soil-Water Environment, College of Water Conservancy and Hydropower, Hohai University, Nanjing, 210098, China*
[3]*State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, College of Hydrology and Water Resources, Hohai University, Nanjing, 210098, China*
[4]*Ministry of Agriculture and Irrigation, River Nile State, P.O. Box 8168, Adamar, 12217, Sudan*
[*]For correspondence: abubaker@ujs.edu.cn

Abstract

When to irrigate and how much water should be apply and at which operation speed? All this question marks covered by our study, in case of potato irrigated under center pivot irrigation. To investigate the effect of interaction between operating speeds 80 (S1), 70 (S2) and 60% (S3) and water regimes 596 (W1), 447 (W2) and 298 (W3) mm per season, on the hydraulic performance of center pivot irrigation, water use efficiency, yield and yield characteristics of potato crop during winter season, in the River Nile State, Sudan. Results demonstrated that high operating speeds showed negative effect on distribution uniformity, coefficient uniformity and positive effect on application efficiencies. W2 recorded high significant values of application efficiency % with less values of coefficient uniformity and distribution uniformity (%). Interaction of the operating speeds and amounts of water showed positive effect, whereas S3 showed higher values of coefficient uniformity and distribution uniformity (%) efficiencies with W2 and W1, respectively. However, lowest water use efficiency values were recorded under S1W1, while highest productivity achieved by S3W2. Hence, with careful management, using center pivot irrigation under the study would give high irrigation efficiency and high water use efficiency, with fewer amounts water applied, thus saving water for other agricultural activities. © 2016 Friends Science Publishers

Keywords: Irrigation; Sprinkler center pivot; Hydraulic performance; Potato

Introduction

Worldwide, particularly the developing countries has given considerable attention to modern irrigation techniques, since it suite to the different agricultural soils with high efficiencies and has wide range of usage. Thus, good management could be achieved through applying such as these techniques. sprinkler center pivot irrigation system (CPI) is covers large irrigation areas because it has many advantages such as high efficiency of distribution and application water over the field, high degree of mobility, and potentiality to apply water and nutrients at the same time (Asough and Kiker, 2002). In Sudan, River Nile State (RNS) represented as a model of using CPI, because this area characterized by high evaporation and sand soil. Hence, CPI led to create suitable climatic condition for enhance agricultural production, water management and decrease operation costs of irrigation by reduce the power.

The RNS northern Sudan, are characterized by a relatively unique cool winter, which makes them the most suitable for production of winter crops, e.g. wheat, legumes, spices, potatoes and onion (Elgilany *et al.*, 2014) to obtain high application water efficiency thus, when evaluating the performance of irrigation system, it is useful to examine the efficiency of each system component, which identifies the defect in each component (Yan *et al.*, 2000). Irrigation efficiency is a term use to characterize irrigation performance, evaluate irrigation water use and promotes better performance. There are many different criteria proposed for the design and evaluation of farm irrigation systems. The most famous ones for CPI are coefficient uniformity, distribution uniformity, consumptive use and distribution uniformity efficiencies (Basheer *et al.*, 2015). Since the water application is controlled by the speed rotation in CPI (Scherer, 1998), and it could be one of the factors that help in managing water according to the crop grown and soil type (James, 1988).

Globally, water amount required of the potato has been received considerable attention as one of the key factors affecting potato yield. Presently, the area of land

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under potato cultivation in Sudan approximately 15 000 ha (Baldo *et al*., 2010), with an average yield range of 5–30 t ha^{-1} (Moamedali, 1989). Most of the potato in Sudan are grown under conventional farming system and are suffering from shortage of irrigation water and, therefore, productivity considered is low without used right technical packages. However, the total amount of water per season for potato crop needs to optimize for better productivity in the developing countries. CPI systems are generally operating at very low levels of performance in Sudan. This is attributed mainly to the fact that these systems have been introduced without being subjected to proper research study. The efficiency of the CPI is solely dependent upon the operating parameters (speed) and the hydraulic design of the system. Uniformity coefficient from CPI should exceed 90%. Therefore, our current study aims to assess CPI under a set of performance evaluating parameters to determine the optimum speed for best coefficient uniformity (CU%) application efficiency (AE%), distribution uniformity (DU%).

The study hypotheses that, the CPI operating speed significantly affect the hydraulic performance and as a result affect the crop growth. Moreover, the water regimes will play a great role in managing water without high effect on yield and yield components of crops.

Materials and Methods

Description of Experimental Site

A field experiment was carried out during winter 2014 in an area of 252 ha at Tala Agricultural Scheme, River Nile State (RNS) (Fig. 1), North of Sudan at the intersection of 16º-20°N, 32º - 35°E, which was adopting center pivot irrigation system (CPI) where growing and producing potato crop.

The climate of study area is classified as arid and semi-arid which is hot in summer and cold in winter with range variation in temperature between 7 and 49ºC. Rainfall vary from 0 to 100 mm in the north and south, respectively. The soil texture is a sandy clay loam with high to relatively low infiltration rate ranging from 2–3 mm h^{-1}. Soil characterizations of the study area are presented in (Fig. 2).

Experimental Design and Treatments

For conducting the experiment, three CPI operating speeds i.e., 80 (S1), 70 (S2) and 60 % (S3), and three irrigation water regimes {560 mm (100% W1), 447 mm (75% W2) and 298 mm (50% W3)} of potato water requirement (ETc), were used with three replications.

The main features and specification of aforementioned system are a power source and pumping unit; where Volvo Penta internal combustion engine (280 hp) was used to drive a deep well turbine pump with 203 mm diameter, pivot point, drive unit, pipeline, sprinklers, the fertilizer applicator, and control panel. Each system is 250 m long with 8 spans each span is 50 m long, with uniform nozzle spacing of 2.7 m. thus, each system contain 154 different nozzles sizes for providing increment in the discharge along radial distance from the pivot point (Fig. 3).

Technical System Performance

For testing the performance of each system, a 693 catch cans with same specifications were used to collect water applied by the nozzles, where the system allowed completely pass over them. The cans were placed at uniform distances (4.5 ×1 m) in a straight line arranged from the pivot point towards the outward direction. To determine the volume of water that collected from cans, measuring cylinders, measuring type, sensitive balance and square sampling ring were used (Fig. 4).

The nozzles water application rate was adjusted to apply a reasonable average depth of water. The total system discharge was measured using a cumulative flow meter according to James (1988). The frequency of irrigation was adjusted to be every 3 days to give the water regimes those above mentioned. To convert readings to depths of water (mm) the following equation were used:

$$H = \frac{V}{A} \qquad (1)$$

Where: H: height in cm; V: volume of water collected in ml; A: bottom surface area of can in cm^2.

Christiansen coefficient of uniformity and was determined using the equation that stated by Christiansan (1942), as follow:

$$Cu\% = 100\left[1 - \frac{\sum x}{mn}\right] \qquad (2)$$

Where: CU %: Coefficient of uniformity (%); m: Average volume of water collected (mm); n: number of total observations; x: deviation of individual observation from the mean (mm).

Meanwhile, the formula described by Merriam *et al.* (1980), was used to measure the application efficiency (EA %), calculated by dividing the average depth in catch cans over application depth that measured by system flow-meter using the following equation:

$$EA\% = \frac{Dc}{Df} \times 100 \qquad (3)$$

Where: EA: Application efficiency (%); Dc: catch cans average water depth (mm); Df: flow-meter average depth of water application (mm).

Distribution uniformity (Du %) equation; was used to determine the distribution of water applied according to method of Asough and Kiker (2002) and could be stated as follow:

$$DU\% = \frac{Lm}{Da} \times 100 \qquad (4)$$

Where: DU %: Distribution uniformity %; Lm: Average of lowest one-quarter of the amount water caught in catch cans (mm). Da: Average of the total irrigation depths (mm).

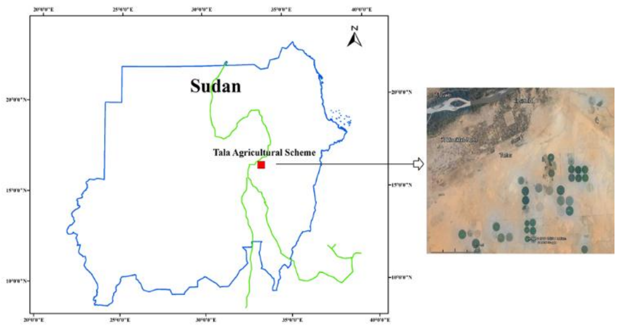

Fig. 1: Location of study

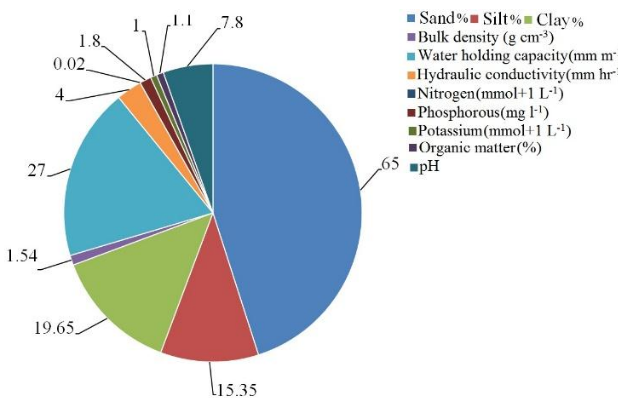

Fig. 2: Soil physical and chemical characteristics of the study area

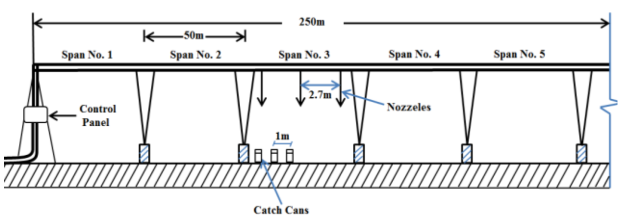

Fig. 3: Description of center pivot irrigation system

Cultural Practice

For this study, potato cultivar (*Agria)* imported from the Netherlands was used. The experimental soil was prepared by deep plow to 50 cm followed by a second deep plow to 30 cm, harrowing, leveler and ridging for irrigation system. Then, the tubers seed pieces, was planted at spacing of 25 cm between plants with same seed tubers of uniform size were used to plant the whole field in November, 2014. According to Abubaker *et al.* (2011) recommended fertilization dose of nitrogen and the phosphate were applied at planting at the rate of 238 kg ha^{-1} as mono soluble fertilizers. Moreover, plant protection and crop managements were carried out as recommended. A twenty plants sample after eight weeks of planting was taken to determinate number of leaves and stems, number of stolons and tubers per plant. At crop maturity, the fresh weight of tubers were recorded to assess the yield. Data were also collected on total yields of tubers as well as on yield components.

Water Use Efficiency

The CROPWAT software was used to estimate reference crop evapotranspiration (ET_o) based on FAO Penman–Monteith equation. The climatic meteorological data were collected from the River Nile State station (Table 1). Crop coefficient (Kc) for potato crop were estimated according to the method described by Allen *et al.* (1998), consequently crop evapotranspiration could be determine by following equation:

$$ET_c = ET_\circ \times K_c \qquad (5)$$

Where: ET_c: crop evapotranspiration (mm day^{-1}); ET_o: actual evapotranspiration (mm day^{-1}); Kc: Crop coefficient.

Water use efficiency (WUE) was also determined, using the following equation:

$$\text{WUE} = \frac{\text{Crop yield (kg ha}^{-1})}{\text{Total of water used (m}^{3}\text{ha}^{-1})} \qquad (6)$$

Where: WUE: crop water use efficiency (kg m^{-3}).

Statistical Analysis

Data were subjected to using the Statistical Package of Social Sciences (SPSS) version 16 software. Differences of means were considered significant at $P \leq 0.05$ was used to compare between the means.

Results

Hydraulic Performance and Water Deficiency

The evenness at which water is applied or infiltrated throughout the field contingent on system design and maintenance. On the other hand, the amount of water needed for crop production compared with the amount applied to the field depends on system uniformity and management. Nevertheless, (Fig. 5) showed the coefficient uniformity, distribution uniformity and application efficiency (CU, DU and EA %), respectively of the center pivot irrigation (CPI) system as affected by different operating speeds. The statistical analysis revealed that, the S3 ranked (a), while S2 ranked (b) and finally S1 gave (c). It is noted that, there was a significant difference ($P \leq 0.05$) between treatments. These hydraulic performance values are considered reasonable as compared to standard values under ideal conditions (Solomon, 1988). The results indicated that, the general trend is an increase of hydraulic performance values as speeds decrease.

Table 1: Monthly meteorological data for crop water requirement in cropping season

Month	Nov.	Dec.	Jan.	Feb.	Mar.
Mean temp ºC	25.0	22.6	21.8	24.5	27.8
Mean RH* (%)	28.7	31.7	30.7	28.4	14.2
MWS*	5.06	25.23	5.72	6.36	7.58
Sunshine (h)	10.1	11.2	9.1	9.9	9.8

RH: Relative humidity (%); MWS*: mean wind speed (m h^{-1}) at 2 m height

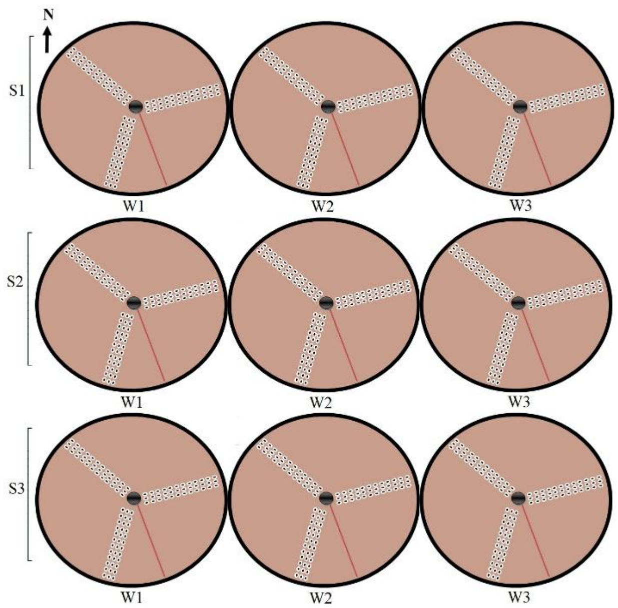

Fig. 4: Collection cups layout
Operation speeds: S1 (80%), S2 (70%), S3 (60%); water amount (mm): W1 (596), W2 (447), W3 (298)

Fig. 6 shows that, watering amounts had a highly significant (P≤0.05) effect on the three aforementioned efficiencies. Highest EA value (91%) was recorded by W3 followed by W2, while W1 gave the lowest application efficiency. These results are consentient by Almasraf *et al*. (2011). Moreover, the W2 and W1 had the highest ranking of the means of CU% and DU%, whereas W3 ranked last. The general trend is that CU% and DU% are increased with increasing watering amounts. This is in accordance with the results obtained by Dukes and Perry (2006).

The interaction of operating speeds and water amounts had detected effect on the hydraulic efficiencies (Fig. 5 and 6). S3W3 combination recorded the maximum EA %, while the S2W1 combination recorded the lowest value. These lead to relatively high water application uniformity by S2. On the other hand, S3W1 recorded the highest value of CU%, while the lowest values were registered by the S1W3 combination.

The combination of S3 with both W1 and W2 showed the highest values of DU%. With most irrigation systems speeds the EA % decreased with increasing water amounts in contrast to the CU % which was increased with increase of water amounts.

Yield and Yield Components

The data in (Fig. 7A) show that, the number of leaves were not significantly affected by the water amount; however, there was a slight increase with increasing irrigation water amount up to W1. The combination of S3W2 recorded 72 leaf per plant which is higher than S3W3.

For stem number, our results obtained showed that, there were increment with decreasing of the operating speeds, hence, as the water amounts is better distribution as declared by S3W2 combination (Fig. 7B). Many studies indicated that number of stems of the potato crop affected by irrigation water quantities which clearly realized on size of the seed tuber (Islam *et al*., 1990).

A similar trend is registered also for the number of stolons and tubers per plant as presented in (Fig. 7C and Fig. 8A). These parameters exhibited the same trend of vegetative growth components i.e., watering significantly affect yield components which, however, responded significantly to lower rates in different speeds. Regarding, the fresh weight of tubers per plant, ten weeks after planting, was not significantly different among treatments, but the difference was significant in the operating speeds (Fig. 8B). The highest values were obtained by S3W1 and S3W2 corresponding to values 980.9 and 976.7 g, respectively and were not significantly differ.

In the latter, fresh weight of tubers showed an increasing tendency with increasing irrigation water. Succinctly, it is concluded that the highest values of yield and yield components recorded from W1 under different speeds followed by W2 in the same situation. Taking in account there is no significant different among them at 5% level of probability. A typical gauge of efficiency is the measurement of system uniformity since under-watered areas (i.e., from non-uniform irrigation application) will require overwatering to maintain acceptable crop yield and quality, thus resulting in inefficiency (Dukes, 2006). Likewise, highest total yield resulted from the S3W1 irrigation water treatments, while the lowest yields were obtained from both the highest speed (80% speed) and lowest applied water quantity (298 mm). There was an increasing trend in total yield with increasing amount of applied irrigation water toward W1 (Fig. 9).

Water Use Efficiency

The water use efficiency (WUE) of adopting different speeds depends on the level of water resource management (Fig. 10). As it's presented, the averaged water use efficiencies values versus water regime and operation speeds for potato, whereas, the greatest WUE values were obtained under S3W3 combination which significantly differ from the other treatments.

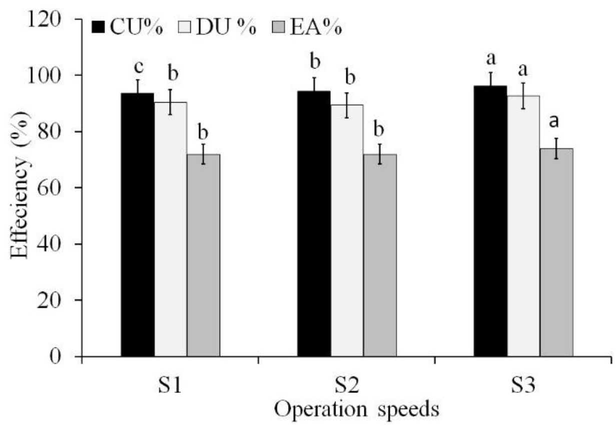

Fig. 5: Center pivot hydraulic characteristics under different operating speeds

Note: Means with the same letter within the same group are not significantly different at 5% level of probability. S1 (80%), S2 (70%), S3 (60%): operation speeds; CU%: coefficient uniformity DU%: distribution uniformity; EA%: application efficiency

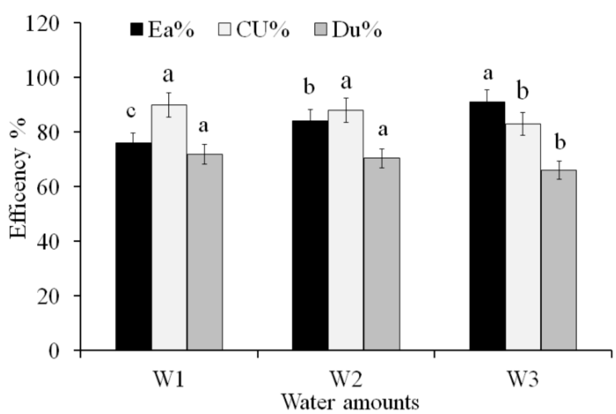

Fig. 6: Effect of applied amount of water on irrigation efficiencies

Note: Means with the same letter within the same group are not significantly different at 5% level of probability. W1 (596), W2 (447), W3 (298) mm: water amount; CU%: coefficient uniformity DU%: distribution uniformity; EA%: application efficiency

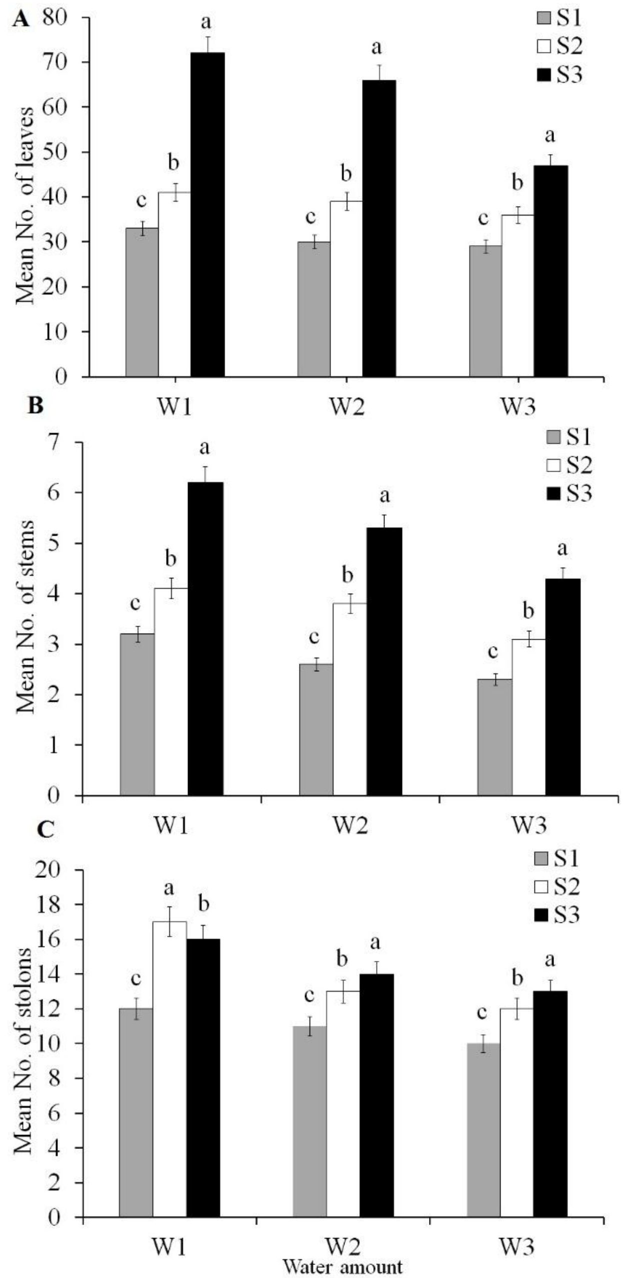

Fig. 7: Potato growth components as affected by water amounts and operation speeds

Note: Means with the same letter within the same group are not significantly different at 5% level of probability. S1 (80%), S2 (70%), S3 (60%): operation speeds; W1 (596), W2 (447), W3 (298) mm: water amount

Discussion

The hydraulic performance of the CPI consider one of the most important factors that limit the crop production. In this study, the variations in hydraulic performance could be attributed to clogging of nozzles which caused by sedimentation, salinization and wind drift (Evans and Sneed, 1996). The results obtained are similar to those obtained by El-Badawi (2001), who found that, the coefficient of uniformity (CU %) about 81%, this may be due to some factors such as wind drift which had a greater negative impact. Furthermore, Osman (2002) during his investigation found that the values of DU% were 84% and 81% for 100% and 50% operating speeds, respectively. Also, Saeed (2001) obtained uniformity ranges from 81.5% to 90.4% for center pivot tested under variable wind velocities. Likewise, the results obtained are in line with those obtained by El-Badawi (2001) who found the uniformity coefficient of 85% at central Sudan. The CU% values were lower than the 85%, but it lays under normally recommended range for sprinkler systems (Ayman, 2008).

Similar results were obtained by Ali (2004) who carried out performance evaluation on CPI, his investigation showed that fewer than 50% speed gave 83%, 74% and 87.2% for the coefficient uniformity, distribution uniformity and application efficiency , respectively.

This may be due to the fact that there is variation in water store in root-zone due to the different operating speeds and water amounts (Msibi *et al.*, 2014).

Thus, the efficiencies under the CPI system may be improved considerably if the operating speeds is taken into consideration in order to achieve the best irrigation practices for CPI systems. It has been demonstrated that the uniformity of irrigation water application has an effect on crop yield (Al-Ghobari, 2003).

This might attributed to increment amount of water available within the root-zone. This findings is in accordance with Vos and Haverkort (2007). As it's known in arid and semi-arid crops are exposed to environmental conditions such as high temperature and low air humidity, in this situation results from experiment observations will be useful consideration in the environment assuagement, reduced transpiration and mitigated abiotic stress for potato production. Therefore, these results emphasize the importance of selecting suitable operating speeds. As general, the amount of irrigation water and operating speeds had effect on the number of stem. The results showed that W2 was superior in number of leaves per plant when combined with S3, which was significantly different from other treatments.

The results of stolons and tubers per plant indicated that for maintaining more stolons and tubers per plant, adequate soil moisture W1 (596 mm) would be needed by the plant, while both speeds (S1 and S2) and deficit watering's have negative effect. The number of tubers per plant have more pronounced decline in response to water deficiency as mentioned by Levy *et al.* (2013), many potato cultivars are shallow rooted, which is sensitive to water stress and requires adequate water in the root zone for optimum yields. It is generally recommended to maintain soil moisture useful to have a successful avoidance (Liao *et al*., 2016). However, Haverkort *et al*. (1990) claimed that the number of tubers per stem was greatly increased or remained unchanged as a result of soil moisture stress. It is evident how operating speeds affected? it could be justified by, appropriate speed according to experiment may help systematic distribute water in terms of uniformity in an over the crop field, in contrast with high speeds, which might dispersion water and reduce the water distribution uniformity.

The reduction in yield with high operation speed have been observed under S1, this possibly could be due to low hydraulic efficiencies. These results agree with reports in the literature which indicated that moisture stress, occurring before the tuber initiation reduces tuber per stem and thereafter, effectively reduced the number and fresh weight of tubers. Thus, to obtain high tuber yields the main factor is soil moisture which should be maintained at all stages of plant growth (Wright and Stark, 1990). Nevertheless, the number of stolons per stem was reduced by water stress but the number of tubers increased or remained unchanged (Haverkort *et al*., 1990). It's noted that there is similar findings as ours with regard to water amounts but the combination of these water regimes with different operating speeds of center pivot is so rare. As above-mentioned, operating speeds affect the distribution of applied water, therefore, it is easier to understand that select appropriate operating speeds for CPI system is the key for increasing potato yield by applying the optimum water amount. This observation supports the hypothesis that operating speeds affects crop yield due to its effect on system hydraulic efficiency. For the total yield, both water stress and operation speeds have effect on plant growth and total yield of potato. So, it could be possible to set and appropriate operating speed and water amounts as S3W1 in order to obtain a good yield. Moreover, crop productivity is influenced by weather conditions which affected crop growth and development and ultimately yield (Garcia *et al*., 2009). From the results obtained the appropriate quantity of irrigation water for the best growth and total yield of potato ranged from 596 to 447 mm per season (5960–4470 m^3 ha^{-1} per season) to be applied in 28–30 irrigations. In this regard, similar trends are registered by Bahramloo and Nasseri (2009), who reported that a well irrigated potato crop required less than 6640 m^3 ha^{-1}, by irrigated with 18 irrigation events and 518.94–554.26 mm per season found by Naroua *et al*. (2014).

With response to water use efficiency (WUE), Bahramloo and Nasseri (2009) reported that potato (cv. *Agria*) should well irrigate to achieve the optimum yield and WUE. These results support the fact that WUE is the subject to yield of crops and applied depth of irrigation water which also means that the lowest water applied method the highest WUE. This may be refer to the fact that, WUE could be improved by increasing yield per unit of the land area and improved agronomic practices, or by considering the time of cultivation crop as mentioned by Shideed (2005). Katerji and Mastrorilli (2009) found that, WUE of crops is widely influenced by water irrigation stewardship. In this context, Salvador *et al.* (2011) claimed that WUE could be used as considers index to assess the irrigation performance.

Conclusion

This study shaded a light mainly on appropriate CPI operating speeds and water application levels. Hence, from the results obtained, the highest values of growth parameters were recorded from W1 under the three operating speeds followed by W2 and W3. Likewise, highest total yield resulted from the S3W1 irrigation water treatments, while the lowest yields were obtained from the highest operating speed (80%) and lowest applied water quantity (298 mm).

From the conclusion we could recommend that, the optimum amount of water for the best growth and yield of the potato crop at arid and semi-arid environment ranges between 447 (W1) and 596 (W2) mm ha^{-1} per season, to be applied in 28–30 irrigations hence, in order to save power costs and to give a good performance, it is recommended to operate system at S3 (60%) rather than S1 (80) and S2 (70%) in terms of irrigation uniformity and to avoid evaporation losses. Finally, economic considerations for using optimum speeds for CPI system should not be neglected in parallel with trying to improve the system uniformity in order to obtain maximum crop production.

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References

Ali, M.A.E., 2004. Technical Evaluation of Centre Pivot Irrigation System for Lucme (*Medicago sativa*) Production in the River Nile State. *MSc Thesis,* University of Khartoum, Sudan

Al-Ghobari, H.M., 2003. The areal distribution of applied water above and below soil surface under center pivot Sprinkler irrigation system. *J. Saudi. Soc. Agric. Sci.,* 2: 207–221

Almasraf, S., J. Jury and S. Miller, 2011. *Field Evaluation of Center Pivot Sprinkler Irrigation Systems in Michigan*. Final Draft. Dept. of Biosys. and Agric. Eng. Michigan State University. East Lansing, Michigan, USA

Ayman, H., 2008. Performance of a Semi Portable Solid Set Sprinkler Irrigation System under Sudan Conditions. *MSc Thesis*, University of Khartoum, Sudan

Asough, G.W. and G.A Kiker, 2002. The Effect of Irrigation Uniformity on Irrigation Water Requirements. *Water SA.,* 28: 235–241

Abubaker, S., A. AbuRayyan, A. Amre, Y. Alzubi and N. Hadidi, 2011. Impact of cultivar and growing season on potato (*Solanum tuberosum* L.) under center pivot irrigation system. *World J. Agric. Sci*., **7**: 718–721

Allen, R.G., L.S. Pereira, D. Raes and M. Smith, 1998. *Crop Evapotranspiration Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage. Paper No. 56, FAO, Rome, Italy

Baldo, N.H., S.M. Elhassan and M.M. Elballa, 2010. Occurrence of Viruses Affecting Potato Crops in Khartoum State, Sudan. *Potato Res.,* 53: 61–67

Basheer, A.K., A.B. Ali, N.A. Elshaikh, M. Alhadi and O.A. Altayeb, 2015. Performance's Comparison Study between Center Pivot Sprinkler and Surface Irrigation System. *In.t J. Eng. Works,* 2: 6–10

Bahramloo, R. and A. Nasseri, 2009. Optimum irrigation events for potato cultivar *Agria. Int. J. Agric. Biol.,* 11: 712–716

Christiansan, J.E., 1942. *Irrigation by Sprinkler. Agricultural Experiment Station,* California Agric. Exp. Bull. No. 570. University of California, Berkely, California, USA

Dukes, M.D. and C. Perry, 2006. Uniformity testing of variable-rate center pivot irrigation control systems. *Prec. Agric.,* 7: 205–218

Dukes, M.D., 2006. Effect of wind speed and pressure on linear move irrigation system uniformity. *Appl. Eng. Agric.,* 22: 541–548

Elgilany, A., S. Jamalludin and M. Saidatulakmal, 2014. Assessment and comparison of conventional and modern irrigation systems to manage irrigation water supplies in the River Nile State of Sudan. *Desalin. Water Treat.,* 52: 5284–5294

Evans, R.O. and R.E. Sneed, 1996. *Selection and Management of Efficient Hand-move, Solid-set and Permanent Sprinkler Irrigation Systems.* Published by: North Carolina Cooperative Extension Service. Publication NO: EBAE-91–152

El Badawi, A.M., 2001. Center Pivot Performance at Omdoum a Case Study. *MSc Thesis,* University of Khartoum, Sudan

Garcia, Y.A., C.L. Guerra and G. Hoogenboom, 2009. Water use efficiency of sweet corn under different weather conditions and soil moisture regimes. *Agric. Water Manage.,* 96: 1369–1376

Haverkort, A.J., M. Waart and K.B.A. Bodlaender, 1990. The effect of early drought stress on numbers of tubers and stolons of potato in controlled and field conditions. *Potato Res.,* 33: 89–96

James, L.G., 1988. *Principle of Farm Irrigation System Design,* 4th edition. John Wiley and sons Published by Ernest Ben Limited London

Katerji, N. and M. Mastrorilli, 2009. The effect of soil texture on the water use efficiency of irrigated crops: results of a multi-year experiment carried out in the Mediterranean region. *Eur. J. Agron.,* 30: 95–100

Islam, T., H. Sarker and J. Alam, 1990. Water use and yield relationships of irrigated potato. *Agric. Water Manage.,* 18: 173–179

Levy, D., W.K. Coleman and R.E. Veilleux, 2013. Adaptation of potato to water shortage: irrigation management and enhancement of tolerance to drought and salinity. *Amer. J. Potato Res.,* 90: 186–206

Liao, X., Z. Su, G. Liu, L. Zotarelli, Y. Cui and C. Snodgrass, 2016. Impact of soil moisture and temperature on potato production using seepage and center pivot irrigation. *Agric. Water Manage.,* 165: 230–236

Moamedali, G.H., 1989. The performance of several Dutch potato cultivars in the arid tropics of northern Sudan. *Potato Res.,* 32: 473–475

Merriam, J.L., M.N. Shearer and C.M. Burt, 1980. Evaluation of Irrigation Systems and practices. *In*: *Design and Operation of Farm Irrigation Systems,* pp: 721–760. (E.d.M.E. Jensen). A.S.A.E., Michigan, USA

Msibi, S.T., N.I. Kihupi, A.K.P.R. Tarimo and A.M. Manyatsi, 2014. Evaluation of speed effect on the technical efficiency of centre pivot irrigation at Ubombo Sugar estate, Swaziland. *Int. J. Agric. Sci. Biores. Eng. Res.,* 3: 14–22

Naroua, I., L. Rodríguez Sinobas and R. Sánchez Calvo, 2014. Water use efficiency and water productivity in the Spanish irrigation district¿ Río Adaja. *Int. J. Agric. Pol. Res.,* 2: 484–491

Osman, O.A., 2002. Evaluation of the performance of center pivot irrigation system. *MSc Thesis,* University of Khartoum, Sudan

Scherer, T., 1998. *Selecting a Sprinkler Irrigation System.* North Dokota State University Extension Service, North Dokota, USA

Solomon, K.H., 1988. *Irrigation Systems and Water Application Efficiencies.* California State University, Fresno, California, USA

Saeed, M.M., 2001. Probable Impact of the Hamadab Dam. *MSc Thesis*, University of Khartoum, Sudan

Shideed, K., 2005. *Assessing On-Farm Water-Use Efficiency: A New Approach Methodology and Six Case Studies.* International Center for Agricultural Research in the Dry Areas (ICARDA) and The United Nations Economic and Social Commission for Western Asia (ESCWA), Aleppo, Syria

Salvador, R., A. Martinez-Cob, J. Cavero and E. Playán, 2011. Seasonal on-farm irrigation performance in the Ebro Basin (Spain): Crops and irrigation systems. *Agric. Water Manage.,* 98: 577–587

Vos, J. and A.J. Haverkort, 2007. Water availability and potato crop performance. *In*: *Potato Biology and Biotechnology: Advances and Perspectives*, pp: 333–351. Vreugdenhil, D., J. Bradshaw, C. Gebhardt, F. Govers, M.A. Taylor, D.K.L. MacKerron and H.A. Ross (eds.). Elsevier, Amsterdam, The Netherlands

Wright, J.L. and J.C. Stark, 1990. Potato. *In*: *Irrigation of Agricultural Crops. American Society of Agronomy*. Stewart, B.A. and D.R. Nielson (eds.). Crop Science Society of America, Soil Science Society of America, Madison, Wisconsin, USA

Yan, KC., M.H. Alia, L.T. Shui, A.F. Eloubaidya and K.C. Foong, 2000. Modeling water balance components and irrigation efficiencies in relation to water requirements for double cropping systems. *Agric. Water Manage.,* 46: 167–182

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