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Wind Drift Evaporation Loss and Soil Moisture Distribution under Sprinkler Irrigated Blackgram (*Vigna mungo* L.)

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Abstract

An experiment was conducted during March–June 2018 with the sprinkler irrigation system covered in an area of 39×42 m^2. Proper design and management of sprinkler irrigation systems improves the uniformity of moisture distribution and reduces wind drift and evaporation losses (WDEL) for effective crop growth. Uniformity coefficient, wind drift and evaporation loss of the sprinkler system at a different pressure head of 2 kg cm^{-2}, 2.5 kg cm^{-2} and 3 kg cm^{-2} were studied. Wind speed was observed by using handheld anemometer. The wind speed ranged between 0.9 to 4.5 m s^{-1}. The highest uniformity coefficient of 88.19% and wind drift and evaporation loss of 3.5% were obtained at the pressure head of 3 kg cm^{-2} and the wind speed of 0.9 m s^{-1}. Soil samples were collected at different depths of 0–10 cm, 10–20 cm, 20–30 cm and at a radial distance from 0 m, 3 m, 6 m, 9 m, 12 m respectively to determine the soil moisture distribution pattern. The soil moisture content values were plotted by using the computer software, surfer 10 of the windows version and contour maps were drawn. The moisture content was found to be more at 0–10 cm depth, as compared to 10–20 cm and 20–30 cm depth. The percentage of moisture was found to be highest at a 6 m distance, which was due to overlapping of the sprinkler system.

Keywords: Evaporation losses, soil-moisture distribution, uniformity coefficient, winddrift

1. Introduction

Sprinkler irrigation is widely used in the world and is the most significant advanced irrigation method. The sprinkler irrigation method is used for high value crops and vegetables. It increases the crop productivity by 10-35% with 30–35% water saving. It can be used for irrigating all cereals, pulses, oilseed, and vegetables. Uniformity distribution and wind drift and evaporation losses are the parameters affecting sprinkler irrigation performance. Martinez-cob et al. (2008) explained the occurrence of WDEL by describing it as a trajectory of water droplets from the sprinkler nozzle to the irrigated surface. Even if some of these losses drift out of the irrigated area, it could be assumed that all this water was finally lost to evaporation. Sanchez et al. (2011) reported that wind velocity was an important environmental parameter contributing to CUC and WDEL.Suryanarayana et al. (2013) also observed that in the horizontal distribution, the moisture content decreased with increased with the distance from the sprinkler because the spray nozzle had less spreading

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area away from sprinkler than the impact nozzle.

Sprinkler irrigation system categorized under pressurized irrigation system, required less operating pressure, involved less labour and provided higher water use efficiency (Koech and Langat, 2018). Poor uniformity distribution in sprinkler irrigation led to wastage of water, less yield of produce, poor quality of produce and other operational cost (Darko et al., 2017). Higher water use efficiency was reported in drip irrigation and sprinkler irrigation system in rice-wheat cropping system compared to check basin irrigation method (Meena et al., 2015).Sprinkler irrigation was adopted with different irrigation levels in different Blackgram varieties and studied the soil moisture distribution pattern (Kumar et al., 2018). Silva et al.(2013) studied the soil moisture distribution and application efficiency of micro sprinkler with three different capacity sprinkler nozzle with different crop geometry in banana plantation. The possible water wastage in sprinkler irrigation system was due to wind drift and evaporation rate of water droplets during water sprinkling from nozzle to the plant canopy (Irmak et al., 2011). The uniform soil moisture distribution depended on types of sprinkler nozzles, size of nozzle, number of nozzles used, operating pressure head and the intensity of wind. The coefficient of uniformity and distribution uniformity were calculated (Sistanto, 2014). The study of distribution uniformity is very important to avoid nutrient losses through deep percolation during irrigation and reported exact amount of water application would minimize gross irrigation requirement (Ascough and Kiker, 2014). Vallal Kannan (2019) studied the impact of mechanization in blackgram seed sowing with sprinkler irrigation and obtained better yield and water use efficiency under sprinkler irrigation system. Uddin et al. (2013) studied the evaporation loss and evapotranspiration in sprinkler irrigation system through precision energy budget method. The operating pressure needed to be managed in order to get uniform application of water for getting maximum water use efficiency and better soil moisture distribution in sprinkler irrigation system (Abd El-Wahed et al., 2016). Adoption of pressurized irrigation like drip and sprinkler irrigation system led to less extraction of water source due to higher uniform application efficiency (Fishman et al., 2015). Darko et al. (2017) insisted water management technologies to improve farm production and indicated the uniformity distribution and water use efficiency of sprinkler irrigation system to ensure proper application of water in the crop root zone. Dey and Ray (2017) studied different irrigation methods like furrow irrigation, micro sprinkler irrigation and gravity fed irrigation and worked out the water use efficiency in different potato varieties.

2. Materials and Methods

A field experiment during March–June 2018 was carried out in Agricultural Engineering College and Research Institute, TNAU, Kumulur, Tamil Nadu, India. The experimental site is geographically situated in the Cauvery delta zone of Tamil Nadu at 10.93˚ N latitude and 78.84˚ E longitude at an altitude of 57 masl. The mean maximum and minimum temperatures during the experimental season were 32.1°C and 22.5˚C respectively. The relative humidity was 62.8%. The wind drift loss and uniformity coefficient were calculated with different wind speed conditions. The texture of the soil was sandy loam, with a pH of 8.7 and electrical conductivity of 0.35 dSm^{-1}. The infiltration rate of soil was studied by using a Double ring infiltrometer. The infiltration rate was tested in the field. The infiltration rate obtained was 2.4 cm hr^{-1}.

The experiment was conducted in an area of 39×42 m^2 with a sprinkler irrigation system during the winter and summer season. The layout of the sprinkler system consisted of 75 mm of PVC main pipes, which were used to convey the water from the source to the field. The laterals with 63 mm PVC pipes were connected to the main to a length of 40m. The sprinkler heads were placed at 12 m intervals along the laterals to have 50% overlapping of the wetted area and lateral pipes were placed at an interval of 12 m along the main line. Six sprinkler heads were used to irrigate the experimental plot. The sprinkler head was tested in the field before the experiment at 2 kg cm^{-2}, 2.5 kg cm^{-2} and 3.0 kg cm^{-2} pressure. The discharge from the nozzle was calculated using the orifice formula derived by Toricelli.

$$q=C_d a\sqrt{2gh} \qquad \text{..........(1)}$$

where,

q=sprinkler nozzle discharge, $m^3 s^{-1}$

a=Nozzle crosssectional area, m^2

h=Pressure head at nozzle, m

g=acceleration due to gravity, m s^{-2}

C_d=Co-efficient of discharge.

The sprinkler system layout was designed in order to obtain maximum uniformity under low wind speed. Four sprinkler heads were used to irrigate the experimental plot with a spacing of 12×12 m^2. The sprinkler system consisted of two nozzles, the main nozzle and the auxiliary nozzle with 4.36 mm and 3.1 mm diameter. Catch cans were arranged at a distance of 2×2 m^2 from the sprinkler in a grid pattern. The sprinkler was operated for 15 minutes under different pressure of 2.0 kg cm^{-2}, 2.5 kg cm^{-2} and 3.0 kg cm^{-2} and varying wind speed conditions. The radius of coverage obtained at 2.0 kg cm^{-2}, 2.5 kg cm^{-2} and 3.0 kg cm^{-2} pressure was 8 m, 9 m and 10 m and the discharge rate obtained was 1522 lph, 1702 lph and 1864 lph respectively.

Christiansen uniformity coefficient and wind drift and evaporation loss were estimated in order to evaluate the performance of the sprinkler irrigation system and to ensure uniform distribution of the irrigation water. Christiansen uniformity coefficient was obtained by the equation given by Christiansen (1942)

$$Cu=100(1.0-(\sum x/mn)) \qquad \text{............ (2)}$$

Where, C_u=uniformity coefficient in percent m=average rate of water application, (mm)

n=total number of observation

x=numerical deviation of individual observation from the average application rate, (mm).

To arrive soil moisture characteristics curve, the soil moisture content was estimated by taking soil samples at the effective root zone depth of black gram for different soil moisture tension. The soil moisture tension value was measured with tensiometers installed at the effective root zone depth of blackgram. The moisture content was estimated by oven dry method.

2.1. *Wind drift and evaporation loss (WDEL)*

WDEL was estimated by determining the sprinkler irrigation depth ID_D (discharge of the sprinkler, sprinkler spacing and time of operation) and the irrigation water collected in the pluviometers ID_c during the field experiment (Dechmi et al., 2003; Sanchez et al., 2011).

$$WDEL=(ID_D-ID_C/ID_D)\times 100 \quad \text{.............. (3)}$$

Where, WDEL=wind drift and evaporation loss, percent,

ID_D=mean water depth emitted by the sprinkler, mm.

ID_C=mean water depth collected in pluviometer, mm.

ID_D can be obtained by the equation

$$ID_D=(q\times t)/S \quad \text{.............. (4)}$$

Where,

q=sprinkler discharge, lps

t=time of operation, s

S=spacing between sprinkler, m

Discharge of the sprinkler system was determined by Torricelli's equation given in equation 1.

3. Results and Discussion

3.1. *Uniformity distribution*

Uniformity coefficient, wind drift and evaporation loss (WDEL) were calculated under three different operating pressure rates 2.0 kg cm^{-2}, 2.5 kg cm^{-2} and 3.0 kg cm^{-2}. The varying wind conditions and the amount of water collected were observed under a solid set experiment. The experimental study conducted showed that the Christiansen Uniformity Coefficient (CUC) decreased when the wind speed increased, which led to an increase in wind drift and evaporation loss (WDEL). This is in agreement with the several studies conducted on sprinkler irrigation, whereby it was reported that wind is the main environmental factor thataffects the performance of sprinkler irrigation (Dechmi et al., 2003; Sanchez et al., 2011). It was observed that the highest uniformity coefficient (UC) obtained was 83.6%, 85.8% and 88.1% at a pressure of 2.0 kg cm^{-2}, 2.5 kg cm^{-2} and 3.0 kg cm^{-2} with a wind speed of 1.1 m s^{-1},1.0 m s^{-1} and 0.9 m s^{-1} and the WDEL obtained was 2.4%, 6.9% and 3.5%. The lowest UC obtained was 75.7% 79.5% and 74.5% at a wind speed of 4.2 m s^{-1}, 3.7 m s^{-1} and 4.5 m s^{-1} and the WDEL was 24.4%, 24.1% and 37.9%. The data obtained for CUC is represented in Figure 1 and the data recorded for WDEL is represented in Figure 2 respectively. It was observed that when the wind speed was below 2 m s^{-1} higher uniformity and low WDEL wereobtained. The results were in close conformity with the studies conducted by several researchers (Dechmi et al., 2003; Sanchez et al., 2011). In accordance with these studies, in the experimental study conducted, wind velocity decreased the UC and increased the WDEL.

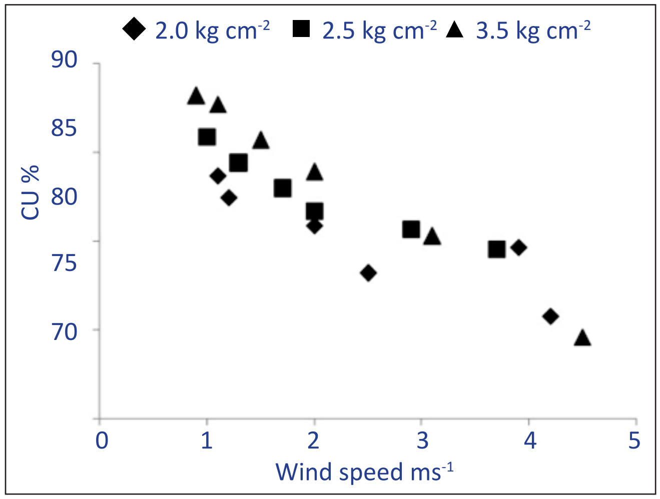

Figure 1: Christiansen uniformity coefficient vs wind speed at different pressure

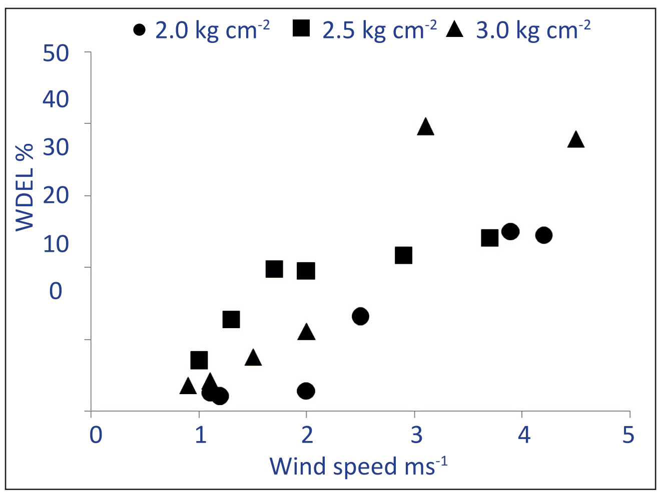

Figure 2: Wind drift and Evaporation losses vs wind speed at different pressure

The depth of water collected maximum at the distance of 4 m from sprinkler at lesser wind speed. When wind speed increased the depth of water collected was found maximum at the distance of 6–8 m from the sprinkler. This finding was supported by Dwomoh et al. (2015) that at the operating pressure of 300 kPa, at wind of 4.5 m s^{-1} around 30% of the total volume travelled beyond overlapping distance and remaining 70% fell down between sprinklers. As the wind speed increased the wind drift evaporation losses also increased with varying pressure head. When the wind speed increased from 1 to 4 m s^{-1} the percent evaporation loss was increased from 20–30%. Similar finding was reported by Molle et al. (2012) that major evaporation losses was due to the impact of wind during droplets sprayed rather than evaporation by climatic parameters.

UC was observed to improve on increasing the pressure head from 196 to 294 kPa when the wind speed was low to moderate (below 2 m s^{-1}). On the contrary, for the same pressure head, UC decreased with increasing wind speed (above 2 m s^{-1}). The Wind drift evaporation losses (%) and uniformity coefficient at 196 kPa, 245 kPa and 294 kPa with varying wind conditions are given in Table 1 to 3. Tarjuelo et al. (1999) reported that sprinkler spacing of 12×12 m^2 produced maximum uniformity of water application rate. Uniformity was greatly affected with wind speeds higher than 2 m s^{-1} regardless of the spacing and an increase in pressure improved the UC only in the presence of low wind speed. This result corroborated the findings of Kincaid (1985) who reported that UC gradually decreased when the wind speed exceeded 2.2 m s^{-1} for spacing of 12×12 m^2. Therefore at a pressure head between 196 to 294 kPa, if the wind speed exceeded 4 m s^{-1}, the irrigation should not be applied since the UC would drop below 75% which indicated nonuniformity in water distribution as proposed by Keller and Bliesner (1990).

Table 1: WDEL (%) and CUC (%) at 196 kPa pressure with varying wind conditions

Sl. No.	D+d (mm)	P (kPa)	W (m s^{-1})	IDe (mm)	IDc (mm)	WDEL (%)	CUC (%)
1.	4.36+3.1	196	4.2	2.64	1.99	24.45	75.76
2.	4.36+3.1	196	2.5	2.64	2.29	13.04	78.18
3.	4.36+3.1	196	3.9	2.64	1.98	24.96	79.64
4.	4.36+3.1	196	1.2	2.64	2.62	0.78	82.86
5.	4.36+3.1	196	0.7	2.64	2.57	2.45	83.68
6.	4.36+3.1	196	2	2.64	2.56	2.79	80.87

D: main nozzle diameter (mm); d: auxiallary nozzle diameter (mm); P: Pressure (kPa); W: Wind speed m s^{-1}; IDe: Sprinkler irrigation depth (mm); IDc: Catchcan irrigation depth (mm)

Table 2: WDEL (%) and CUC (%) at 245 kPa pressure with varying wind conditions

Sl. No.	D+d (mm)	P (kPa)	W (m s^{-1})	IDe (mm)	IDc (mm)	WDEL (%)	CUC (%)
1.	4.36+3.1	245	3.7	2.95	2.24	37.92	74.58
2.	4.36+3.1	245	2.9	2.95	2.31	39.60	80.28
3.	4.36+3.1	245	2	2.95	2.37	11.09	83.90
4.	4.36+3.1	245	1.7	2.95	2.37	7.49	85.69
5.	4.36+3.1	245	1.3	2.95	2.57	4.17	87.7
6.	4.36+3.1	245	1	2.95	2.75	3.50	88.19

D: main nozzle diameter (mm); d: auxiallary nozzle diameter (mm); P: Pressure (kPa); W: Wind speed m s^{-1}; IDe: Sprinkler irrigation depth (mm); IDc: Catchcan irrigation depth (mm)

Table 3: WDEL (%) and CUC (%) at 294 kPa pressure with varying wind conditions

Sl. No.	D+d (mm)	P (kPa)	W (m s^{-1})	IDe (mm)	IDc (mm)	WDEL (%)	CUC (%)
1.	4.36+3.1	294	4.5	3.23	2.08	37.92	74.58
2.	4.36+3.1	294	3.1	3.23	1.95	39.60	80.28
3.	4.36+3.1	294	2	3.23	2.87	11.09	83.90
4.	4.36+3.1	294	1.5	3.23	2.99	7.49	85.69
5.	4.36+3.1	294	1.1	3.23	3.10	4.17	87.7
6.	4.36+3.1	294	0.9	3.23	3.12	3.50	88.19

D: main nozzle diameter (mm); d: auxiallary nozzle diameter (mm); P: Pressure (kPa); W: Wind speed m s^{-1}; IDe: Sprinkler irrigation depth (mm); IDc: Catchcan irrigation depth (mm)

Wind drift evaporation loss will be affected by the wind speed and relative humidity. Sanchez et al. (2011) reported WDEL ranged between 2% and 36% and Dechmi et al. (2003) reported the values of WDEL ranged between 6% to 40% with an average of 20%. Wind velocity makes the greatest contribution in explaining the CUC and WDEL. In accordance with these literature findings, in this study also it was confirmed that the wind speed decreased the CUC and increased WDEL. Several authors also reported wind speed as the most significant variable affecting the WDEL.

3.2. Soil moisture characteristics curve

The soil moisture characteristics curve was derived to understand the soil moisture at the effective root zone depth of blakgram. As the soil moisture tension value increased the volumetric moisture content was found decreased. At the soil moisture tension near field capacity the moisture content was found maximum (20-23%) (Figure 3).

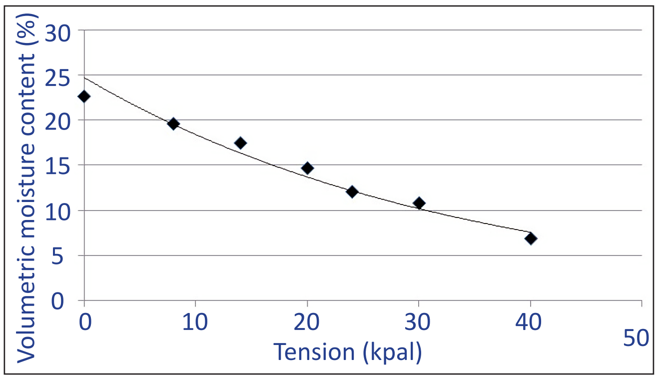

Figure 3: Soil moisture characteristics curve

3.3. Soil moisture distribution pattern

The soil moisture content at a depth of 0–10 cm, 10–20 cm, 20–30 cm at a different radial distance of 0 m, 3 m, 6 m, 9 m, 12 m between two sprinklers were taken. The presence of moisture content in the soil before and after irrigation was estimated. It was observed that the moisture content increased at different depths after irrigation. The maximum moisture (21.9%) was observed in the mid-point between two sprinklers at 0–10 cm depth and minimum moisture (18.09%) was observed near the sprinkler position at 20–30 cm depth. It was clear that the moisture content was more at 0–10 cm depth. Maximum moisture distribution was found in the mid-point between two sprinklers, which might be due to overlapping of the sprinkler water distribution. The soil moisture content values were plotted by using the computer software surfer 10 of the windows version and contour maps were drawn. The soil moisture contour maps showed the moisture available at different depths vertical as well as horizontal movement of water in the experimental field, before and after irrigation.

Before irrigation, the moisture distribution was seen to be greater in the mid-point of two sprinklers and the top soil layer had maximum moisture content. The soil moisture distribution in the sprinkler plot before irrigation is depicted in Figure 4. The soil moisture distribution pattern under sprinkler irrigation system with 12×12 m^2 spacing after irrigation showed the moisture lines indicating more moisture distribution in top soil layer (0–10 cm) and at the mid-point of two sprinklers. The moisture distribution decreased as depth increased which might be due to loss of water through drift and evaporation. The soil moisture distribution after irrigation is depicted in Figure 5. More moisture content was found in the zone of two or more sprinkler overlaps.

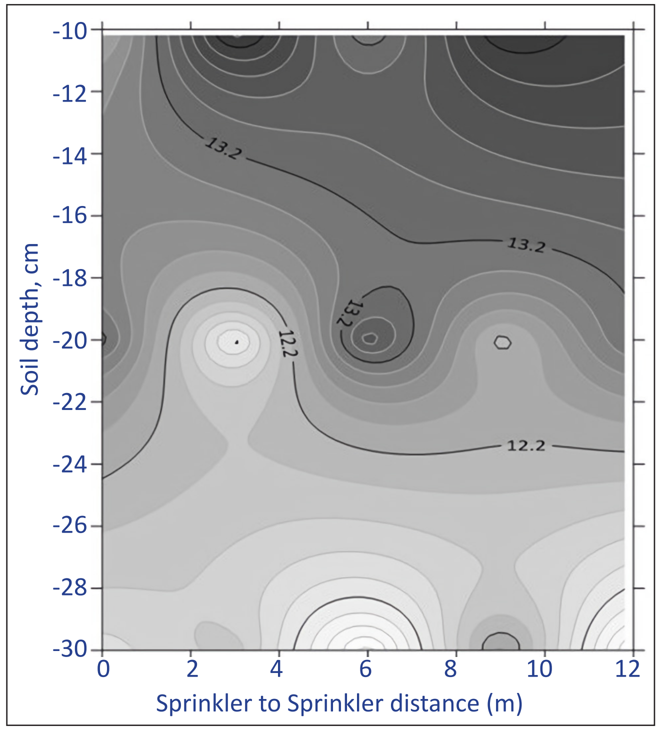

Figure 4: Soil Moisture distribution pattern before irrigation

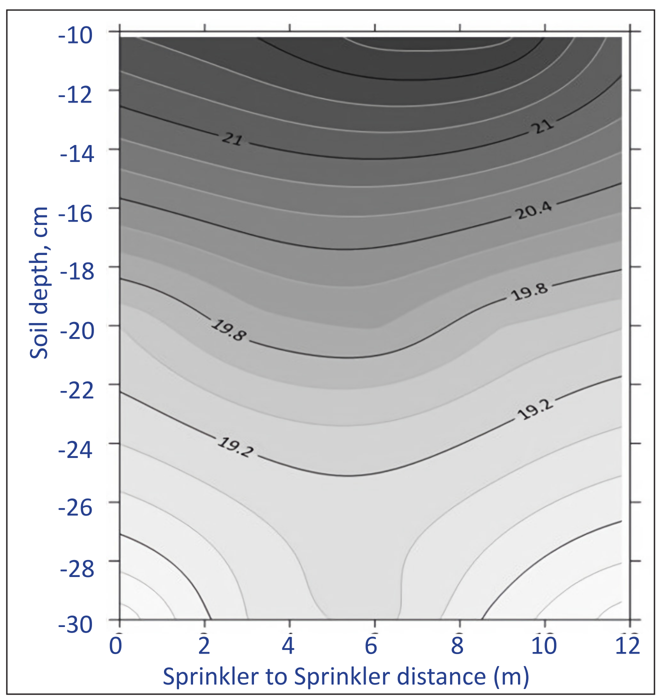

Figure 5: Soil Moisture distribution pattern after Irrigation

4. Conclusion

Uniformity coefficient, wind drift and evaporation loss of the sprinkler system at a different pressure head of 2 kg cm^{-2}, 2.5 kg cm^{-2} and 3 kg cm^{-2} were studied. Wind speed was recorded during the experiment, the wind speed ranged between 0.9 to 4.5 m s^{-1}. The highest uniformity coefficient was obtained as 88.19% at a pressure head of 3 kg cm^{-2} and at the wind speed of 0.9 m s^{-1}and the wind drift and evaporation loss were obtained as 3.50%.

5. Acknowledgement

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