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EFFECT OF CORN CANOPY ON APPLICATION RATE AND UNIFORMITY OF WATER DISTRIBUTION USING A SPRINKLER

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ABSTRACT

The study evaluated the effects of cultivation under a canopy, concerning plant density, row spacing, and cultivation without a canopy, on the application rate and the uniformity coefficient with different catch-can heights. The experiment was conducted at the Fishery and Aquaculture Technology Farm in the Volta Region of Ghana. Catch-cans were arranged at the heights of 0.5, 1.0, 1.5, and 2.0 m, respectively, and the working pressure varied from 150~250 kPa. The average infiltration rate with the canopy and without it was 31.2 mm h^{-1} and 37.08 mm h^{-1}, respectively. Corn under the canopy significantly influenced (p-values 0.001) the infiltration depth before runoff. However, the effect of the cultivation without a canopy was insignificant ($p = 0.05$). The average application rates obtained under the canopy at the catch-can heights of 0.5, 1.0, 1.5, and 2.0 m were 56.6, 61.4, 68.0, and 52.0 m h^{-1}, respectively. The maximum and the average uniformity coefficient (Cu) values obtained under the canopy were 79% and 64%, respectively. The average sediment productions (gm^{-2}) were 2.0, 2.53, 3.0, 3.63, 5.95 and 70.2, respectively, in the treatments of 40.1 mm·h^{-1} and duration (Dur) 80 min, 45.2 mm·h^{-1} and Dur 60 min, with 30.4 mm·h^{-1} and Dur 110 min, 28.4 mm·h^{-1} and Dur 120 min, and 59.2 mm·h^{-1} and Dur 40min.

Introduction

Irrigation application efficiency can be defined as the percentage of sprinkler water retained in the plant rooting volume (Armstrong and Mitchell, 1987; Ayers et al.,1991; Saffinga et al., 1976; Bui and Box, 1992; Zhou, 2019). A crop canopy structure can significantly change the temporal and spatial water distribution between the top of the canopy and the soil surface (Prado, 2016; Prado et al., 2019). The percentage of irrigation reaching the substrate is called the percentage of capture (% capture). The percentage of capture refers to the percentage of irrigation falling above the plant canopy in the projected vertical cylinder of the container collected on the substrate surface. Since the canopy characteristics can change the amount of water reaching the substrate surface rather than falling directly to the container, assuming no leaching, the overhead application efficiency is calculated by multiplying the captured amount by the percentage of the bed area occupied by the container (Yuan, et al., 2017; Zheng, et al., 2018).

Previous studies on the canopy interception mainly focused on the impact of rainfall on the plant canopy interception (Jiao et al., 2016; Kermavnar and Vilhar, 2017; Ghilain et al., 2020). Many scholars (Fan et al., 2019; Llorens and Domingo, 2007; Fan et al., 2014) have proved that the water loss of the forest ecosystem is partly due to the rainfall loss caused by the canopy interception and subsequent atmospheric evaporation. Gómez et al. (2001) discussed the water distribution of spring maize above and below the canopy at different growth stages from the perspective of water distribution and canopy structure. Li et al. (2007) studied the effect of sprinkler irrigation on sprinkler distribution after being intercepted by the winter wheat canopy. Li et al. (2016) conducted a field experiment on the interception of winter wheat canopy. Liang et al. (2016) determined the relationship between the stem flow quantity, plant growth, and rainfall. Li et al. (2018) designed a new method to measure the canopy interception of winter wheat under sprinkler irrigation. Through field experiments, Li et al. (2007) explored the effect of maize canopy on water distribution. Lima et al. (2002) introduced a new method to measure canopy water retention. Molle (2002) tested and analysed the maximum canopy interception of crops such as soybean and corn. However, the effect of the plant density at different catch can heights needs further study. The purpose of this study was to determine the impact of the canopy, concerning plant density, on water application and the coefficient of uniformity under different catch-can heights using the dynamic fluidic sprinkler.

Materials and Methods

The field study was conducted at the Teaching and Research Farm of Fishery and Aquaculture Technology in the Volta Region of Ghana. The research farm is located at 7° 17' N latitude and 5° 14' E longitude in the humid Tropical Rainforest area of Ghana. The annual average rainfall ranges from 1300 to 2700 mm. The average temperature ranges from 25 to 31 degrees Celsius during the rainy season and below 32 degrees Celsius in the dry season. The test periods were selected taking into consideration the fact that several field tests could be performed under different wind conditions. Before and during the experiment, the surrounding weather conditions were recorded at 10-minute intervals as each experiment lasted 1 hour. The soil physical properties, such as temperature, pH value, and soil moisture, were measured. Similarly, the collected soil samples were analysed, and the soil properties are shown in Table 1.

The sprinkler head was installed on a 1.5 m riser at an angle of 90º to the horizontal plane. A centrifugal pump was used to supply water from a reservoir with a constant water level. Catch cans used in these experiments were cylindrical, 200 mm in diameter and 600 mm in height. As shown in Figure 1, catch cans were positioned at the heights of 0.5, 1.0, 1.5, and 2.0 m, respectively, with the working pressure ranging from 150 to 250 kPa. The water collected in each catch can was measured directly from the measuring cylinder. The integrated soil moisture sensor was used to measure soil temperature and soil moisture. The measurement range of soil temperature was 20 to 60°C $\pm$ 0.5°C, and the measurement range of soil volume moisture content was 0%~100% $\pm$ 4%. The soil temperature and volume moisture content at depths of 0, 10, 20, 30, 40, 50, and 60 cm from the surface were measured by the Integrated Soil Moisture Sensor. An infiltrometer was used to evaluate the soil's infiltration rate in the field.

Figure 1. Experimental setup in the outdoor

The experiment was carried out at three close or adjacent sites with identical soil conditions at each location to collect the average infiltration value while keeping in mind that the original soil layer should not be disturbed. We maintained a uniform suction head of 2 cm as instructed in the handbook because we are aware that the infiltration rate varies depending on the soil. The instrument was positioned on the topsoil surface in the beginning, when time was zero, after being made horizontal so that its bottom made proper contact with the soil surface. The water in the instruments began to move downward as soon as it contacted the dirt, and this was observed at various time intervals. Every experiment was run for a minimum of five minutes. After the surface runoff began, the drained water volume was measured every minute and every five minutes, and a sample was collected to estimate sediment production. In the laboratory, aluminium sulphate was added to the samples to promote flocculation and precipitation of suspended solids for 24 hours. After this period, the excess water of each sample was removed, and the solid material was placed in an oven at 105°C. After drying, the sediment mass was calculated in each test based on the sum of samples from the same field. Furthermore, soil from the location was brought to the Department of Civil Engineering at Koforidua Technical University for carrying out bulk density and saturated hydraulic conductivity tests. The classification of the soil samples based on sieve analysis was also performed.

Calculation of combined CUs

The uniformity of water application rate was calculated using the Christiansen uniformity coefficient (CU) in equation (1).

$$CU = (1 - \frac{|\Delta h|}{\bar{h}}) \times 100\% \quad (1)$$

In the formula, h_i represents the average dispersion of spraying water depth at each measuring point (mm); $\bar{h}$ indicates the average spraying water depth (mm) on the sprinkling irrigation area.

$$\bar{h} = \frac{\sum_{i=1}^{n} h_i}{n} \quad (2)$$

$$\Delta h = \frac{\sum_{i=1}^{n} |h_i - h|}{n} \quad (3)$$

Where n represents the total number of measuring points. h_i represents the i^{th} precipitation depth value (mm).

Water Application Rate

The water application rate from the sprinklers at a given location was calculated using Equation (4):

$$Wa = \frac{W_V}{C_{tw}} \quad (4)$$

Where Wa is the water application rate from sprinklers, mm h^{-1}; Wv is the water volume in the catch can, mm^3; C is the opening area of the catch can, mm^2; and tw is the irrigation time in the test of water application rate, (h).

The water infiltration depth before runoff (I, mm) suggested by Zheng (2018) can be calculated as:

$$\mathrm{I}\, C_1 + C_2 \times t^{\frac{1}{2}} \quad (5)$$

Where C_1 governs the hydraulic conductivity of the soil, and C_2 is linked with the soil absorptivity. Employing the value of C_1 at the suction head value, the value of K_{sat} was estimated using the expression (6), which was proposed by A closed-form equation for predicting the hydraulic conductivity of unsaturated soils Van Genuchten (1980)

$$K_{sat} = \frac{C_1}{a} \quad (6)$$

where K_{sat} represents the soil saturated hydraulic conductivity, using the Van Genuchten retention factors for a different type of soil, and its coefficient a would be found using the relationship (7), which was proposed by Zheng (2018)

$$\alpha = \frac{11.65\left(n^{0.1}-1\right)\exp[7.5(n-1.9)\alpha h_0]}{(\alpha * r)^{0.91}} \quad (7)$$

Here, the n ¼ 1.41 and α ¼ 0.020, which represent the Van Genuchten retention parameters, r is 2.25 cm, which represents the radius of the instrument, and h_0 is the suction head applied.

Runoff and infiltration

The soil surface runoff rate (DR, mm·h^{-1}) was calculated using Equation (5), which incorporated the runoff water volume (DV, mm^3), soil surface area, and runoff duration.

$$DR = \frac{DV}{C_{tc}} \quad (8)$$

where tc is the collection time of runoff, (h).

Sediment and soil loss

The sediment concentration of runoff water was determined using the following equation:

$$SY = \frac{MS}{1000DV} \quad (9)$$

Where MS is the net weight of sediment in runoff water after drying, g. The soil loss rate (SL, g m^{-2}) represents the amount of soil lost per unit area in a unit time, which is an important indicator of the soil erosion degree (Liu et al., 2018). SL was calculated using the following formula:

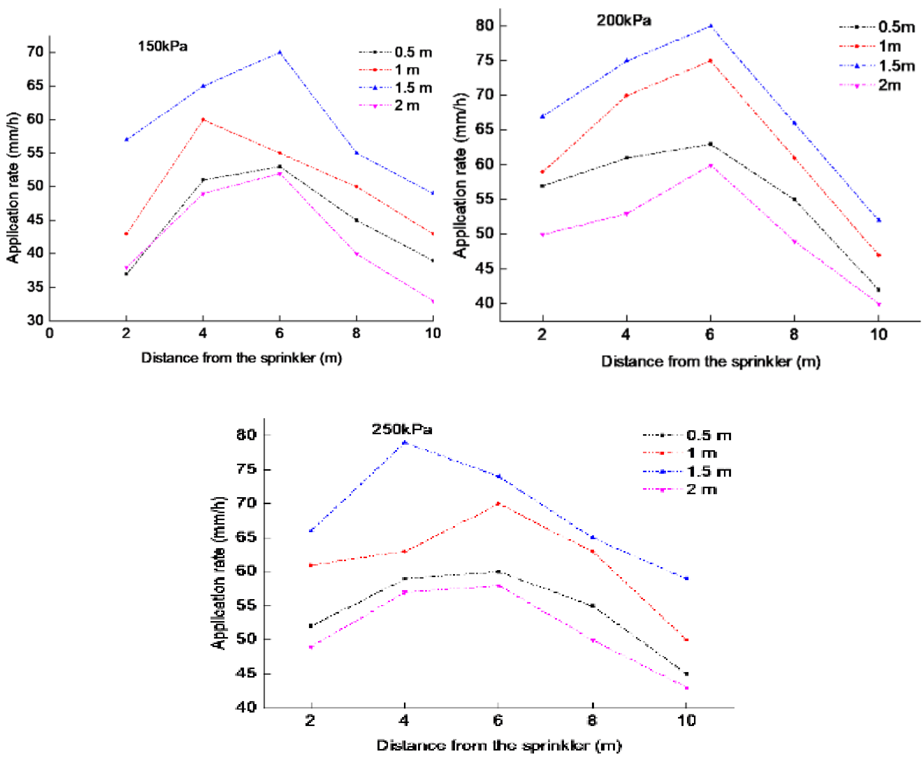
$$SL = \frac{MS}{C_{tw}} \quad (10)$$

Results and Discussions

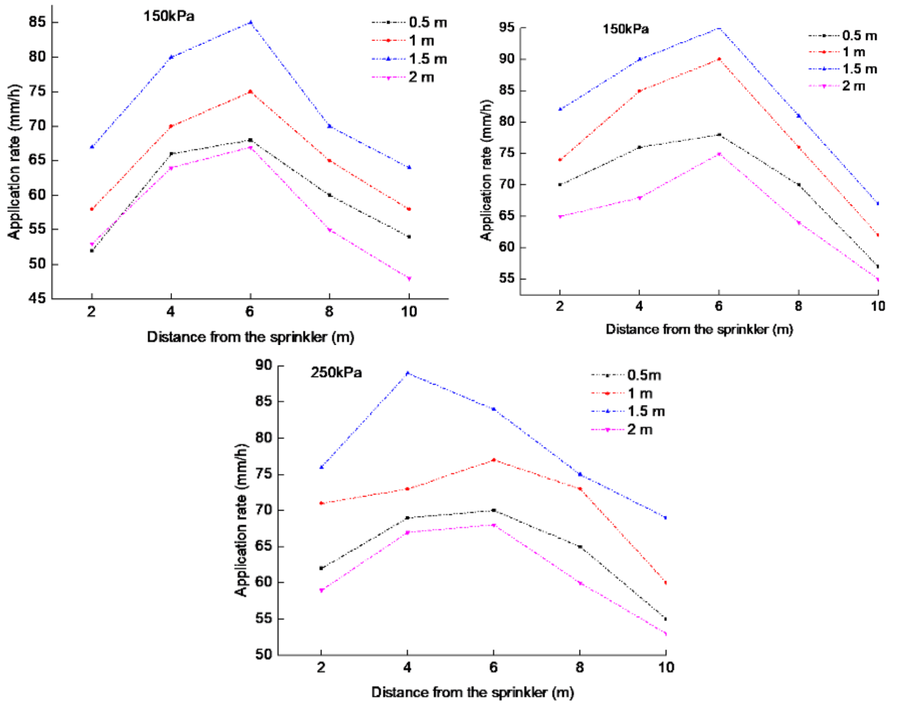
Application rate with canopy and without canopy

Figure 2 shows the application rates at different catch can heights, different distances from the sprinkler, and different operating pressures, namely, 150, 200, and 250 kPa under the canopy and without the canopy. As can be seen in Figure 2, as the distance from the sprinkler increased, the application rate increased until it reached the maximum value of around 4 to 6 m from the sprinkler and then decreased from 6m and above. The average application rates obtained under the canopy for distances of 0.5, 1.0, 1.5, and 2.0 m from the sprinkler were 56.6, 61.4, 68, and 52 mm·h^{-1}, respectively. Similarly, without the canopy, the average application rates were 70.2, 78.4, 83-, and 65.4-mm·h^{-1} at 0.5, 1, 1.5, and 2 m away from the sprinkler, respectively. In this study, the maximum application rate without the canopy was 90 mm·h^{-1}. A high average application rate above the average infiltration rate may lead to run-off. This means that it will be highly desirable from an economic and environmental point of view.

With the canopy, a catch-can height of 1.5 m recorded a higher average application rate of 80 mm·h^{-1}, and the catch-can height of 2 m recorded the lowest average application rate of 52.2 mm·h^{-1}. This observation is inconsistent with previous findings from earlier researchers who reported that as the catch-can height increased, the average application rate also increased. This may be due to the interference of the canopy and wind conditions, which were low and perpendicular to the irrigation lateral, distorting the pattern (Liu et al., 2003; Liu et al., 2018). The consideration of the application rates indicates that the heterogeneity of application rates is very large. These differences may or may not always lead to yield differences, but they should be considered in the design review.



(A) Water application rate with canopy



(B) Water application rate without canopy

Figure 2. Water application rate variation with distance from the sprinkler location (2, 4, 6, 8, and 10 m) at different operating pressure conditions (150, 200, and 250 kPa) and different catch can heights (0.5, 1.0, 1.5, and 2.0 m) for with and without canopy

Plant density influence on application rate

This section introduces the use of the analysis of variance (ANOVA) – a statistical analysis to show the influence of the plant density on the application rate. The current research demonstrated that the plant density had a significant impact on the water application rates and catch distribution. Different row spacings were set for each line, with 10 different row spaces (50, 45, 40, 35, 30, 25, 20, 15, 12, and 8 cm). The corresponding plant densities were 3.33, 3.70, 4.17, 4.76, 5.56, 6.67, 8.33, 11.11, 13.30, and 16.67 plants·m^{-2}, respectively. From the present study, increasing planting density resulted in a decrease in the catch-can water application rate. These can be attributed to the density resistance, which might eventually cause water evaporation of the water intercepted by the canopy. It was found that the estimated average sprinkled water volume after canopy interception was 1.64 mm, which is 2.9 mm lower than that of a plant density of 0 plant·m^{-2}.

The coefficient of variation of water applications for corn under the canopy under different catch-can heights was higher. Catch-can height variations of 0.5, 1.0, 1.5, and 2.0 m recorded a coefficient of variation of 14%, 11%, 9%, 3%, and 12.9%, respectively. The highest variation was 4%. This occurrence can be attributed to the reduction in catch-can heights. Among catch-can heights, deviations were comparatively small, from 1.5 to 1.0 m, with the average coefficient of variation (CV) of 6.2%.

Effects of Application depth on Soil moisture

Table 1 shows the physical properties of the study area at different distances. It was found that the soil layer at 0 cm is a complete sand layer, and the soil temperature fluctuates greatly with time, while the soil layer at 10–60 cm is the transition zone between complete sand and sandy loam. Before irrigation, the moisture contents measured at distances of 2, 4, 6, 8, and 10 m were 9, 7.9, 7.3, 7.8, and 7%, respectively. After irrigation, the soil moisture increased by 35.55%, 37.3%, 39.48%, 40.00%, and 44.42% on average, respectively. This is because the soil type found in the study area is mainly sandy loam. However, as more water replaces the air in the pores, the water from the soil surface penetrates more slowly and finally reaches a stable temperature. The reduction of the irrigation level may lead to a reduction in plant yield. However, due to the gradual progress of the growth stage, increasing the irrigation level may increase the number of leaves.

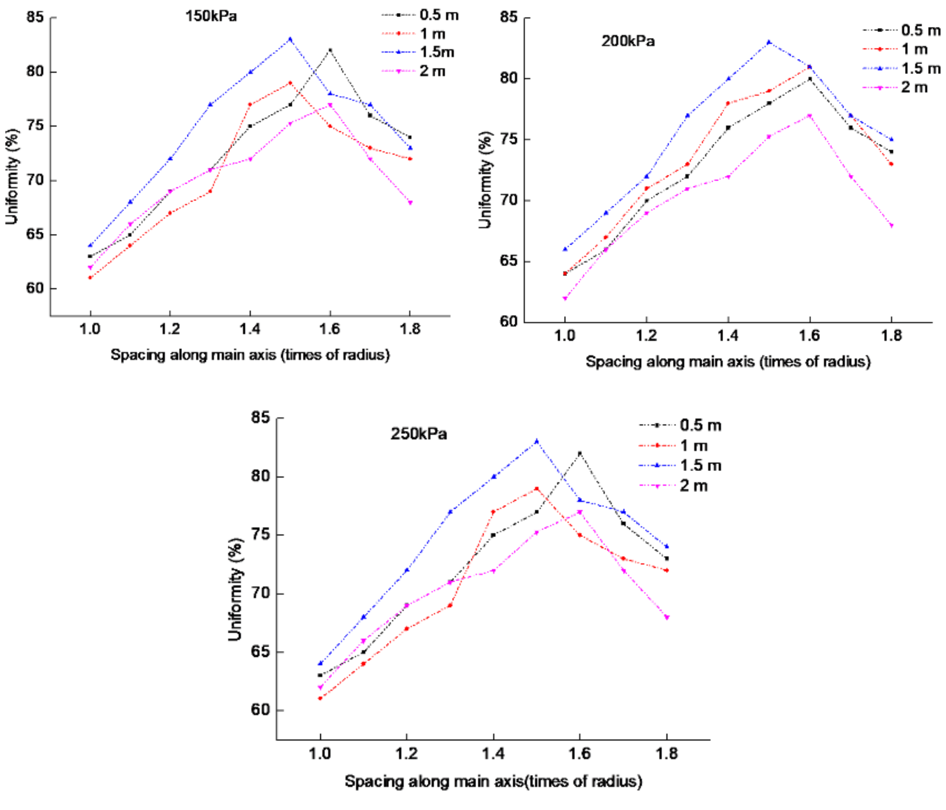
With the growth of plants, leaves may also increase, and with the increase in leaves, the weight will also increase. Under the same soil conditions, the average soil temperature at 2 m, 4 m, 6 m, 8 m, and 10 m decreased by 17.18%, 19.03%, 20.03%, and 26.28%, respectively. Using the ANOVA test, the response of the soil temperature to water irrigation without the canopy fields was significantly higher than that in the canopy fields ($p<0.05$). These findings are similar to previous work by Xu et al. (2018), Fordjour et al. (2020), and Zhu et al. (2015), who found that about 47% of irrigation water reached the soil surface by flowing down the corn stem. Similarly, Kermavnar and Vilhar (2017) reported similar work, including 76 cm corn rows, 64600 plant populations per ha, and 103 and 310 kPa irrigation sprinklers. They found that about half of the irrigation water flowed down the corn stalk.

Table 1.
The physical properties of soil in the test site.

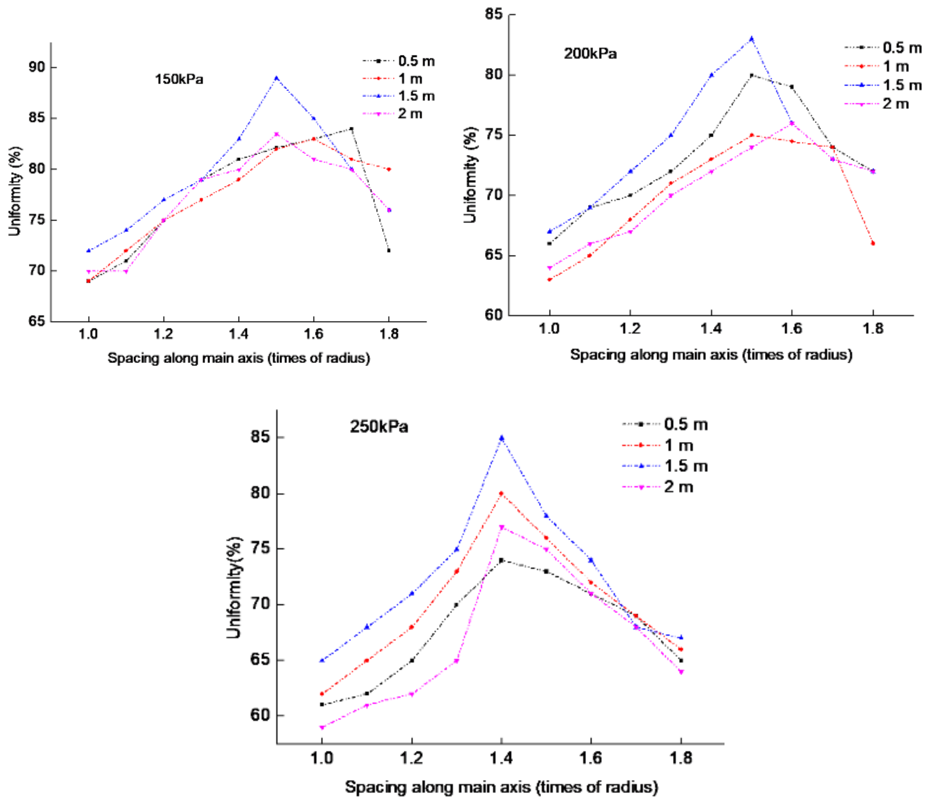
Distance (m)	Before the experiment			After the experiment			Standard deviation	Coefficient of Variation (%)
	pH	Tempt (°C)	Soil moi-sture	pH	Tempt (°C)	Soil moisture		
2	7.80	37.4	9.0	9.00	39.80	9.8	0.56	0.32
4	8.24	38.2	7.9	9.00	39.00	11.6	2.61	6.84
6	7.00	43.9	7.3	8.20	8.20	11.8	3.18	10.12
8	7.86	41.0	7.8	8.14	37.40	8.9	0.78	0.60
10	9.00	39.0	7.0	7.84	35.00	9.7	1.97	3.64

Application Uniformity

Figure 3 shows the combined uniformity for the canopy and without the canopy. The sprinkler was evaluated using the coefficient of uniformity, and square spacing for lateral radius times 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, and 1.8 for different catch can heights, respectively. Different working pressures, of 150, 200, and 250 kPa, were used in the calculation of the combined uniformity for the canopy and without it. As can be seen in Figure 3, with increasing spacing, the CU for the canopy and without it increases to a maximum and then decreases. The uniformity without the canopy had good application uniformity, and the uniformity coefficient (CU) of the single irrigation event was between 76% and 89%. The maximum CU value of the canopy was about 79%, and the average value was 64%, which occurred at the catch-can height of 1m. These occurrences could be attributed to the decline of wind variability and interference from leaves. In terms of heights, 1.5 m gave a CU value of 82%. Lang et al. (2015) and Jobbágy et al. (2019) suggested that the CU value from 80 to 90% is required for adequate distribution of chemicals applied via irrigation water. Therefore, the uniformity values of different catch can heights obtained in this study are sufficient for the application of waterborne chemicals. As can be seen from Figure 3, the impact of catch can height was very significant.



(A) Uniformity with the canopy

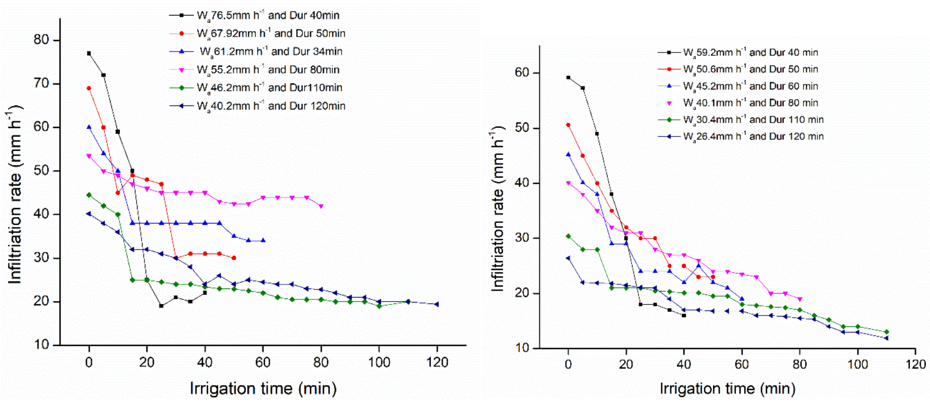


(B) Uniformity without canopy

Figure 3. *Uniformity variation with spacing along the mean axis different operating pressure conditions (150, 200, and 250 kPa), and different catch can heights (0.5, 1, 1.5, and 2 m) for with and without canopy*

Infiltration rate with canopy and without canopy

The infiltration rate with the irrigation time under various treatments for the cultivation under the canopy and without the canopy is shown in Figure 4. It was found that in both cases, the infiltration rate declined as the irrigation time increased. At the beginning of the irrigation, the infiltration rate was high and matched the rate at which the sprinkler sprayed water. The infiltration depth trend shows that the soil did not reach the state that was nearly saturated in a few places. There are differences in the infiltration depth as shown in Figure 4, since most of the soil is sandy soil with larger porosity. It was noticed that the infiltration depth was higher at 40 minutes (77 mm·h^{-1}); however, the infiltration depth was lower at 120 minutes (40.2 mm·h^{-1}), which could be attributed to the soil sample's low amount of clay and silt. In contrast to irregular soil particles, which have fewer vacancies and are rougher, granular soil particles have a lamellar space between them from which water must move. Infiltration is higher in sandy soils because of the larger and more granular particle configurations. In terms of the canopy, it was discovered that a higher infiltration depth was observed at 40 min (59.2 mm·h^{-1}) and lower infiltration depth at 120 min (26.4 mm·h^{-1}); these dramatic decreases can be attributed to the top surface cover caused by water droplets energy impact, which helps with the soil penetration and reduces the soil movement. Additionally, the roughness of the grassland lowers surface runoff, which promotes water penetration at different water distribution rates. The results of the regression analysis showed that the corn under the canopy significantly influenced (p-values 0.001) the infiltration depth before runoff, and that the results without the canopy were insignificant (p = 0.05).



(A) without canopy (B) with canopy

Figure 4. The infiltration rate with irrigation time under the treatment for the canopy and without the canopy. Wa: the application rate

Surface runoff

Surface runoff and irrigation time for different treatments are shown in Figure 5. The investigation indicated that the surface runoff was higher in the treatment at 59.5 mm·h^{-1} and Dur 40 min along the entire period of water application, with the maximum value close to 65 mm·h$^{-1.}$ The other treatments were initially higher in the 50.6 mm·h^{-1} and Dur 50 min, 45.2 mm·h^{-1} and Dur 60 min, 30.4 mm·h^{-1} and Dur 110 min, and 40.1 mm·h^{-1} and Dur 80 min. This order of higher runoff started to change after 15 minutes, which may be related to how much water was applied. Because the irrigation intensity and duration increased the rate of sediment production, a higher runoff could be seen for the highest intensities if they were accompanied by longer durations. In terms of the treatments, the mean values were 43.5, 26.2, 22.56, 8.61, 19.30, and 19.33 mm·h^{-1} for 59.2 mm·h^{-1} and Dur 40 min; 50.6 mm·h^{-1} and Dur 50 min; 45.2 mm·h^{-1} and Dur 60 min; 40.1 mm·h^{-1} and Dur 80 min; 30.4 mm·h^{-1} and Dur 110 min; and 26.4 mm·h^{-1} and Dur 120 min, respectively. This outcome is consistent with what Yan et al. (2011), Mathys et al. (2005), and Bertol et al. (2017) discovered in their runoff study using sandy loam.

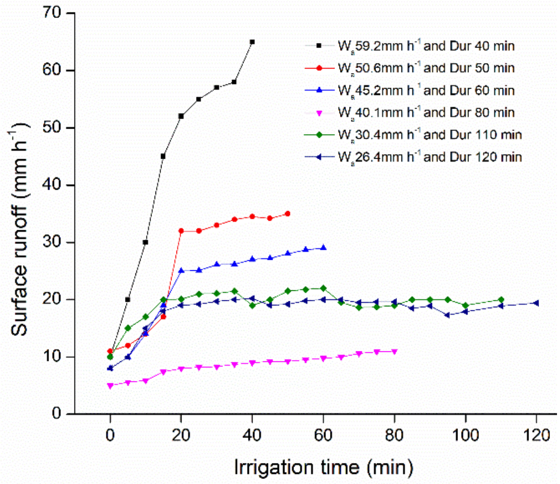


Figure 5. Surface runoffs with irrigation time under the different treatments

Sediment and soil erosion

Figure 6 depicts the sediment production as a function of irrigation time after the beginning of the surface runoff under various treatments. When runoff was initially noticed, there was a greater concentration of sediment. As the irrigation process progressed, the sediment concentration was higher but later decreased as the irrigation continued, and finally reduced. As presented in Figure 6, sediment concentration varied from 1.7 to 9.3 g·m^{-2}, respectively in the treatments 59.2 mm·h^{-1} and Dur 40 min and 30.4 mm·h^{-1} and Dur 110 min. The average sediment productions (g·m^{-2}) were 2.0, 2.53, 3.0, 3.63, 5.95, and 70.2, respectively, in the treatments of 40.1 mm·h^{-1} and Dur 80 min, 45.2 mm·h^{-1} and Dur 60 min, 30.4 mm·h^{-1} and Dur 110 min, 28.4 mm·h^{-1} and Dur 120 min, and 59.2 mm·h^{-1} and Dur 40 min, respectively. It could be observed that the significant decrease in the various treatments can be associated with the high sediment generation rates and surface runoff. This indicates that the disruption of the soil surface structure was made worse by water application. Among the treatments, it can be seen from Figure 6 that 40.1 mm h^{-1} and Dur 80 min had the lowest sediment production, followed by 45.2 mm·h^{-1} and Dur 60 min. The highest sediment production was recorded under the treatment of 59.2 mm·h^{-1} and Dur 40 min, and these can be explained by factors such as organic porosity and aggregate stability, influenced by the time during which the area remained covered by grass. This finding conforms to previous studies on sediment production (Carvalho et al., 2015).

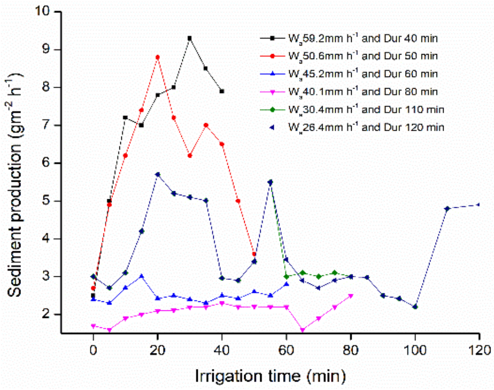


Figure 6. Sediment production as a function of irrigation time after the beginning of surface runoff for the different treatments

Table 2 presents the surface runoff, cumulative sediment production, and the time for the surface runoff for different treatments. In this study, it was observed that water applications with different combinations of duration and intensity affect sediment production, although no significant differences were found in the surface runoff. Other authors have also reported similar results regarding the surface runoff and sediment production under simulated rainfall (Ran et al., 2019; An et al., 2014; Wang et al., 2019). For all treatments, the surface runoff rates stabilized after approximately 20 min of rainfall application, which has also been observed under laboratory conditions (He et al., 2021). It was demonstrated that the sediment production decreased as the runoff time decreased. These can be explained by factors such as organic carbon content, porosity, and aggregate stability, influenced by the time the area remained covered by grass. The carbon supplied to the soil by grass roots contributes to the formation of larger, more stable aggregates and favours soil porosity by structuring the soil and through the physical effect of the roots, creating spaces for water infiltration. These differences may be associated with the variability of soil physical properties, erodibility, terrain cover conditions, and the characteristics of the water applied.

Table 2.

Surface runoff, cumulative sediment production, and time for surface runoff for the different treatments

	Treatments					
Variable	W_a26.4 mm·h^{-1} and Dur120 min	W_a 30.4 mm·h^{-1} and Dur110 min	W_a 40.1 mm·h^{-1} and Dur 80 min	W_a 45.2 mm·h^{-1} and Dur 60 min	W_a 50.6 mm·h^{-1} and Dur 50 min	W_a59.2 mm·h^{-1} and Dur 40 min
Runoff (mm)	444.7	424.8	146.39	293.01	288.7	392
Sediments (g·m^{-2})	83.5	78.89	35.11	32.84	65.5	63.2
Time for runoff (min)	13.97	26.90	14.95	14.80	12.90	12.80

W_a - application rate

Practical recommendations for farmers

Based on the findings, it is recommended that the soil profile analysis of irrigation fields is necessary to determine the appropriate water application rate to avoid surface run-off and sedimentation. For low runoff and sedimentation, water application rates of 40.1 mm·h^{-1} for 80 min and 45.4 mm·h^{-1} for 60 min are recommended when using the dynamic fluidic sprinkler. For the case of under the canopy, there was a reduced surface runoff, which facilitates water absorption at various distribution rates. It is therefore recommended that farmers ensure as much as possible that the ground is not bare for effective infiltration. It is also advisable for farmers to use a catch can height of 2 m without the canopy (on bare soils) to achieve low application, runoff, and sedimentation.

Conclusion

This study evaluated the influence of the canopy and the absence of the canopy on the application rate and uniformity coefficient (Cu) under different catch can heights using the dynamic fluidic sprinkler. The following conclusions can be drawn from this study. The average application rates obtained under the canopy with a catch can height of 0.5, 1, 1.5, and 2 m were 56.6, 61.4, 68-, and 52-mm·h^{-1}, respectively. Similarly, without the canopy, the average application rates with the catch can height of 0.5, 1, 1.5, and 2 m were 70.2, 78.4, 83-, and 65.4-mm·h^{-1}, respectively. The maximum CU value of the canopy was 79%, and the average value was 64%, which occurred at the catch can height of 1m. The coefficient of variations of the corn canopy with different catch can heights were much larger. The variations at the catch can heights of 0.5, 1, 1.5, and 2 m were 14%, 11%, 9.3%, and 12.9%, respectively. About 70% of the irrigation water reached the soil surface in the area with a diameter of 150 mm at the bottom of the corn plant. It was established that the estimated sprinkled water volume after the canopy interception was 1.64 mm, which is 2.9mm lower than that without the canopy. The study found that the average infiltration rate was 31.2 mm·h^{-1} under the canopy and 37.08 mm/h without the canopy. Sediment production varied from 1.7 to 9.3 g·m^{-2}, respectively, in the treatments with 59.2 mm·h^{-1} and Dur 40 min and treatment of 30.4 mm·h^{-1} and Dur 110 min. The average sediment productions (g·m^{-2}) were 2.0, 2.53, 3.0, 3.63, 5.95, and 7.2, respectively, in the treatments 40.1 mm·h^{-1} and Dur 80 min and 45.2 mm·h^{-1} and Dur 60 min, and with 30.4 mm·h^{-1} and Dur 110 min and 28.4 mm·h^{-1} and Dur 120 min and 59.2mm·h^{-1} and Dur 40 min.

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References

Armstrong, C. L., & Mitchell, J. K. (1987). Transformations of rainfall by plant canopies. *Transactions of the ASAE, 30*(3), 688-696.

Ayers, J. E., Hutmacher, R. B., Schoneman, R. A., & Dettinger, D. R. (1991). Influence of cotton canopy on sprinkler irrigation uniformity. *Transactions of the ASAE, 34*(3), 890-896.

Bertol, I., Schick, J., Bandeira, D. H., Paz-Ferreiro, J., & Vázquez, E. V. (2017). Multifractal and joint multifractal analysis of water and soil losses from erosion plots: A case study under subtropical conditions in Santa Catarina highlands, Brazil. Geoderma, 287, 116-125.

Bui, E. N., & Box Jr, J. E. (1992). Stemflow, rain throughfall, and erosion under canopies of corn and sorghum. *Soil Science Society of America Journal, 56*(1), 242-247.

Carvalho, D. F. D., Eduardo, E. N., Almeida, W. S. D., Santos, L. A., & Alves Sobrinho, T. (2015). Water erosion and soil water infiltration in different stages of corn development and tillage systems. *Revista Brasileira de Engenharia Agrícola e Ambiental, 19*, 1072-1078. https://doi.org/ 10.1590/ 1807-1929/

Fan, J., Oestergaard, K. T., Guyot, A., & Lockington, D. A. (2014). Measuring and modelling rainfall interception losses by a native Banksia woodland and an exotic pine plantation in subtropical coastal Australia. *Journal of Hydrology, 515*, 156-165.

Fan, Y., Meijide, A., Lawrence, D.M., Roupsard, O., Carlson, K.M., Chen, H.Y., Röll, A., Niu, F., & Knohl, A. (2019). Reconciling canopy interception parameterization and rainfall forcing frequency in the Community Land Model for simulating evapotranspiration of rainforests and oil palm plantations in Indonesia. *Journal of Advances in Modelling Earth Systems,11*(3), 732-751.

Fordjour, A., Zhu, X., Jiang, C., & Liu, J. (2020). Effect of riser height on rotation uniformity and application rate of the dynamic fluidic sprinkler. *Irrigation and Drainage, 69*(4), 618-632. https://doi.org/10.1002/ird.2462

Ghilain, N., Arboleda, A., Barrios, J.M., & Gellens-Meulenberghs, F. (2020). Water interception by canopies for remote sensing-based evapotranspiration models. *International Journal of Remote Sensing, 41*(8), 2934-2945.

Gómez, J.A., Giráldez, J.V., & Fereres, E. (2001). Rainfall interception by olive trees in relation to leaf area. *Agricultural Water Management, 49*(1), 65-76.

He, Y., Hu, Y., Song, J., & Jiang, X. (2021). Variation of runoff between southern and northern China and their attribution in the Qinling Mountains, China. *Ecological Engineering, 7*, 106374.

Jiao, J., Su, D., Han, L., & Wang, Y. (2016). A rainfall interception model for alfalfa canopy under simulated sprinkler irrigation. *Water*, *8*(12), 585.

Jobbágy, J., Michlian, N., Dacanin, P., & Rigó, I. (2019). Application and the evaluation of performance quality of hose-reel irrigation machine. *Acta Technoogica Agriculture, 22*(4), 109-114.

Kermavnar, J., & Vilhar, U. (2017). Canopy precipitation interception in urban forests in relation to stand structure. *Urban Ecosystems*, *20*, 1373-1387.

Lang, J.B., Wang, J., Li, T.N., & Wang, D.W. (2015). Require high-efficiency of high efficiency water-saving irrigation on equipment under the background of water-saving and grain-increasing action in Heilongjiang Province. *Journal of Drainage Irrigation Machinery Engineering*, *33*(5), 456-460.

Li, H., Yuan, S. Q., Liu, J. P., Xiang, Q.J., Zhu, X. Y., & Xie, F. Q. (2007). Wall-attachment fluidic sprinkler. Ch. Patent No. 101224444 B.

Li, Y. F., Liu, J. P., Li, T., & Xu, J. E. (2018). Theoretical model and experiment on the fluidic sprinkler wet radius under multi-factor. *Journal of Drainage Irrigation Machinery Engineering*, *36*(8), 685-689.

Liang, X. Z., Wu, Y., Chambers, G.R., Schmoldt, L. D., Gao, C., Yan, L. L., Sun, C., &Kennedy, A. J. (2016). Determining climate effects on US total agricultural productivity. *National Academy of Sciences*, *114*(12), 2285-2292.

Lianhao, L., Xinyue, Z., Xiaodong, Q., & Guiming, L. (2016). Analysis of the decrease of center pivot sprinkling system uniformity and its impact on maize yield. *International Journal of Agricultural and Biological Engineering*, *9*(5), 108-119.

Lima, J.L., Torfs, P. J. F., & Singhc, V. P. (2002). A mathematical model for evaluating the effect of wind on downward-spraying rainfall simulators. *Catena, 46*, 221-241.

Liu, H. J., Kang, Y. H., & Liu, S.P. (2003). Regulation of environmental conditions by sprinkler irrigation and its effect on water use efficiency of winter wheat. *Transactions of the China Society of Agricultural Engineering, 19*, 46-51.

Liu, J.P. Zhu, X. Yuan S.Q. & Liu. X F. (2018). Droplet motion model and simulation of a complete fluidic sprinkler. *Transactions of the ASABE,* 61(4), 1297-1306.

Llorens, P., & Domingo, F. (2007). Rainfall partitioning by vegetation under Mediterranean conditions. A review of studies in Europe. *Journal of Hydrology, 335*(1-2), 37-54.

Mathys, N., Klotz, S., Esteves, M., Descroix, L., & Lapetite, J. M. (2005). Runoff and erosion in the Black Marls of the French Alps: observations and measurements at the plot scale. *Catena, 63*(2-3), 261-281. https://doi.org/10.1016/j.catena.2005.06.010

Molle, B. (2002). Characterizing the droplet distribution of an irrigation sprinkler water application. 18th International Congress on Irrigation and Drainage, Montréal, Canada, Volume IA,1-19.

Prado, G., Colombo, A., & Barreto, A.C. (2019). Water distribution model for center pivot end gun sprinklers. *Revista Brasileira de Engenharia Agrícola e Ambiental, 23*(7), 477-483.

Prado, G.D. (2016). Medium distribution from medium-sized sprinkler system set sprinkler systems. *Revista Brasileira de Engenharia Agrícola e Ambiental, 20*(3), 195-201.

Ran, Q., Hong, Y., Chen, X., Gao, J., & Ye, S. (2019). Impact of soil properties on water and sediment transport: A case study at a small catchment in the Loess Plateau. *Journal of Hydrology, 574*, 211-225.

Van Genuchten, M.T. (1980). A closed-form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil science society of America journal, 44*(5), 892-898.

Wang, Y.Z., A.M., Zhao, K., & Song, L. (2019). Fast solution for deformation characteristics of flexible bearing of the robot based on thin-walled ring theory. *Transactions of the Chinese Society of Agricultural Engineering, 35*(3), 60-66.

Xu, Z.D. Xiang, Q.J, Waqar, A.Q. & Liu, J. (2018). Field combination experiment on impact sprinklers with aerating jet at low working pressure. *Journal of Drainage Irrigation Machinery Engineering, 36*(9), 840-844.

Yan, H. J., Bai, G., He, J. Q., & Lin, G. (2011). Influence of droplet kinetic energy flux density from fixed spray-plate sprinklers on soil infiltration, runoff, and sediment yield. *Biosystems Engineering, 110*(2), 213-221.

Yuan, S.Q., Ransford, O.D., Zhu, X.Y., Liu, J.P., & Tian, K. (2017). Optimization of movable irrigation system and performance assessment of distribution uniformity under varying conditions. *International Journal of Agricultural and Biological Engineering, 10*(1), 72-79. https://doi.org/10.3965/j.ijabe.20171001.2293844.

Zheng, J., Fan, J., Zhang, F., Yan, S., & Xiang, Y. (2018). Rainfall partitioning into through, stemflow, and interception loss by maize canopy on the semi-arid Loess Plateau of China. *Agricultural Water Management, 195*, 25-36.

Zhou, X.J. (2019). Application of agricultural machinery automation technology to realize the intelligent operation of agricultural machinery equipment. *Agricultural Engineering Information, 39*(36), 91-93.

Zhu, X., Yuan, S., Jiang, J., Liu, J., & Liu, X. (2015). Comparison of fluidic and impact sprinklers based on hydraulic performance. *Irrigation science, 33*, 367-374.

WPŁYW ARCHITEKTURY ŁANU KUKURYDZY NA STOPIEŃ APLIKACJI I JEDNORODNOŚĆ DYSTRYBUCJI WODY ZA POMOCĄ ZRASZACZA

Streszczenie. Celem niniejszej praca jest ocena wpływu łanu, mianowicie gęstości rośliny, odległości między rzędami oraz ocena uprawy bez łanu, na tempo aplikacji oraz współczynnik jednorodności przy różnych wysokościach ustawienia zbiornika. Doświadczenie przeprowadzono na farmie technologii rybołówstwa i akwakultury w rejonie Volta w Ghanie. Zbiorniki umieszczono odpowiednio na wysokości 0,5; 1,0; 1,5 oraz 2,0 metry a ciśnienie robocze wahało się w zakresie 150~250 kPa. Średnie tempo infiltracji pod łanem oraz bez łanu wynosiła odpowiednio 31,2 $mm \cdot h^{-1}$ oraz 37,08 $mm \cdot h^{-1}$. Uprawa kukurydzy „pod łanem" miała istotny wpływ (wartości – p 0,001) na głębokość infiltracji zanim nastąpiła ucieczka wody, przy czym wpływ uprawy „bez łanu" był bez znaczenia (p = 0,05). Średni stopień aplikacji osiągnięty pod łanem przy wysokości zbiorników 0,5; 1,0; 1,5 oraz 2 m wyniósł odpowiednio 56,6; 61,4; 68,0; and 52,0 $m \cdot h^{-1}$. Maksymalny i średni indeks jednorodności osiągnięty pod łanem wyniósł odpowiednio 79 i 64% . Średnia produkcja osadu ($g \cdot m^{-2}$) wynosiła odpowiednio 2,0; 2,53; 3,0; 3,63; 5.95 oraz 70,2 podczas zabiegów 40,1 $mm \cdot h^{-1}$ i przy czasie trwania (Dur) 80 min, 45.2 $mm \cdot h^{-1}$ i czasie trwania 60 min, podczas zabiegu 30,4 $mm \cdot h^{-1}$ i czasie trwania 110 min, 28.4 $mm \cdot h^{-1}$ oraz czasie trwania 120 min, oraz 59, 2 $mm \cdot h^{-1}$ i czasie trwania 40 min.

Słowa kluczowe: dynamiczny zraszacz strumieniowy; wysokość; stopień aplikacji wody; współczynnik jednorodności; architektura łanu kukurydzy, tempo infiltracji.