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Utilizing A Micro-Sprinkling Hose to Produce Alfalfa

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Abstract— **Micro-sprinkling irrigation hose is a new micro irrigation technology that uses grouped orifices to spray pressure water in the field. Study of hydraulic performance, as operating pressure, spray width, spray angles, and uniformity coefficient are important indices for the optimal design and management of the micro-sprinkling hose. A field study was conducted on a private farm located on the Cairo-Alexandria desert road, Giza Governorate, Egypt, to evaluate the hydraulic performance of the micro-sprinkling hose under field conditions and verify its reliability for irrigating alfalfa. The field experiment included five treatments with three replicates distributed in RCBD, including two hose spacings (4 and 5) m and two irrigation levels (100 and 80%) ETc, and was compared to the impact sprinkler system. The alfalfa was planted in April 2022 and mowed in eight cuttings until March 2023. The results indicated that, at the recommended operating pressure (100 kPa), spray angles ranged from 90° for the orifice on the hose centerline (No. 4) to 40° for the orifice nearest to the hose edge (Nos. 1 and 7). The spray width ranged from 0 for orifice 4 to ≈ 4m for orifices 1 and 7. The net precipitation rate and application efficiency for the micro-sprinkling hose and impact sprinkler were 1.6 mm h^{-1}, 85.9%, and 5.3 mm h^{-1}, 82.8% respectively. The highest uniformity coefficient was 86.9% at 125 kPa and 4m between hoses, while for the impact sprinkler it was 75%. The highest and lowest ETc was 7.9 and 2.74 mm/day, respectively. The highest dry matter yield was 7779 kg fed-1 at 100% ETc and 4m between the hoses, and the lowest was 6332 kg fed^{-1} at 80% ETc and 5m between the hoses. For the impact sprinkler, it was 5681 kg fed^{-1}, where the high percent of gravel restricted seed germination. The highest water productivity was 1.10 kg m^{-3} at 80% ETc and 4m between hoses, and the lowest was 0.95 kg m^{-3} at 100% ETc and 5m between hoses. For the impact sprinkler, it was 0.64 kg m^{-1}**

Keywords: *micro-sprinkling hose, precipitation rate, uniformity, alfalfa, water productivity*

I. INTRODUCTION

The demand for water in the agricultural sector is increasing as a result of rapid population growth rates, but water scarcity represents the main obstacle to the global expansion of irrigated agriculture. In these conditions of scarcity, rationalization of irrigation water use is crucial for sustainable agricultural development; irrigation system optimization can save irrigation water and raise irrigation efficiency (Kirnak, 2006). The use of modern irrigation systems coupled with proper irrigation scheduling has become an effective water saving strategy for dealing with water scarcity and raising agricultural production (Man et al. 2017). Micro sprinkling hose is a hopeful irrigation technique that combines the advantages of pressurized irrigation systems and addressing some of the negative aspects of drip and sprinkler irrigation systems (Zhou et al. 2003). Micro sprinkling hose irrigation (MSHI) is a common watering system in China evolved after drip and sprinkler irrigation systems; it is a micro-flow irrigation system that sprays pressurized water evenly across the field using multiple ports on fine sprinkler hoses (Dou et al. 2012). Utilization of MSHI to irrigate crops during the growing period is consider a proper solve to surface irrigation problems and is beneficial in increasing productivity and water productivity (Man et al. 2014). MSHI is an effective irrigation technique based on drip and sprinkler irrigation, it is a technique that water is delivered at low pressure to spray emitters using tapes clustered many orifices together to emit water to the soil. It is inexpensive and simple to use, and it has received a lot of attention (Zhang et al. 2016). The low pressure technique in MSHI reduces labor and saving water and electricity costs; also beneficial to the integration of water and fertilizer (Cai et al. 2017).

Water application intensity distribution (WAID), spray width (B), and uniformity coefficient (CU) are essential performance criteria for micro-sprinkling hoses; also spray angle and hose length are essential factors affecting water distribution because they affect the emission range and pressure loss in the hose (Zhang et al. 2009). Many factors can affect the performance of MSHI, involving hose materials, orifices characteristics (set, area, shape), operating pressure, wind speed, and air temperature (Dou et al. 2015, Wang et al. 2018 and Wang et al 2021). The spray width of MSHI is tightly related to the operating pressure and tape length, which basically defines the field layout spacing of the tapes. However, it is often difficult to ensure effective irrigation quality and regularity as vegetative barriers in the middle and late growth stage obstructs water movement and seriously reduces spray width and application uniformity (Bai et al. 2015, Xu et al. 2021 and Wang et al. 2022a).

Alfalfa is perennial forage known as the king of forage; the production area exceeds 32 million hectares in the world (Zhang et al. 2021). It is considered one of the most protein-containing forage crops, as protein concentrations in its leaves range from 500 to 890 g/kg. (Hojilla- Evangelista et al. 2017). Its sprouts can be utilized as a staple crop for both animals and humans because of its superior nutritional content, practically vitamins B, C, D, and E and other vital minerals (Mattioli et al. 2019). Alfalfa consumes a large amount of water compared to other crops reached to 2380 mm because of its long growing season, deep root structure and high vegetation mass (Schneekloth and Andales 2017). Many irrigation practices affect alfalfa yield and water productivity, which emphasis on irrigation system, application uniformity, amount of water applied and timing (Montazar and Sadeghi 2008, Singh et al. 2021 and Tong et al., 2022). Irrigation systems have a strong relationship with alfalfa growth and water use efficiency through the distribution of water and root in the soil. There are many problems in utilizing drip irrigation for alfalfa, such as emitter clogging, equipment damage to drip lines and insufficient water supply during the seedling stage; as a result, sprinkler irrigation systems have become a common technique of water conservation due to advantages in irrigation efficiency, irrigated area coverage, and labor expenses (Yan et al, 2018).

Deficit irrigation means the controlled application of water below the crop's full irrigation requirement over a critical period or throughout the crop's growth (Kirda, 2002). In view of the limiting water resources around the globe, deficit irrigation has the potential to be widely employed as a valuable practice for alfalfa production (Ismail and Almarshadi, 2013; Holman et al., 2016). Under deficit irrigation, subsurface drip irrigation produced more alfalfa water productivity than flood irrigation, while forage yield varied according to growth stages (Liu et al. 2021). Compared to full irrigation, deficit irrigation decreased alfalfa yield by 17.4% and raised the water productivity by 14%. In coarse-textured soils, the effect sizes on production reduction were smaller than those on water productivity improvement (Li et al. 2023).

The objectives of this study were (i) to evaluate the hydraulic characteristics of micro-sprinkling hose and the influence of the distance between the laterals hydraulic performance, and (ii) to investigate the reliability of micro-sprinkling hose for irrigating alfalfa with a deficit irrigation strategy.

II.MATERIALS AND METHODS

A. Site Description

Field experiment were carried out on a private farm located on the Cairo-Alexandria desert road, Giza Governorate, Egypt (30˚ 10′ 21″ N, 30˚ 47′ 32″ E, above sea level 75.4 m) during the years 2022 and 2023. Table 1 displays meteorological data including average monthly air temperature (T_{mini} and T_{max}), wind speed (WS), relative humidity (RH), and cumulative monthly rainfall.

Table 1. Meteorological data for the experiment site

Month	T_{max}, °C	T_{mini}, °C	Rain fall, mm	RH, %	WS, m/sec
Apr., 2022	30.5	12.5	0.0	49.2	3.1
May, 2022	32.7	15.9	0.0	44.9	3.3
June, 2022	36.8	20.3	0.0	45.6	3.4
July, 2022	37.8	20.6	2.8	47.0	3.3
Aug., 2022	37.9	22.0	1.5	49.1	3.2
Sept., 2022	36.2	20.9	1.6	51.0	3.1
Oct., 2022	30.3	17.5	3.0	58.8	2.9
Nov., 2022	25.2	13.0	1.7	60.7	2.2
Dec., 2022	22.8	11.2	23.4	65.4	2.2
Jan., 2023	20.3	8.2	43.4	67.9	2.2
Feb., 2023	18.8	6.5	14.9	68.5	2.4
Mar., 2023	25.3	10.5	7.9	55.0	2.7

The physical and chemical properties of the soil and chemical analysis of the ground water for the experimental site prior to starting the experiment are described in Tables 2 and 3. The soil texture was classified sandy soil. The gravel content was more than 50% in the soil layers 0–60 cm, this percentage restricted seed germination especially under sprinkler irrigation system.

Table 2. Some physical properties of the experimental site

Soil depth, cm	Particle size distribution			FC, %	PWP, %	AW, %	Gravel, %
	Sand, %	Silt, %	Clay, %				
0-20	92.0	3.7	4.3	14.0	5.8	8.2	53.1
20-40	92.8	3.2	4.0	13.5	5.0	8.0	54.0
40-60	94.4	2.7	2.9	12.2	4.7	7.5	59.9

Table 3. Chemical properties of experimental soil and irrigation water

Parameter		Soil	Ground water
PH		7.49	6.7
EC, ds/m		5.8	4.5
Cations, meq / L	Mg^{+2}	5.9	1.6
	Ca^{+2}	14	12.9
	K^{+}	1.6	5.4
	Na^{+}	57.2	36.2
Anions, meq / L	So_4^{-2}	29.2	32.9
	Cl^{-}	44.8	21.7
	Hco_3^{-}	3.7	1.5
	Co_3^{-2}	---	---
SAR		18.1	13.4

B. Micro-Sprinkling hose

A micro-sprinkling hose (Driptech, India) made of low density Poly Ethylene was used in this study Fig. 1. The folded diameter (D) was 50 mm. Laser drilling was used to create the orifices in groups on one face of the hose, with seven orifices in each group. The distance between each orifice within the group (L_2) was 45 mm. The distance between each group of orifices (L_1) varied from 40 to 50 mm. The axial length of an orifice group (L_3) was 270 mm. Water is sprayed from each orifice at a certain angle with the hose axis. When the micro sprinkler hose was filled with water, the cross-sectional shape was almost circular. An angle was formed between the orifice center and the ground plane was defined as the orifice angle α_n, which was calculated based on the distance from the center of the orifice to the hose edge l_n using the arc length formula.

$$\alpha_n = \frac{180\, l_n}{\pi\, r} \quad \text{--------------------} \ (1)$$

In which: r is the radius of the circular cross-section of a micro-sprinkling hose filled with water (16 mm), and *n* is the orifice number in orifices group.

The angle formed by the water paths sprayed from one orifice to the ground plane was defined as the spray angle $\bar{\alpha}_n$. This angle directly impacts the spray width and minimum distance between the spray hose and the next plant row, ensuring unobstructed water flow.

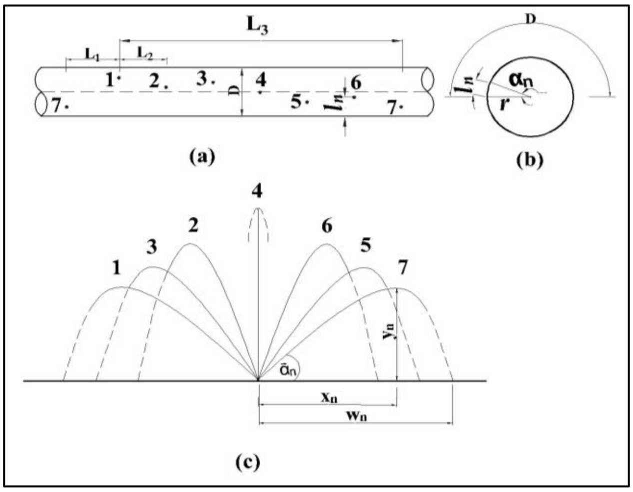

Fig. 1. Micro-Sprinkling hose structure (a) orifices distribution, (b) orifice angle α_n and (c) spraying angle ($\bar{\alpha}_n$) and water path dimensions.

Indoor experiment was set up to measure spraying angle ($\bar{\alpha}_n$) and path dimensions for orifices group (maximum path height y_n, the horizontal distance from the orifice to maximum height x_n , and spray width w_n); the unmeasured orifices group covered with PE pipe cut in half lengthwise.

C. Experimental layout

The soil was prepared using a moldboard plow, followed by the disc, and leveled. Alfalfa (Giza 1) was sown on April 5, 2022, at a rate of 25 kg fed^{-1}. The fertilization dose was 200 kg/fed P_2O_5 divided into two equal doses at sowing and after cutting 1, and 300 kg/fed $(NH_4)_2SO_4$ divided into three equal doses at sowing, after cutting 1, and after cutting 4. Pests and weeds were controlled following recommended practices. The irrigation was scheduled three times in the summer and twice in the winter, according to farm management practices.

D. Irrigation water requirements

Crop evapotranspiration (ETc) was computed by the CROPWAT 8.0 software program based on the FAO Penman-Monteith method (Allen et al. 1998):

$$\boldsymbol{ETc = ETo * K_c} \text{ ------------- } (2)$$

In which: ETo is reference crop evapotranspiration (mm/day), and Kc is crop coefficient values for alfalfa.

General lengths and crop coefficient (K_c) for the four different growth stages (initial, develop, mid and late) was provided using FAO Irrigation and Drainage Paper 24 (Doorenbos and Pruitt, 1977).

An irrigation water requirement (IWR) was computed by (Vermeirer and Topling 1984):

$$\boldsymbol{IWR = \frac{ETc}{E_a\,(1-LR)}} \text{ ------------ } (3)$$

In which: E_a is irrigation system efficiency (assumed 80 % for micro-sprinkler hose and 70 % for sprinkler irrigation system), LR is leaching requirement (%) was calculated according to (Corwin et al. 2007) “35% of the determined applicable irrigation water was applied per irrigation for leaching”.

E. Irrigation treatments

The experimental field was divided into five irrigation treatments, which were irrigated separately. The experiment procedures were carried out in the area between specific micro-Sprinkling hoses, while the outer area was considered a buffer zone. The classification of different treatments is explained in Table 4.

Table 4. Classification of different treatments

Treatment	Classification*
T1	Micro-Sprinkling hose irrigation with 4 m between hoses + 100 % ETc
T2	Micro-Sprinkling hose irrigation with 4 m between hoses + 80 % ETc
T3	Micro-Sprinkling hose irrigation with 5 m between hoses + 100 % ETc
T4	Micro-Sprinkling hose irrigation with 5 m between hoses + 80 % ETc
T5 (Control)	Impact sprinkler irrigation (IS) with square layout and 100 % overlapping + 100 % ETc

* 4 m between hoses = 100 % overlapping, 5 m between hoses = 80 % overlapping

F. Irrigation network components

Irrigation network consisted of submersible pump with 35 m^3/h discharge driven by electrical engine 30 hp; back flow prevention valve, pressure gauges, control valves and infiltration unit (sand media and screen). Main line (Φ110 PVC pipe), sub-main line (Φ90 HDPE pipe), and lateral line (Φ63 HDPE pipe); micro-sprinkling hose with 25 m length joined by the lateral line with 63 mm valve. A plastic impact sprinkler was a 1.0 inch diameter, 2.0 m^3/h discharge and 10 m throw radius at 125 kPa working pressure; the sprinklers layout was square with 100 % overlapping. The experiment layout and treatment distribution are shown in Fig. 2.

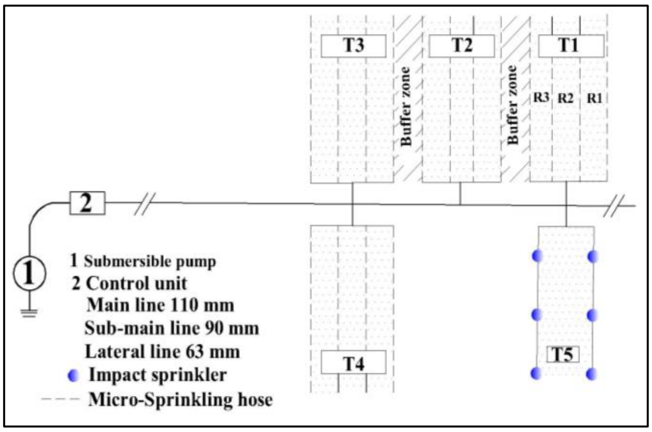

Fig. 2. Experiment layout and treatments distribution

G. Measurements

1. The irrigation performance parameters

The relationship between operating pressure and both the discharge rate and the manufacturer’s coefficient of variation

The discharge rate per meter length (q, l/min.m) was measured at different operating pressures ranging from 50 to 175 kPa with an increment of 25 kPa by gradually increasing the pressure; the burst pressure of the tested micro-sprinkling hose was 200 kPa. The relationship between the discharge rate and the operating pressure was defined as a power function according to equation 4 as follows:

$$q = kP^{x} ------(4)$$

In which: q is the discharge rate per meter, l/h.m; P is operation pressure, kPa; k is the discharge coefficient; and x is the discharge exponent.

The emitter manufacturer's coefficient of variation (C_{v}, %) is defined as the ratio of the standard deviation of the emitter's discharge rate to the average discharge rate of the same emitters (ASAE, 2003).

Precipitation rate, water application patterns and application efficiency of individual hose

The precipitation rate is the speed at which the hose applies the water to the soil surface. Gross and net precipitation rate (GPR and NPR) and application patterns for individual hose were calculated according to (SWAT 2012).

Water application efficiency (Ea, %) is expressed as the ratio of the average depth of water collected to the average depth of water discharged.

Precipitation uniformity

The Christiansen uniformity coefficient (CU) was utilized to estimate the hose precipitation uniformity at an operating pressure of 50 to 175 kPa at the beginning of the experiment, according to (Christiansen 1942) as follows:

$$CU = 100\left(1.0 - \frac{\sum_{i=1}^{n}|X_i - X^{-}|}{n\,X^{-}}\right) --- (6)$$

In which: X_i is the water depth collected by a catch can number *i* (mm), X^{-} is the average of all the water depth in catch cans (mm), and *n* is the total number of catch cans.

2. Alfalfa yield and water productivity

The alfalfa was mowed eight harvests over the year, on June 1, July 10, August 15, September 20, November 1, December 12, January 27, and March 15. Each cut was mowed whereas 20-30% of the alfalfa plants were in the flowering stage (Cacan et al. 2016). The replicated treatment plots were divided into small sample plots of 1.0 m^2 and the forage green yield was estimated. The dry matter yield (kg/fed) of collected green fodder was calculated by drying it at 60ºC for 48 hours or reaching a consistent weight.

Water productivity (WP), which is the ratio of forage green yield to the seasonal irrigation water requirement, was calculated for different treatments.

3. Statistical analysis

Five treatments with three replicates were arranged in a randomized complete block design (RCBD). Co-Stat software program was employed for analysis of variance (ANOVA). The mean results for different treatments were compared at a 5% significance level.

III.RESULTS AND DISCUSSION

1. The irrigation performance parameters

A. The relationship between operating pressure and both the discharge rate and the manufacturer's coefficient of variation

The emitter discharge rate and the manufacturer's coefficient of variation are important factors in evaluating the performance of micro-sprinkling hose. The average discharge rate and the manufacturer's coefficient of variation for the tested micro-sprinkling hose at different operating pressures from 50 to 175 kPa with a burst pressure of 200 kPa are presented in Table 5. The discharge started at 96 l/h.m at 50 kPa operating pressure until it reached the highest value of 270 l/h.m at 250 kPa, and the k and x values in equation 4 were 1.48 and 0.59. The orifices discharge is related to the hydraulic pressure, with a correlation value of 0.948. Increasing operating pressure from 50 kPa to 100 kPa tended to decrease C_v from 12.0 to 5.5%, then increased at 125 and 150 kPa to 7.2 and 9.9%, respectively, and decreased to the lowest value of 5.3% at 1.75 kPa. The C_v values were classified as good according to (ASAE, 2003) except for 50 kPa, which was classified as average. A working pressure of 100 kPa is recommended based on the C_v data, although the lowest C_v value was obtained at an operating pressure of 175 kPa, which is much closer to the explosion pressure. The recommended operating pressure (100 kPa) corresponds to that recommended by the manufacturer.

Table 5. Discharge rate and manufacturing coefficient of variation at different operating pressures

Parameter	Operating pressure, kPa					
	50	75	100	125	150	175
q, l/h.m	96	126	144	210	231	270
	$q = 1.48\ x^{0.59}$			$R^2 = 0.948$		
* C_v, %	12.0	9.4	5.5	7.2	9.9	5.3

* Values less than 10% are classified as "good," and values between 10% and 20% are classified as "average."

B. Orifice and spray angles and water path dimensions.

Orifice and spray angles and water path dimensions at recommended operating pressure (100 kPa) are listed in Table 6. Each orifice group consists of 7 orifices distributed on one side of the hose as follows: The fourth orifice is on the centerline, and the others are spaced symmetrically on both sides at an equal distance of 5 mm in the direction of the edge, the first and last orifices (1 and 7) located 10 mm from the hose edge. As a result, the values of the angles (orifice and spray) on both sides of the central line match. The results showed that the spray angle was higher than the orifice angle, but the difference was small. The same result obtained by (Wang et al 2022b). The angle of the orifices and water path dimensions vary depending on the position of the orifice; in other words, the distance of the orifice from the center line defines the angle values. Orifice No. 4 had the highest angle values of 90°, where the spray path moves vertically, producing the highest y_n value and no x_n or w_n. The lowest angles associated with the lowest y_n and highest x_n and w_n were obtained by orifices 1 and 7. The most important parameters are $\bar{\alpha}$ and w_n; as $\bar{\alpha}$ identifies the nature of the plant suitable for the MSHI in terms of plant height and the shortest distance between the hose and the next plant row, and w_n identifies the optimal distance between the spray hoses.

C. Precipitation rate, water application patterns and application efficiency of individual hose

Table 7 shows the precipitation rate (gross and net) and application efficiency values for individual hose at different operating pressures and compares them to the impact sprinkler. Increasing the operating pressure increased the GPR and NPR values. The micro-sprinkling hose raised GPR and NPR compared to the impact sprinkler. The highest application efficiency was 85.9%, obtained at 100 kPa, while the lowest was 81.2% at 175 kPa. At the recommended operating pressure, MSH enhanced Ea compared to the impact sprinkler.

Table 6. Orifice and spray angles and water path dimensions at 100 kPa

Parameter	Number of the individual orifice						
	1	2	3	4*	5	6	7
l_n, mm	10	20	15	25	15	20	10
α, °	35.8	71.7	53.7	89.6	53.7	71.7	35.8
$\bar{\alpha}$, °	40.0	74.0	57.0	90.0	57.0	74.0	40.0
x_n, m	2.4	1.3	2.3	0.0	2.3	1.3	2.4
y_n, m	2.0	4.4	3.5	4.7	3.5	4.4	2.0
w_n, m	4.1	1.8	3.6	0.0	3.6	1.8	4.1

* ($\bar{\alpha}$ = 90°) depends on controlling the hose's horizontality on the soil surface without twisting.

Table 7. Precipitation rate (gross and net) and water application efficiency of individual hose and impact sprinkler

	Operating pressure, kPa						
MSHI		50	75	100	125	150	175
	GPR, mm/h	16.0	19.4	19.2	24.7	27.2	30.0
	NPR, mm/h	13.2	16.2	16.5	20.1	23.3	24.3
	Ea, %	82.7	83.7	85.9	81.5	85.7	81.2
Impact sprinkler	Recommended operating pressure 125 kPa						
	GPR, mm/h	6.4					
	NPR, mm/h	5.3					
	Ea, %	82.8					

Water application patterns for MSH at different operating pressures are shown in Fig. 3. Within the spraying area, the precipitation rate fluctuates between increases and decreases. The instantaneous water precipitation rate began with a high near the MSH and tends to decrease rapidly until it approaches low values at a distance of 1.0 to 1.75 m from the MSH. Then it tended to rise again at a distance of 1.75 to 2.5 m from the MSH and then decline again, reaching zero. At the recommended pressure (100 kPa), the NPR began at 35.5 mm h^{-1} and quickly decreased to 10.6 mm h^{-1} at 1.0 m from the hose. After that, the NPR increased reaching 23.2 mmh^{-1} at a distance of 2.25 m from the hose. The NPR decreased again, reaching zero at 4.0 m from the hose.

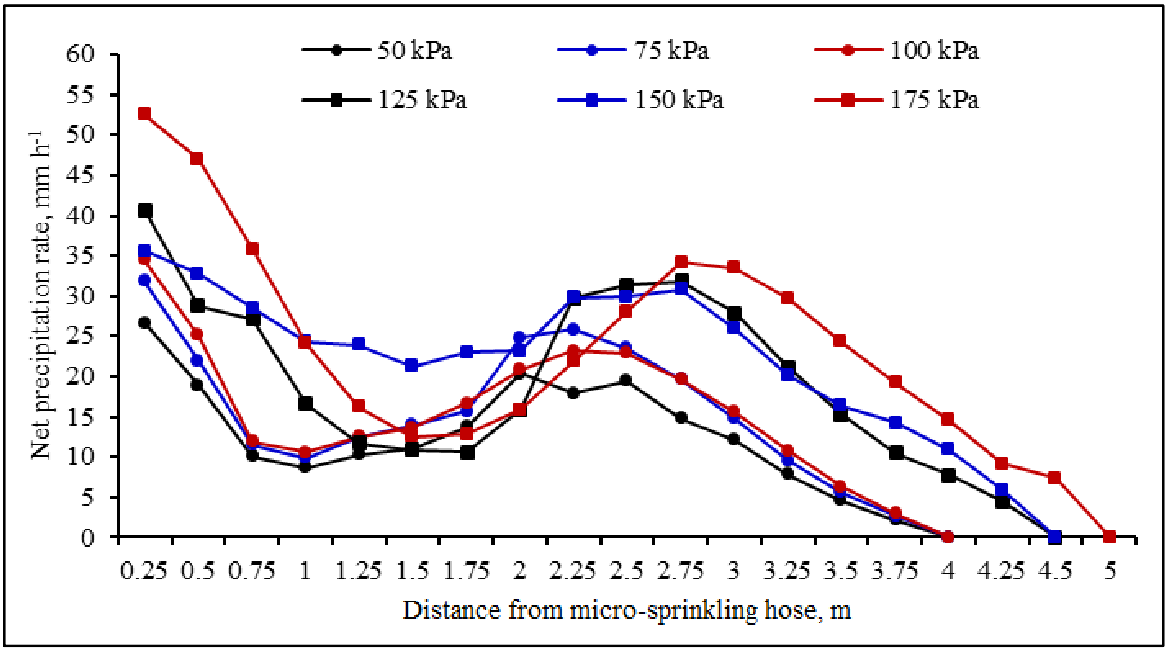

Fig. 3. Water application patterns for MSH at different operating pressure

D. Precipitation uniformity

The Christiansen uniformity coefficient (CU) for MSH at two distances between hoses (D4 = 4 m and D5 = 5 m) and different operating pressures from 50 to 175 kPa and for

IS at the recommended pressure is shown in Fig. 4. The results showed that the CU increased with increasing operating pressure from 50 to 125 kPa, reaching the highest value, and then decreased after that. The D4 performed uniformly higher than the D5 under different operating pressures. The highest CU value was 86.9% obtained at 125 kPa and D4 treatment, while the lowest value was 67.7% produced at 50 kPa and D5. The CU value for the impact sprinkler was 75%, which is 9.6% less than the CU value for MSHI under recommended pressure. If a distance of 5 m between hoses is applied, an operating pressure of 125 kPa is recommended. The statistical analysis indicated a high significant difference between different treatments.

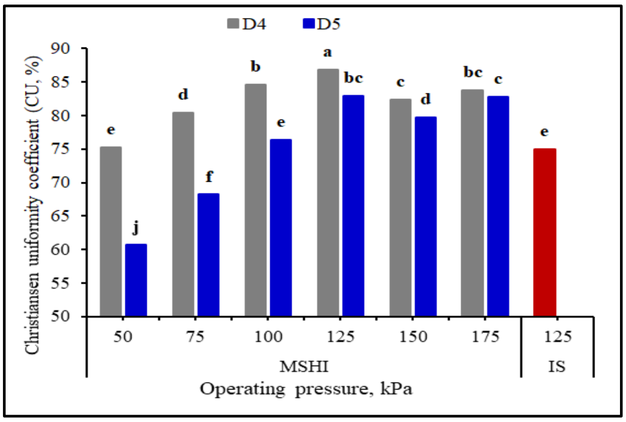

Fig. 4. Christiansen uniformity coefficient (CU, %) for MSHI and IS

2. Irrigation water requirement

Alfalfa is harvested many times during the growing season, which is known as "cutting cycles”. The growing period in every cutting was divided into four stages (initial, development, mid-season, and late season), and each stage had a different Kc value. Growth stages and the Kc curve were defined based on FAO Irrigation and Drainage Paper No. 24. Growth stages for the first cutting were 10/20/20/5 days, and for subsequent cutting, they were 5/20/10/10. The Kc curve for individual cutting periods starts at 0.4, increases linearly to a maximum of 1.2 in mid-season, and decreases linearly to 1.15 in late season. The crop evapotranspiration for alfalfa under experimental conditions during the growing season at field efficiency 70% is shown in Fig. 5. ETc increased rapidly with time after the first irrigation in the cutting cycle, reaching maximum values before the following cutting. The first cutting had the highest ETc, reaching 7.9 mm/day before cutting, and then ETc decreased gradually with the following cuttings, reaching the minimum ETc in the sixth cutting, which was 2.74 mm/day before cutting. Starting with the seventh cutting, the ETc began to increase again. The general behavior of crop evapotranspiration is closely related to the metrological conditions of the region and the plant growth rate. The total consumption water under MSHI and IS were 1216 and 1389 mm respectively.

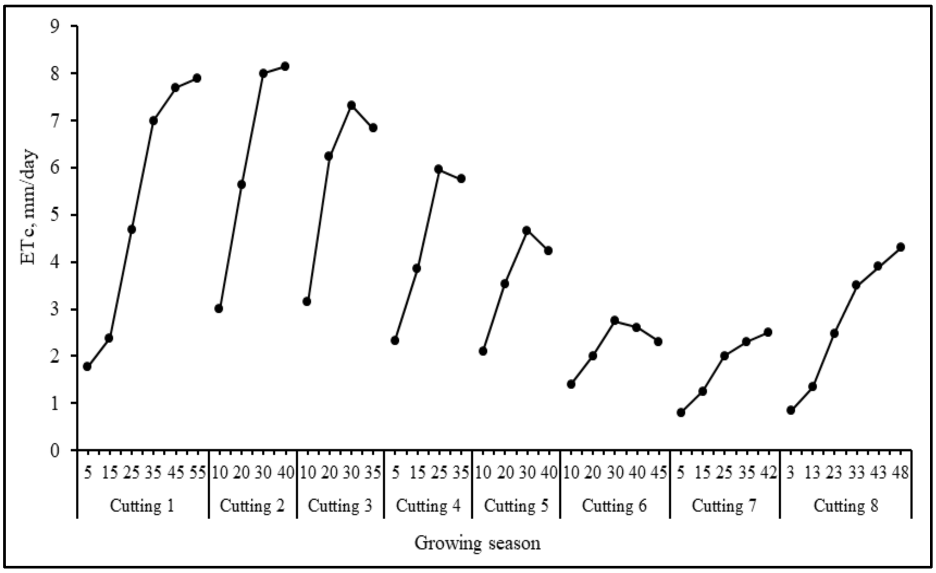

Fig. 5. Crop evapotranspiration (ETc, mm/day) for alfalfa under experiment conditions

Taking into account pre-planting irrigation (180 m^3 fed^{-1}), effective rainfall (0.75 rainfalls), leaching requirement (0.35), and irrigation system efficiency, the irrigation water requirement (IWR, m^3 fed^{-1}) for different treatments was as shown in Table 8. The IWR were 7664, 6157, and 8945 m^3 fed^{-1} for 100%ETc, 80% ETc, and IS treatments respectively.

Table 8. Irrigation water requirements for different treatments

Cutting	T1	T2	T3	T4	T5
1st	1910	1563	1910	1563	2157
2nd	1408	1126	1408	1126	1610
3rd	1136	910	1136	910	1300
4th	950	760	950	760	1086
5th	780	624	780	624	897
6th	520	408	520	408	600
7th	340	270	340	270	410
8th	620	496	620	496	885
Total, (m^3 fed^{-1})*	7664	6157	7664	6157	8945

*Feddan (fed.) = 4200 m^2

3. Dry matter yield and water productivity

Dry matter yield (DMY, kg fed^{-1})

Alfalfa dry matter yield for different treatments for eight cuttings is shown in Fig. 6, and total dry matter yield is listed in Table 9. The results referred to specific variation in DMY between cuttings. The DMY for the first cut was lower than that of subsequent cuts, which increased to the maximum value in the third cut. The DMY declined beginning with the fourth cut and reached its lowest value in the eighth cut. The statistical analysis showed a significant difference between the treatments in DMY at level 0.01. The highest effect was obtained with the T1 treatment with a total DMY of 7779 kg fed^{-1}, while the lowest effect was obtained with the T5 treatment with a total DMY of 5681 kg fed^{-1}. Decreasing the yield with IS system (T5) may be due to that, the large droplet size of the impact sprinkler washed the soil cover above the alfalfa seeds, and as a result of the high percent of gravel in the soil, the soil temperature rose quickly, which negatively affecting the germination rate. The effect of high gravel percent in the soil on crop yield was discussed by (Beck-Broichsitter et al. 2023). The ability of MSHI to enhance the uptake and utilization of water and nitrogen was pointed out by (Zhang et al. 2016). Increasing the distance between the hoses had a negative effect on DMY, as increasing the distance from 4 to 5 m led to a decrease the DMY of 6.6 and 16.4% at 100 and 80% ETc respectively. The same effect of sprinklers overlapping on peanut yield was obtained by (Amer et al. 2010), where the highest peanuts yield was obtained with 100% overlapping between sprinklers. Limited irrigation also had a negative impact on DMY, as reducing the irrigation level from 100 to 80% ETc resulted in a decrease in DMY of 12.6 and 12.8% at 4 and 5 m between hoses. Many researchers have reported a reduction in alfalfa yields under limited irrigation technology (Hanson et al. 2007; Lamm et al. 2012).

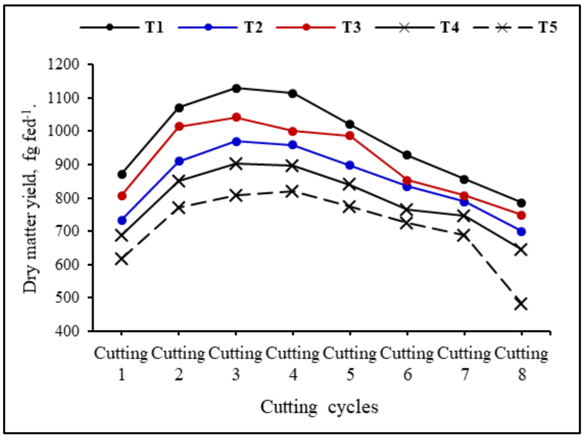

Fig. 6. Alfalfa dry matter yield for eight cuttings under various treatments

Table 9. Total dry matter yield for different treatments

Cutting	T1	T2	T3	T4	T5
DMY	7779 a	6797 c	7263 b	6332 d	5681 e

Water productivity (WP, kg m^{-3})

The averages of water productivity for eight cuttings are shown in Fig. 7, and seasonal water productivity is listed in Table 10. The results referred to specific variation in WP between cuttings. The lowest WP was at the first cutting, where there was the highest water consumption and low DMY. Then it gradually increased with the growing season, reaching the highest value at the seventh cutting, where there was the lowest water consumption. Then it began to increase again with the eighth crop. The statistical analysis showed a significant difference between the treatments in seasonal WP at level 0.01. The highest effect was obtained with the T2 treatment with a seasonal WP of 1.10 kg m^{-3}, while the lowest effect was obtained with the T5 treatment with a seasonal WP of 0.64 kg m^{-3}. The limited irrigation increased seasonal WP with 7.8 and 8.4% at 4 and 5 m between hoses, where the seasonal applied water decreased. Increasing the distance between hoses from 4 to 5 m decreased seasonal WP with 6.9 and 6.4% at 100 and 80% ETc. The reduction in seasonal WP at IS treatment was expected due to a rise in irrigation water consumption, which was accompanied by a noticeable reduction in alfalfa DMY. Effect of limited irrigation on water productivity studied by (Lamm and AbouKheira 2011) who reported that, Water productivity was higher in the limited irrigated treatments (70% ETc) than in the fully irrigated treatments.

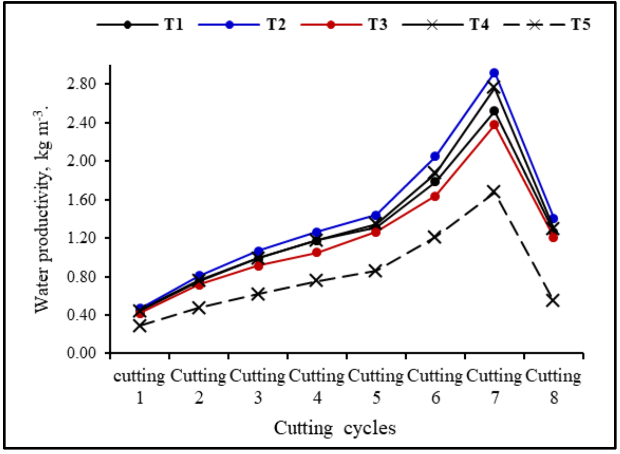

Fig. 7. Water productivity for eight cuttings under various treatments

Table 10. Seasonal water productivity for different treatments

Cutting	T1	T2	T3	T4	T5
WP	1.02 ab	1.10 a	0.95 b	1.03 ab	0.64 c

IV. CONCLUSIONS

This study was carried out to identify the hydraulic characteristics of the micro-sprinkling hose as a new irrigation system for optimal design and management and to investigate its suitability for alfalfa cultivation. Evaluation the spray angles at recommended operating pressure is an important factor to determine spray width, and consequently the optimal hose distances. Also $\bar{\alpha}$ identifies the nature of the plant suitable for the MSHI in terms of plant height and the shortest distance between the hose and the next plant row. The optimum distance between hoses is that not excess than the spray width. The MSHI enhanced alfalfa dry matter yield and water productivity comparing to sprinkler irrigation system. The highest yield obtained at full irrigation and 4m (distance equal spray width) between hoses. The limited irrigation produced water productivity more than full irrigation.

Recommendations

1. A micro-sprinkling hose is recommended in soil with high gravel content, as the sprinkler system exposes and damages the seeds due to the heat of the gravel.

2. Several experiments on irrigating various crops with a micro-sprinkling hose, particularly crops with high vegetation cover, are required to assess its suitability.

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