Evaluation of the hydraulic performance of pressure-compensating emitters

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Abstract: Evaluating the effect of pressure on the water distribution uniformity in drip irrigation system is important in irrigation water management and could serve as the basis for optimizing water use efficiency and improving crop productivity. This study was to evaluate pressure compensating (PC) drip emitters to determine optimum operating conditions that achieve high water distribution uniformity, Average emitter discharge (Qvar), the coefficient of variation (CV), the coefficient of uniformity (CU) and emission uniformity (EU) were evaluated under different levels of operating pressure. A 15 and 30 m length PE pipe with selected randomized emitter points on each lateral were considered for four different operating pressure OP (50, 100, 150 and 200 kPa). PC drip emitters used in this study had a design or manufacturing discharge rate of 4 L h^{-1}. Coefficient of uniformity (CU) values for 50 kPa the OP value is under 90% and classified as good based on criteria for assessing drip irrigation system. Emission uniformity (EU) values decreased as OP was reduced. Flow variations are essentially kept minimum as the OP is increased. As a result, the 200 kPa OP is recommended over the other OP considering the lateral length in the study. The results led to the following conclusions: Discharges were increased by increasing operating pressure for both lateral lengths; The highest water distribution uniformity was achieved at an operating pressure of 200 kPa for both lateral lengths; The values of water distribution uniformity for lateral length 30 m are higher than the values of lateral length 15 m at the same conditions of operating pressures.

Key words: emitters, hydraulic performance, pressure compensating, distribution uniformity.

Citation: Karim, A. M., M. A. Hassan, M. K. Afify, and A. M. Zedan. 2026. Evaluation of the hydraulic performance of pressure-compensating emitters. Agricultural Engineering International: CIGR Journal, 28(2): 60-67.

1 Introduction

Drip irrigation is one of the micro irrigation systems which have many advantages. Water and energy savings are the most important advantage, as water and energy consumption is lower than that of other irrigation systems. Capital cost and maintenance requirements are low. Micro irrigation achieves higher irrigation efficiency and higher yields than other irrigation systems.

Hydraulic performance evaluation which is used to determine and verify the characteristics of the bubbler systems can be determined on the basis of parameters, such as coefficient of manufacturing variation (CV), coefficient of uniformity (CU), emitter discharge coefficient (k) and emitter discharge exponent (x) parameters. The key to efficient irrigation is coefficient of uniformity. Irrigation system performance can be expressed in terms of the determined CV and CU. The more uniformly water is applied, the more efficient the irrigation can potentially be.

Irrigation technology has evolved in tandem with

Received date: 2025-06-17 **Accepted date:** 2026-03-20

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advances in water technology, water transport, and agricultural systems. The efficient and sustainable use of water for agriculture has become a global issue, and it contributes to the advancement of agricultural production processes (Jusoh et al., 2020; Shabbir et al., 2020). Over-irrigation wastes water and energy, and can result in nutrient leakage from the root zone, surface soil erosion, and a decrease in soil air content. Drip irrigation has rapidly grown around the world as a result of water shortage and scarcity worries, and is projected as a revolutionary irrigation technology for keeping the soil root zone wet (Soomro et al., 2013; Tayel et al., 2019). Compared to other irrigation methods, the drip irrigation method provides high uniformity, typically using about 30% to 50% less water, as it provides only the amount of water needed by plants. When correctly designed, implemented, and managed, it is an effective kind of irrigation that may have water application and crop water consumption efficiency as high as 90%-95%, as the system design necessitates meticulous engineering. Irrigation schedule may be carefully regulated to match crop demands, promising better yield and quality. The crop root structure and soil characteristics influence the choice of emitter spacing and tape depth (Shock, 2013). The water is made to flow under the effect of gravity, and the water pressure in the system is proportional to the ground level. A pressurized pipeline with an inline or online emitter is used in a lateral drip irrigation system. These pipes are often composed of polyvinyl chloride (PVC) or polyethylene (PE), materials which do not degrade rapidly when exposed to direct sunlight. As water flows through the laterals, pressure head loss occurs, resulting in a pressure differential between the head and tail ends. This water goes along a predetermined path inside the emitter, and some head is lost in the process. There are also some local losses produced by the emitter barbs protruding into the flow. Pressure compensating (PC) emitter characteristics under low pressure are significant for the design of gravity-fed drip irrigation systems (Asenso et al., 2014). Al-Mastawi et al. (2024) and Alobaidy and Hassan (2024) showed a significant effect for the type of irrigation system and soil tillage system on soil water content. The soil moisture content starts to increase gradually in all tillage methods until the end of the growing season and reaches to 20.14% in 20 cm depth after the final irrigation stages of the growing, soil water content depends on the type of plowing methods which reflects the way manipulation of the soil layers and as a result facilitate water irrigation to penetrate soil layers, some treatment recorded (21.04%) and other recorded (19.13%). The predicting models show significant differences with acceptable accuracy in predicting soil humidity in the growing season.

Emitters are defined hydraulically by their necessary operating pressure heads and nominal flow, and information on the flow of emitters and their flow regime is critical for the design and maintenance of a drip irrigation system. According to basic hydraulic principles, drip emitter discharge is an exponential function of emitter head. The actual head at the emitters will vary throughout the system due to friction and slight losses along the pipeline as water is carried from the source to the emitters. Water distribution uniformity is a significant aspect in assessing the efficiency of drip irrigation system design. The efficiency of the drip irrigation system is determined by the uniformity of water distribution, which may be evaluated by monitoring the flow rate in each emitter. Drip irrigation system performance is also affected by emission uniformity (EU) throughout the system, which assesses the consistency of emissions emitted by all emitters. The coefficient of variation (CV) and the coefficient of uniformity (CU) are two more metrics that are also taken into account (Sharu and Ab Razak, 2020).

Ayars et al. (2023) and Liu et al. (2019) mentioned that the manufacturer's coefficient of variation for five models tested ranged from 8% to 21%, which is relatively high for micro irrigation emitters. ASAE Standards (2001) recommends values less than 11% and suggests that values greater than 15 % are unacceptable.

Habib and Awady (1992) stated that the discharge uniformity from drip irrigation system is controlled by varying the tube diameter and/or length and/or using valve for each drip along lateral line.

An ideal irrigation system should minimize the losses and apply the water uniformly (Haman et al., 2003). To design an efficient drip system, it is necessary to determine the optimum operating conditions that achieve high CU and EU excellent distribution efficiency, therefore the purpose of this study was to assess the effect of operating pressure (OP) (50, 100, 150 and 200 kPa) and lateral length (15 and 30 m) on the water distribution uniformity of pressure compensating (PC) drip emitters.

2 Materials and methods

2.1 Description of the experimental site

The experimental work was carried out at a private farm located in Zifta City, Gharbia Governorate, with coordinates of 30° 40′ 33″ E longitude and 31° 13′ 53″ N latitude during the season 2024. The experimental unit consists of a water source, pump, control valve, pressure gauge, flow meter, and pressure regulator. Pressure compensating (PC) drip emitters were installed as a permanent system and tested at different operating pressures OP (50, 100, 150, and 200 kPa) and lateral lengths (15 and 30 m). Emitters with a flow rate of 4 liters/hour were used for drip irrigation system. These emitters were 50 cm emitter distance and 50 cm between laterals. Drip line saddles were used to connect the lateral lines to the drip hoses. The Emitters lateral lines were evaluated at different levels of operating pressure. Figure 1 shows a schematic layout of the experimental field, including two similar subunits for each one of treatments lateral length (15 and 30 m). Each subunit consists of three laterals with 15 and 30 m length at distance of 50 cm and each lateral has composed of 30 and 60 emitters, 50 cm apart respectively. Each subunit was equipped with a water meter, valve and pressure gauge. All subunits were connected to a control station equipped with a pump, and pressure gauges.

Plastic catch cans 20 cm in diameter; 20 cm in height were located under emitters to collect the water. The catch cans were distributed according to (ASAE Standard, 2001). The emitters were evaluated at different levels of operating pressure (50, 100, 150 and 200 kPa) and lateral length (15 and 30 m) under Egyptian conditions.

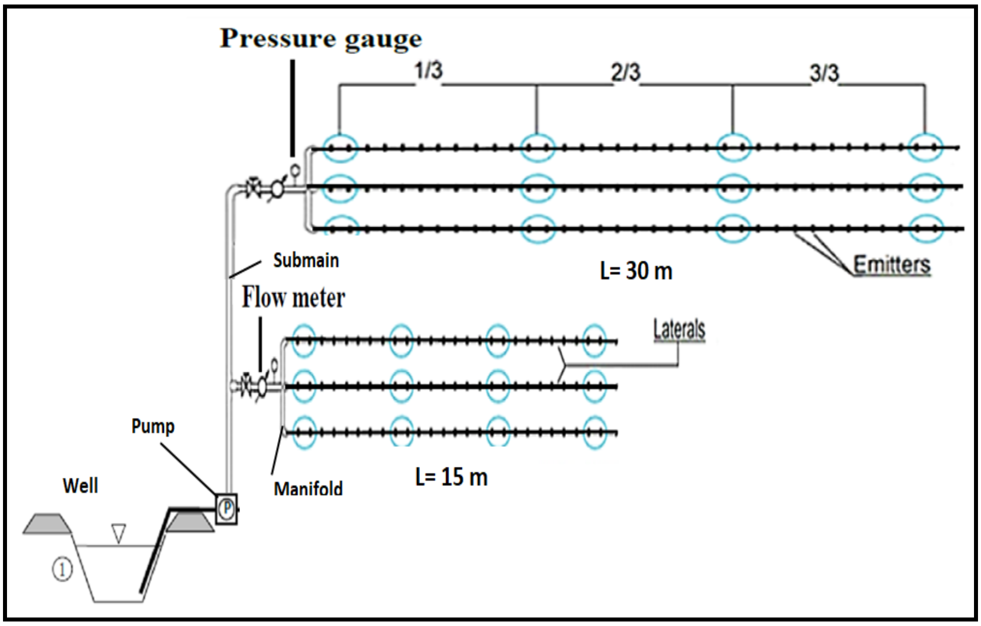

Figure 1 Schematic layout of the experimental field

2.2 Parameters used to evaluate drip emitters

The following criteria were used to compare different drip irrigation products that operated at high and low OP based on the obtained data in the studied area:

Flow rate of the emitter was measured by collecting known volume of water in a container over a specified period (15 min). The flow rate was calculated using Formula (1) (Melvyn, 1983):

$$Q = \frac{V}{t} \quad (1)$$

Where,

Q is the flow rate of emitter in l h^{-1};

V is the collecting water volume in m^3;

t is time of collecting water in h.

Average emitter discharge rate (Qvar): The Average emitter discharge rate (Qvar) is the average quantity of water emitted by each emitter per unit time, which is calculated according to Formula (2) (as classified in Table 1):

$$Q\,\text{var} = \frac{q\max - q\min}{q\max} x100 \quad (2)$$

Where: qmax = Maximum emitter flow rate (l h^{-1}), qmin = Minimum emitter flow rate (l h^{-1}).

Table 1 Criteria for the evaluation of drip emitters based on the average emitter discharge rate

Q_{var} Range	Classification
10% or less	Desirable
10% - 20%	Acceptable
Greater than 25%	Not Acceptable

2.2.1 Standard deviation of emitter flow rate (Sq)

$$Sq = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(qi - q\,\text{var})^2}$$

Where: n = total number of emitters, qi = flow rate of the emitter (4 l h^{-1}).

2.2.2 The coefficient of variation of emitter flow (CV)

Coefficient of variation measures flow variability and is calculated by dividing the standard deviation by the mean. The coefficient of variation for each of a manufacturer's products is generally published (as classified in Table 2).

CV can be written as:

$$CV = \frac{Sq}{q\,\text{var}}$$

Table 2 Classification of coefficient of variation

Coefficient of Variation, CV	Classification
>0.4	Unacceptable
0.4 – 0.3	Acceptable
0.3 – 0.2	Very good
<0.1	Excellent

2.2.3 Coefficient of Uniformity (CU)

Uniformity tests were conducted by placing several identical collectors in an equally spaced grid in the field around emitters. The amount of water caught in each can was measured and recorded and the coefficient of uniformity was calculated by the following equation, Christiansen (1942) (as classified in Table 3).

$$CU = 100\left(1 - \frac{\Sigma\left|X_i - \overline{X}\right|}{n\,\overline{X}}\right)$$

Where, CU is the Christiansen's coefficient of uniformity in %, Xi is the individual collector amount in mm, $\overline{X}$: mean of collectors amount in mm, Σ is the summation of n values, | | is the absolute value and n is the number of measuring collectors.

Table 3 Classification of uniformity coefficient

Coefficient of Uniformity, CU (%)	Classification
Above 90%	Excellent
90% – 80%	Good
80% – 70%	Fair
70% – 60%	Poor
Below 60%	Unacceptable

2.2.4 Emission uniformity (EU): Emission uniformity is calculated as the ratio of the average flow produced by 25% of the emitters with the lowest flow to the mean flow generated by all emitters (Classified in Table 4).

$$EU = \left[1.0 - \frac{1.27CV}{\sqrt{n}}\right]x\left(\frac{q\min}{qavg}\right)x100$$

Where: qmax – maximum emitter flow rate (l h^{-1}), qavg – average flow rate through emitter, l/h (l h^{-1}), n –

number of emitters.

Table 4 Classification of emission uniformity

Emission uniformity, (EU) Ranges	Classification
>90%	Excellent
80% – 90%	Good
70% – 80%	Fair
<70%	Poor

Table 5 Performance criteria for the 50 kPa operating pressure

lateral length (m)	Qvar (%)	Classification	CV	Classification	EU (%)	Classification	CU (%)	Classification
15	29.88%	Not Acceptable	0.16	Marginal	85.03%	Good	87.97%	Good
30	26.42%	Not Acceptable	0.17	Marginal	88.68%	Good	89.84%	Good

Table 6 Performance criteria for the 100 kPa operating pressure

lateral length (m)	Qvar (%)	Classification	CV	Classification	EU (%)	Classification	CU (%)	Classification
15	27.20%	Not Acceptable	0.14	Marginal	86.35%	Good	89.44%	Good
30	15.82%	Acceptable	0.09	Average	93.89%	Excellent	94.20%	Excellent

Table 7 Performance criteria for the 150 kPa operating pressure

lateral length (m)	Qvar (%)	Classification	CV	Classification	EU (%)	Classification	CU (%)	Classification
15	28.91%	Not Acceptable	0.15	Marginal	86.05%	Good	88.10%	Good
30	22.81%	Acceptable	0.15	Marginal	91.60%	Excellent	91.54%	Excellent

Table 8 Performance criteria for the 200 kPa operating pressure

lateral length (m)	Qvar (%)	Classification	CV	Classification	EU (%)	Classification	CU (%)	Classification
15	23.04%	Acceptable	0.11	Average	87.36%	Good	90.95%	Excellent
30	15.32%	Acceptable	0.08	Average	90.18%	Excellent	94.73%	Excellent

2.2.5 Data Analysis

An excel spreadsheet was used to organize the recorded flow rate of each sampled point in the system. The maximum flow rates; qmax, minimum flow rates; qmin, and average flow rates; Qavg, from each sample were used to compute their CV, CU and EU. Tables will be used to present the data.

3 Results and discussions

3.1 Performance evaluation of 50 kPa operating pressure

Variations in the Qvar of the 50 kPa OP (Table 5) were observed to be 29.88% and 26.42% for lateral lengths of 15 and 30 m, respectively. According to Bralts et al. (1987), a change in emitter flow rate of 10% or less is generally regarded as desirable. The discharges from the 50 kPa OP were desired for the various lateral lengths, meeting the criteria for evaluating drip emitters. The expected differences in the discharge of emitters or flow variability, CV which is the ratio of the standard of the measured flow rate to the average flow rate were 0.16 and 0.17 for lateral lengths of 15 and 30 m respectively. The classification of these values according to ASABE (2008) shows that all flow variabilities were marginal. The uniformity of water delivery, EU by emitters in this experiment for the specified lateral lengths of 15 and 30 m were 85.03% and 88.68% respectively. According to ASAE (1996), emission uniformities for 15 and 30 m were Good for OP of 50 kPa. CU values under this OP were 87.97% and 89.84% (15 and 30 m respectively) ranging between 80% – 90% which is good as reported by ASABE (1999) and this meets the desirable criteria for assessing drip emitters for a drip irrigation system these results agree with the results reported by Taha (2008).

3.2 Performance evaluation of 100 kPa operating pressure

Variations in the Qvar of the 100 kPa OP as shown in Table 6 were observed to be 27.20%, and 15.82% for lateral lengths of 15 and 30 m, respectively. According to (Bralts et al., 1987), a change in emitter flow rate of 10% or less is generally regarded as desirable, and so with lateral length 15 discharges was Not Acceptable and with 30 m discharges were Acceptable and meets the criteria for evaluating drip emitters. The expected differences in the discharge of emitters or flow variability, CV which is the ratio of the standard of deviation of the measured flow rate to the average flow rate were 0.14 and 0.09 for lateral lengths of 15 and 30 m respectively. The classification of these values according to ASABE (2008) shows that all flow variabilities were average for 30 m. The uniformity of water delivery, EU by emitters in this experiment for the specified lateral lengths of 15 and 30 m were 86.35% and 93.89% respectively. According to ASAE (1996), emission uniformities for 15 m were Good and for 30 m ware Excellent for OP of 100 kPa. CU values under this OP were 89.44% and 94.20% (15 and 30 m respectively) ranging between 80% – 90% which is good and Greater than 90% which is Excellent as reported by ASABE (1999) and this meets the desirable criteria for assessing drip emitters for a drip irrigation system.

3.3 Performance evaluation of 150 kPa operating pressure

Variations in the Qvar of the 150 kPa OP as shown in Table 7 were observed to be 28.91%, and 22.81% for lateral lengths of 15 and 30 m, respectively. According to Bralts et al. (1987), a change in emitter flow rate of 10% or less is generally regarded as desirable, and so 15 m lateral length of 28.91% were Not Acceptable and meets the criteria for evaluating drip emitters while Qvar values for the 30 m was Acceptable. The expected differences in the discharge of emitters or flow variability, CV which is the ratio of the standard deviation of the measured flow rate to the average flow rate were 0.15 and 0.15 for lateral lengths of 15, and 30 m respectively. The classification of these values according to ASABE (2008) shows that the 15 and 30 m flow variability was Marginal. The uniformity of water delivery, EU by emitters in this experiment for the specified lateral length of 15 and 30 m were 86.05% and 91.60% respectively. According to ASAE (1996), EU for 15 m was Good, and that of 30 m lateral length was Excellent for this OP. The CU value for 15 m length was Good (88.10%), while for 30 m it was Excellent (91.54%) as reported by ASABE (1999) and this meets the desirable criteria for assessing drip emitters for a drip irrigation system.

3.4 Performance evaluation of 200 kPa operating pressure

Variations in the Qvar of the 200 kPa OP (Table 8) were observed to be 23.04%, and 15.32% for lateral lengths of 15 and 30 m, respectively. According to Bralts et al. (1987), a change in emitter flow rate of 10% or less is generally regarded as desirable. The discharges from the 200 kPa OP were Acceptable for the various lateral lengths, meeting the criteria for evaluating drip emitters. The expected differences in the discharge of emitters or flow variability, CV which is the ratio of the standard of the measured flow rate to the average flow rate were 0.11 and 0.08 for lateral lengths of 15 and 30 m respectively. The classification of these values according to ASABE (2008) shows that all flow variabilities were Average. The uniformity of water delivery, EU by emitters in this experiment for the specified lateral lengths of 15 and 30 m were 87.36% and 90.18% respectively. According to ASAE (1996), emission uniformities for 15 were Good and for 30 m were Excellent for OP of 200 kPa. CU values under this OP were 90.95% and 94.73% for 15 and 30 m respectively, ranging between 80% – 90% which is good and Greater than 90% which is Excellent as reported by ASABE (1999) and this meets the desirable criteria for assessing drip emitters for a drip irrigation system.

3.5 Average emitter discharge flow (Qvar)

The experiment on the drip irrigation system was carried out at various OP (50, 100, 150 and 200 kPa) for two laterals lengths (15 and 30 m) of PE pipes to test different drip irrigation system hydraulic characteristics. Drip emitter discharges were measured and recorded at various OP at a 4 L h^{-1} discharge rate for 15 and 30 m, respectively as shown in Figure 1.

The experiment was tested for each of the four OP at the lateral lengths of (15 and 30 m). This was done in order to obtain a more precise value for catchments of average emitter discharge flow rate. The discharge for the selected emitter point was determined using the average discharge value obtained after the test. Figure 2 showed a summarized result of all values collected for the experiment, with a final average value taken for all discharges computed for the selected randomized emitter locations on each lateral and recorded for each OP under the various lateral lengths.

Generally, as the OP was reduced or decreased, values obtained for Qvar for the other OP were increasing. Increasing Qvar or high values for Qvar only yielded unacceptable drip emitter characteristics as reported by Bralts et al. (1987). For desirable values of Qvar, OP should be increased. This applies also to the EU whose values decreased as OPH was reduced. This infers that, excellent EU will be obtained with a relatively high OP, and close to poor or unacceptable EU will be obtained for lower OP. Another reason for low EU along laterals is clogging of emitters. The primary components of the clogging process are suspended particles from the water. These particles, when combined with bacterial biofilms, can decrease emitter flow by forming obstacles in the flow channel. The CU was good and excellent for all OP and meets the criteria for assessing drip emitters for a drip irrigation system these results agree with the results reported by Taha (2008).

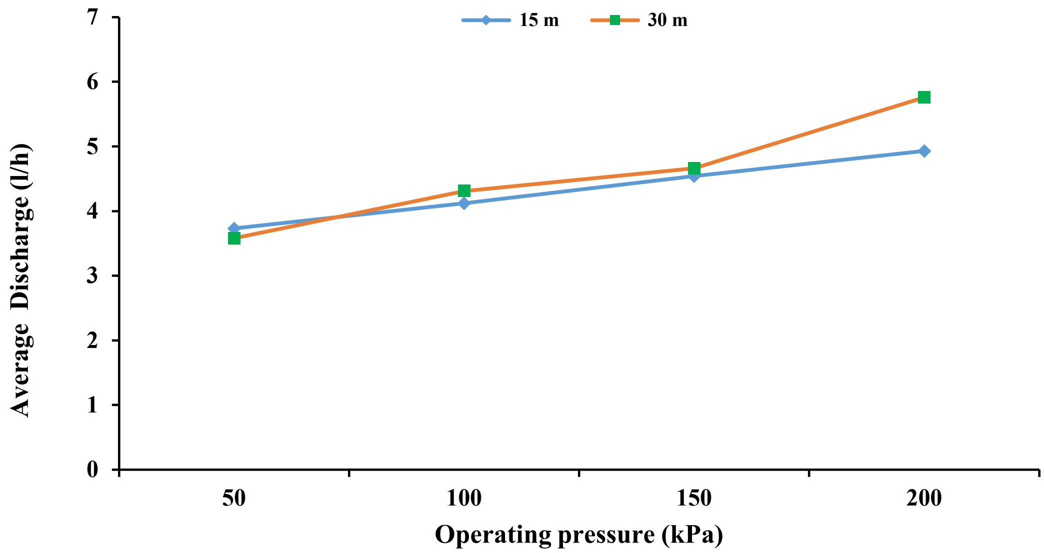

Figure 2 Average emitter discharge flow (Qvar)

4 Conclusions

This study described four operating pressures (50, 100, 150 and 200 kPa) for flow estimates and performance criteria for evaluating drip emitters in a basic drip irrigation system. The results of the experiment indicated that decreasing or reducing the OP resulted in unsatisfactory Qvar values for the 50 kPa OP. operating pressure should be raised to achieve appropriate emitter flow fluctuations. EU values obtained after the experiment show another influence of OP on water distribution. EU values discovered to be decreasing and diverging from the desired as OP was lowered. This implies that a reasonably high-OP will yield a good EU, whereas lower-OP will yield a substandard or unsatisfactory EU.

The water distribution was also affected by lateral length (15 and 30 m). EU climbs to the permissible range as lateral lengths. With 30 m lateral length will provide greater and more effective water distribution uniformity.

It has been concluded that the performance of Pressure compensating (PC) drip emitters was affected by operating pressures. The results led to the following conclusions.

1- Discharges were increased by increasing operating pressure for both lateral lengths.

2- The highest water distribution uniformity was achieved at an operating pressure of 200 kPa for both lateral lengths.

3- The values of water distribution uniformity for lateral length 30 m are higher than the values of lateral length 15 m at the same conditions of operating pressures.

Acknowledgements

The authors are very grateful to the Agricultural Engineering Department, Faculty of Agriculture, Zagazig University for the facilities it provided, which improved the quality of this work.

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