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Performance assessment of the TORO Company Neptune PC AS dripline

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Abstract

In order to design an efficient micro-irrigation system, a monitoring approach allowing quantification of the main variables affecting the level of uniformity should be pursued. In the present work, we assess the performances of a commercial dripline, the product 'Neptune PC AS', furnished by TORO Company, employing an ad hoc built experimental benchmark, in doing so, defining the dripline's acceptable working conditions. Neptune PC AS has been tested at different operating pressure heads (range 1.5-3.5 bar), and its performances have been evaluated employing a series of metrics (the emitter technological variation coefficient, the emitter uniformity, and the application efficiency). The obtained results show that Neptune PC AS is characterised by a strong pressure-compensating effect on the emitters and by very good/excellent performances for all the investigated operating pressure heads. Moreover, Neptune PC AS is characterised by little differences between the maximum and the minimum of the emitter flow rate in the case of operating pressure heads equal to 1.5 bar and 2.0 bar, while such differences tend to increase for higher operating pressures.

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Introduction

Water consumption worldwide is mainly dedicated to agriculture, with an average estimation of 70% of global withdrawals. However, in a climate change context, and with an increasing total population on Earth, it is mandatory to favour the employment of high-efficiency irrigation systems. A typical example is represented by what is occurring in many developing countries, where low-efficiency irrigation systems, like furrows, characterised by an efficiency that usually does not exceed 50%, are being progressively substituted by high-efficiency irrigation systems, like sprinklers or micro-irrigation systems, that are characterised by an efficiency that can overcome 90% (Mendoza *et al*., 2019).

Although sprinkler systems are one of the most popular methods of irrigation worldwide, covering more than 50% of the total irrigated land and with such a percentage increasing up to 90% in several countries, like France (Saretta *et al*., 2018), micro-irrigation systems are characterised by the use of lower water volumes, resulting in water savings when compared to sprinkler systems (Testezlaf, 2011).

Micro-irrigation is the slow application of water on, above, or below the soil, usually performed employing different technologies such as surface drip, subsurface drip, bubbler, and micro-sprinkler systems (Ayars *et al*., 2007). In the present work, we focus on driplines, *i.e*., a series of small diameter pipelines equipped with some single emitters designed to dissipate pressure head and pour on soil a uniform and constant flow rate, known as nominal flow rate. Indeed, the nominal flow rate is reported in technical reports available from manufacturers and constitutes one of the key elements that are considered by professionals when designing a dripline system. Unfortunately, the nominal flow rate reported by factories is determined by employing simple in-door conditions, which often differ from what is present in the field, where additional and detailed information about the relationship between the flow rate of the single emitter and its main hydraulic conditions could be needed. Therefore, when using dripline systems, a proper system design has an important role in irrigation uniformity and efficiency, which directly affects plant growth. In particular, one of the key parameters in designing a dripline system is the level of uniformity, *i.e*., every portion of the soil should be irrigated with the same amount of water to maximise yield and plant quality (Zhang *et al*., 2013).

In order to design an efficient dripline system, a monitoring approach allowing quantifying the main variables affecting the level of uniformity, *i.e*., flow rates, head losses, and pressure heads inside pipelines, can help in determining the performance of the system and in identifying possible problems to be corrected (Solé-Torres *et al*., 2021).

Assessing the level of uniformity and other performances of the dripline system is usually a complex and time-consuming operation. For instance, one of the employed procedures consists in arranging on the ground a series of collectors (catch-cans) and then performing a series of tests in which the water poured by the emitter in the single catch-can is measured. Of course, such tests are rigorous, long, and repetitive, and manual work is labour-demanding. Because of this, for many commercial driplines, only synthetic information is usually provided, and the practitioners aiming to design such systems lack detailed helpful information for assessing their performances in the field (Petroselli *et al*., 2021). Indeed, the manufacturers' catalogues usually provide only summary information such as the maximum dripline length allowed for a series of characteristics such as a fixed nominal pressure head, a nominal flow rate, a selected emitter spacing, and pipe diameter, so that the pressure head stays in a certain admitted range of variability (Baiamonte, 2018). Other detailed information, such as the relationship between the emitter flow rate and pressure head, affecting the amount of water poured to the ground, or the relationship between the head losses and the distance from the beginning of the dripline, is usually lacking.

Hence, this research aims to characterise and evaluate in detail the performances of a commercial dripline, the product 'Neptune PC AS', furnished by TORO Company, employing an ad-hoc built experimental benchmark, in doing so defining the dripline's acceptable working conditions.

Materials and methods

The experimental benchmark

In order to assess the performances of the selected dripline, an experimental benchmark was realised in the testing facility of ARSIAL (Lazio Region Agency for Development and Innovation in Agriculture) near Tarquinia town, in Central Italy (coordinates 42°.224690 N, 11°.733823 E). The experimental benchmark has been built in an open area having a flat surface of 1500 m^2, and it is characterised by the possibility of investigating a dripline up to a total length of 600 m, thanks to the employed layout consisting of 8 connected rows of 75 m each one, with pressure heads ranging from 0.5 to 4 bar.

The system structure (Figure 1) consists of 26 vertical concrete poles (section 10×10 cm) distant 2.9 m each, interred for 0.6 m and then stabilised with cement mortar. In addition, one horizontal wooden pole (2.3 m length, 5 cm diameter) is connected to the corresponding vertical concrete pole at 1 m height from ground level, and it presents 8 steel junctions allowing fixing the driplines, that are also sustained by 8 horizontal steel wires (3 mm diameter, 20 cm distance each one) assembled among the wooden poles.

Figure 1. Experimental benchmark layout. Up left: the area occupied by the system. Up right: particular of driplines connection. Centre: system aerial and lateral view. Down left: concrete and wooden poles. Down centre: steel wire for sustaining the dripline. Down right: steel junctions for dripline.

The hydraulic layout

The water feeding the system can come from a groundwater source, thanks to a well present inside the testing facility of ARSIAL, and/or a pressurised pipeline owned by the local authority. Both the water sources are opportunely filtered, thanks to a safety disc filter (115 microns) for the groundwater source and an automatic double chamber sand filter (75 microns) for the pressurised pipeline. In order to guarantee a constant flow rate to the dripline, the groundwater is routed first in a 1 m^3 tank in the proximity of the system then to the dripline, thanks to an external 1.1 kW pump (Calpeda MGPM 405). An electronic programmer with a closing ball valve operates the circuit, granting the desired flow rate. After the valve, a pressure head controller (OMR 100, precision 0.05 bar) is present, able to regulate the pressure head as desired, then a digital flowmeter (precision 1%), an analogue thermometer (precision 0.1°C) and a digital manometer (precision 0.01 bar) are installed. High-precision digital manometers (0.01 bar) are installed in the dripline, while the water poured by the single emitter is collected in a specific catch can for a fixed temporal duration. At the end of each test, described in the following paragraph, a certain amount of water is collected in the catch can and then weighted in a high precision balance (0.1 g), allowing quantifying the water volume collected in the catch can. Dividing the water volume collected in the catch can for the temporal duration of the test allows quantifying the flow rate emitted at a specific point of the dripline. Closing valves installed at fixed locations in the dripline allows for investigating the dripline characteristics (flow rates, head losses, uniformity of emitters) and selecting a desired total dripline length. In Figure 2, some particulars of the hydraulic layout are shown.

The investigated dripline

The dripline investigated here is the TORO Company 'Neptune PC AS' product. The investigated dripline is a pressure-compensating dripper with high resistance to clogging, multiyear durability, and a wide range of flow rates and spacing. The Neptune PC dripline is available in two versions, presenting pressure-compensating emitters: ANTI-SIPHON (AS; investigated here) and NO-DRAIN (ND). AS prevents impurities from entering from the outside, while ND simultaneously opens and closes all the emitters (0.45 bar opening pressure and 0.20 bar closing pressure). Diameters available for both AS and ND are 16 mm (thickness 0.9-1.0-1.1 mm) and 20 mm (thickness 0.9-1.0-1.2 mm). Nominal flow rates are 1.2, 1.6, 2.4, and 3.8 l/h, while the pressure-compensating effect ranges between 0.5 and 3.5 bar. The pressure-compensating mechanism of the emitters should guarantee a constant flow rate across the wholeline, regardless of the system operating pressure head or the altimetric trend of the land. The investigated dripline is designed to have a distribution uniformity that optimises the crop results; each plant should receive the same amount of water, nutritional factors, and fertilisers. Neptune PC is suitable for the irrigation of orchards, vineyards, olive groves, and greenhouse crops. Its feature of maintaining the same irrigation capacity means it can also be used on large surfaces with long laterals. In addition, the possibility of choosing the spacing together with the range of drippers allows a great variety of applications and considerable flexibility in design. The AS system prevents impurities from entering from the outside and can therefore be installed underground, while the ND system is specifically designed to be installed in all irrigation systems where short and frequent irrigation cycles are required.

Figure 2. Hydraulic layout particulars. Up left: digital flowmeter. Up centre: pressure head controller. Up right: analogue thermometer. Down left and down centre: example of digital manometers. Down right: example of water collection in the catch can.

The performed analysis

Regarding the performed analysis, in the present manuscript, we focused on the AS system with a diameter of 16 mm, a nominal flow rate of 2.4 l/h, emitters spacing of 0.5 m, and operating pressure heads of 1.5, 2.0, 2.5, 3.0, and 3.5 bar. We selected a dripline length equal to the maximum length recommended in the TORO Company technical reports for each operating pressure, and we determined, thanks to the abovementioned instruments, head losses, and flow rates, allowing us to determine the relationship between pressure head in the dripline (H) and emitter's flowrate (Q). In particular, according to the TORO Company official reports, the maximum lengths for the investigated dripline in order to still achieve good water uniformity are 133, 154, 170, 184, and 196 m for operating pressure heads (at the beginning of the dripline) equal to 1.5, 2.0, 2.5, 3.0 and 3.5 bar, respectively. Therefore, following the official recommendations, we inserted closing valves at such distances in the dripline and performed the tests; we imposed operating pressure heads of 1.5, 2.0, 2.5, 3.0, and 3.5 bar at the beginning of the dripline and measured pressure heads and flow rates in 20 points equally spaced in each investigated length, repeating three times each test and averaging the obtained results, following the methodology suggested by Borssoi *et al*. (2012) and Ferrarezi *et al*. (2020).

Finally, we determined the technological variation coefficient (Cv), the emitter uniformity (EU), and the application efficiency (AE) expressed according to the following equations.

$$\mathrm{Cv} = \left(\frac{\sqrt{\sum_{i=1}^{n} (Q_i - Q_a)^2 * \frac{1}{n}}}{Q_a} \right) * 100 \tag{1}$$

where Cv (%) is the technological variation coefficient, n is the number of observations (20 emitters in each test, equally spaced from the beginning to the end of the dripline length), Q_i is the generic flowrate (l/h) for i=1, …, 20, and Q_a is the average emitter flow rate (L/h) (Boswell, 1984).

$$\mathrm{EU} = \left(1 - 1.27 \frac{\mathrm{Cv}}{\sqrt{n}}\right) * \left(\frac{Q_m}{Q_a}\right) * 100 \tag{2}$$

where EU is the emitter uniformity (%), n is the number of observations (20 emitters in each test, equally spaced from the beginning to the end of the dripline length), Q_m is the minimum emitter flow rate (l/h), and Q_a is the average emitter flow rate (l/h) (Boswell, 1984).

$$\mathrm{AE} = \left(\frac{Q_m}{Q_a}\right) * 100 \tag{3}$$

where AE is the application efficiency (%), Q_m is the minimum emitter flow rate (L/h), and Q_a is the average emitter flow rate (L/h) (Boswell, 1984).

Regarding Cv values, they can be classified as excellent (Cv<5%), very good (5%<Cv<7%), good (7%<Cv<11%), poor (11%<Cv<15%), and unacceptable (Cv>15%) (Boswell, 1984).

Regarding EU values, they can be classified as excellent (EU>90%), good (80%<EU<90%), acceptable (70%<EU<80%), poor (66%<EU<70%), and unacceptable (EU<66%) following the classification reported by Merriam and Keller (1978), or they can be classified as high (EU>90%), mean (80%<EU<90%), and low (EU<80%) following the classification reported by Capra and Scicolone (1998).

Regarding AE values, they can be classified as excellent (AE>90%), very good (80%<AE<90%), fair (70%<AE<80%), poor (60%<AE<70%), and unacceptable (AE<60%) following the classification reported by the American Society of Agricultural Engineers (ASAE, 1996a; 1996b).

Three repetitions were performed for each test, and the results were averaged. All tests were performed with air temperature ranging between 14°C and 22°C, air humidity ranging between 69% and 96%, and water temperature ranging between 16°C and 24°C.

It is noteworthy that the length recommended by TORO Company refers to a straight dripline without abrupt discontinuities that could cause local head losses. Conversely, in our experimental benchmark, several 90° curves and Tees (in the presence of instruments) are present; see Figures 1 and 2. In particular, in our experiments, for 'Tee,' we refer to a special piece formed by one closing valve (that remains open during our tests), one Tee, and two fittings (Figure 2). In order to present in the next paragraph results that could be compared with the common situation related to a pure straight dripline (*i.e*., without any local head losses), we calculated the local head losses for 90° curves and Tees adopting the following methodology, and we added the corresponding local head losses to the measured pressure heads. The methodology followed for determining the local head loss due to the single 90° curve (or the single Tee) was: i) creating a segment of the NEPTUNE AS dripline where we inserted twenty 90° degrees curves (or twenty Tees) in sequence; ii) measuring the pipeline flow rate, from 5 to 20 L/min; iii) measuring the pressure head at the beginning and the end of the NEPTUNE AS dripline segment; iv) determining by the difference the local head losses due to twenty 90° degrees curves (or twenty Tees) in sequence; v) dividing the previous difference by 20 in order to reach an accurate value for the single local head loss due to the 90° curve (or to the Tee); vi) reconstructing the relationship between dripline flow rate and head losses due to the single 90° curve (or to the single Tee).

Results and discussion

The results are summarised in Figure 3 regarding the relationships among the local head losses due to a single 90° curve or to a single Tee. In Figure 4, we report the relationships between the distance of the single emitter from the beginning of the dripline (D), the emitter pressure head (H), and the flow rate (Q). Finally, Figures 5, 6, and 7 show the technological variation coefficient (Cv), the emitter uniformity (EU), and the application efficiency (AE) of the emitters with respect to the operating pressure head (OPH) at the beginning of the dripline.

Looking at the Figures, the following considerations can be made. First, regarding the relationship between the total flow rate in the dripline and the local head losses due to the single 90° curve or to the single Tee (Figure 3), the behaviour is clearly not linear, confirming, as expected, the theoretical results of the Darcy-Weisbach equation, where a parabolic behaviour between local head loss and mean water velocity in the pipe (and hence flow rate in the pipe) is reported (*e.g*., Prado *et al*., 2021). The results depicted in Figure 3 can help adequately assess the local head losses that can occur using the selected dripline and special connections. It is well-known in the literature that local head loss computation has a strong relevance in the hydraulic design of irrigation systems, as highlighted by Vilaça *et al*. (2017) or Bombardelli *et al*. (2019).

Regarding the relationship between the distance of the single emitter from the beginning of the dripline and the emitter flow rate, in terms of flow rate absolute values (Figure 4), we can observe that the flow rate values decrease with the increase of the distance. This behaviour was expected since Figure 4 shows the effect of the head losses in the dripline that strongly decrease the pressure head up to the minimum value (*i.e.*, 0.5 bar) allowed for the emitters functioning. In Figure 4, we can note the functioning of the dripline emitters, which present a strong pressure-compensating effect, allowing the flow rate to decrease much less than the pressure head, in doing so, increasing the irrigation uniformity. The relationship between the emitter flow rate (Q) and emitter pressure head (H) can be analysed employing the characteristic equation of the flow-pressure ratio, as done by Mendoza *et al*. (2019):

$$Q = a * H^n \quad (4)$$

Where 'a' is a coefficient characterising the emitter dimension

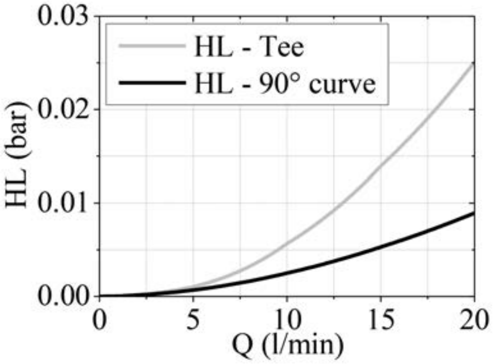

Figure 3. Relationship between the dripline flow rate (Q) and the local head losses (HL) due to the single 90° curve or to the single Tee.

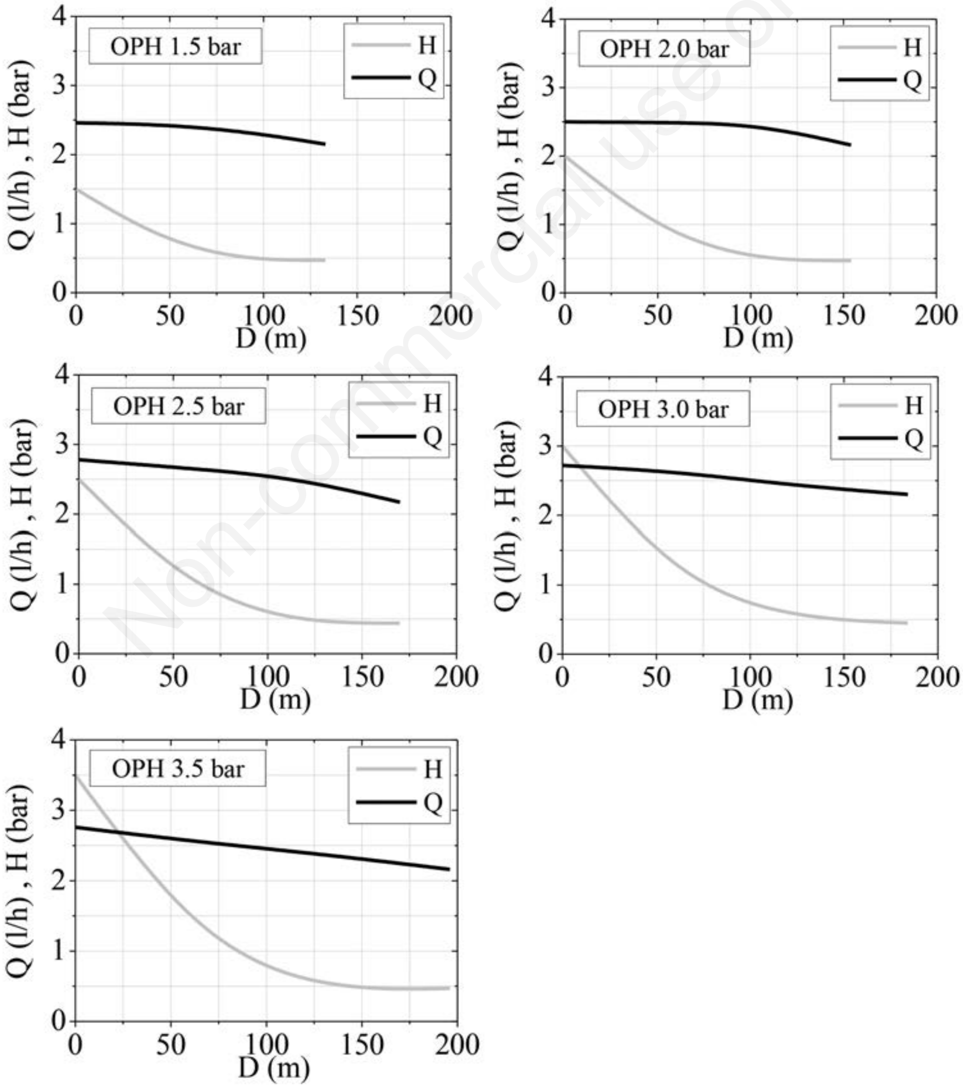

Figure 4. Relationship between the distance of the single emitter from the beginning of the dripline (D), the emitter pressure head (H), and flow rate (Q) for the investigated operating pressure heads (OPH).

and 'n' is the emitter flow regime coefficient (flow exponent). From the results depicted in Figure 4 we can obtain 'n' values in the range 0.08-0.11, testifying the high pressure-compensating effect of the investigated emitters, as Boswell (1984) stated. The obtained 'n' values are in line with the values obtained by Baeza and Contreras (2020) who analysed a series of pressure-compensating emitters determining 'n' values in the range –0.08/0.15. The choice to adopt pressure-compensating emitters on the driplines is, of course, beneficial in terms of achieved water uniformity, as highlighted by Ferrarezi *et al*. (2020) that clearly indicated that a more uniform water distribution could be achieved by replacing the non-compensating equipment with those with pressure-compensating emitters and using such equipment following the pressure range recommended by the manufacturer. Regarding the obtained results, shown in Figure 4, we can observe how much the emitter flow rate decreases with distance increase. In particular, we found limited differences between the maximum and the minimum of the emitter flow rate for the maximum suggested lengths depending on the operating pressures, in the case of operating pressures equal to 1.5 bar (maximum decrease of flow rate equal to 12.6%) and 2.0 bar (maximum decrease of flow rate equal to 13.6%).

In contrast, such differences tend to increase for higher operating pressures. Indeed, for operating pressures of 2.5, 3.0, and 3.5 bar, the differences between the maximum and minimum emitter flow rate are 21.9%, 15.4%, and 21.7%, respectively. These last results indicate that the maximum suggested length for the dripline could be slightly diminished to achieve a better level of uniformity.

Regarding the obtained Cv values (Figure 5), the analysed dripline can be classified (Boswell, 1984) as excellent (Cv<5%) for all the investigated operating pressures since Cv is in the range of 3.16%-4.13%. Regarding the obtained EU values (Figure 6), the analysed dripline can be classified, employing the Merriam and Keller (1978) classification, as excellent for the operating pressure of 3.0 bar (EU is 91.3%) and suitable for the remaining operating pressures (EU is in the range 85.3%-86.7%). Conversely, if the Capra and Scicolone (1998) classification is adopted, the analysed dripline can be classified as high for the operating pressure of 3.0 bar and as a mean for the remaining operating pressures. Finally, regarding the obtained AE values (Figure 7), the analysed dripline can be classified (ASAE, 1996a; 1996b) almost always as excellent (AE is in the range of 90.0%-95.8%), except for the operating pressure of 1.5 bar, where an AE value of 89.6% is reported, so the classification is here very good. The importance of investigating AE has been highlighted by Howell (2003) and confirmed by Rajan *et al*. (2015).

The obtained results, in our opinion, allow us to accurately assess the performances of the investigated dripline to maximise the level of uniformity. In terms of comparison with previous works, it is noteworthy that in literature, TORO Company Neptune driplines have not been so adequately tested and discussed. However, detailed results such as those obtained would be needed to calibrate and use the software that is often used when designing a dripline irrigation system, such as Toro Drip Micro Payback Wizard (Bisconer, 2011) or Toro's AquaFlow (Bisconer and Wolfram, 2014). Literature analysis revealed a lack of applications involving TORO Company Neptune products, while the official reports, as aforementioned, indicate only the maximum lengths for the investigated dripline in order still to achieve good water uniformity.

From a general point of view, the obtained results are in line with recent literature findings for similar applications involving the driplines of different companies. For instance, Sarker *et al*. (2019) analysed driplines with pressure-compensating emitters at a spacing of 0.75 m and operating pressures of 1.5, 2.0, and 2.5 bar. They found Cv values in the range of 4.5%-6%, EU values in the range of 84.8% - 88.1%, and a flow variation in the range of 18.1%-21.1%. Aydin (2019) analysed different driplines with pressure-compensating emitters at spacing 0.33 m and operating pressures from 0.5 to 2 bar and determined EU values in the range of 85.4%-97.8%. Baeza and Contreras (2020) evaluated 38 different commercial models of driplines used for irrigation, and among them, 14 presented pressure-compensating emitters. Limiting to the 14 pressure compensating driplines, they determined Cv values

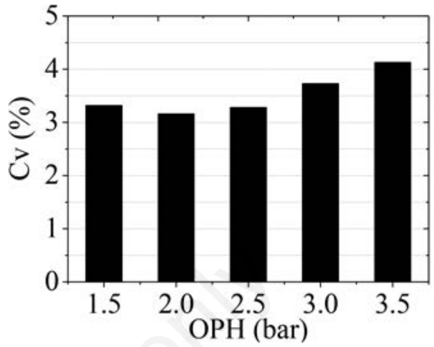

Figure 5. Relationship between the emitter technological variation coefficient (Cv) and the operating pressure head (OPH) at the beginning of the dripline.

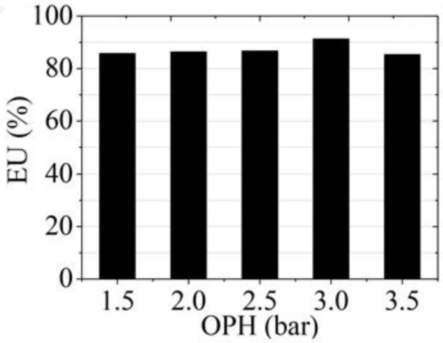

Figure 6. Relationship between the emitter uniformity (EU) and the operating pressure head (OPH) at the beginning of the dripline.

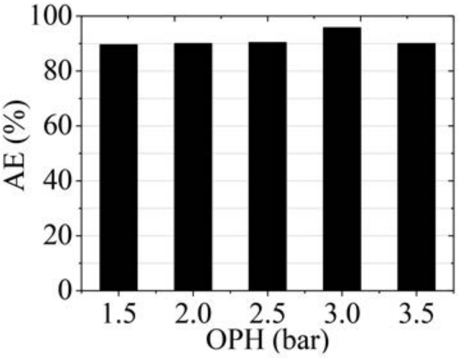

Figure 7. Relationship between the application efficiency (AE) and the operating pressure head (OPH) at the beginning of the dripline.

in the range of 1%-7%. Finally, Dos Santos *et al*. (2022) analysed driplines 200 m long with pressure-compensating emitters at spacing 0.5 m and determined an average EA value equal to 89%.

Conclusions

In the present manuscript, a commercial dripline, the product 'Neptune PC AS', was tested to assess its performances, defining the acceptable working conditions. The investigated dripline, furnished by TORO Company, is a pressure-compensating dripper with high resistance to clogging, multiyear durability, and a wide range of flow rates and spacing. Neptune PC AS has been tested at different operating pressure heads (range 2.0-3.5 bar), and its performances have been evaluated employing a series of metrics, *i.e.*, the technological variation coefficient (Cv), the emitter uniformity (EU) and the application efficiency (AE). The obtained results, of course, valid only for the investigated dripline, seem to support the following conclusions:

i) neptune PC AS is characterised by a strong pressure-compensating effect on the emitters and by very good/excellent performances for all the investigated operating pressure heads, considering the obtained results based on the values of the selected metrics.
ii) neptune PC AS is characterised by limited differences between the maximum and the minimum of the emitter flow rate for the maximum, suggested lengths in case of operating pressures equal to 1.5 bar and 2.0 bar, while such differences tend to increase for higher operating pressure heads. Therefore, in the case of higher operating pressure heads, the maximum suggested length for the dripline could be slightly diminished to achieve a better level of uniformity.

Future investigations will regard the selection and investigation of other types of driplines characterised by different emitters' characteristics. Moreover, at the end of the experimental campaign, the results will be used to develop and calibrate a novel helpful software for designing driplines irrigation systems.

References

ASAE. 1996a. Field evaluation of microirrigation systems. EP405.1. ASAE Standards. Am. Soc. Agric. Eng. St. Joseph, MI, USA, pp. 756-759.

ASAE. 1996b. Design and installation of microirrigation systems. EP409. ASAE Standards. Am. Soc. Agric. Eng. St. Joseph, MI, USA, pp. 792-797.

Ayars, J.E., Bucks, D.A., Lamm, F.R., Nakayama, F.S. 2007. Introduction. In: Lamm, F.R., Ayars, J.E., Nakayama, F.S. (Eds.), Microirrigation for crop production. design, operation and management. Elsevier: Amsterdam, The Netherlands, pp. 1-26.

Aydin Y. 2019. Determination of emitter hydraulic properties of different in-line dripper types. Appl. Ecol. Environ. Res. 17:10195-205.

Baeza R., Contreras J.I. 2020. Evaluation of thirty-eight models of drippers using reclaimed water: Effect on distribution uniformity and emitter clogging. Water (Switzerland) 12:1463.

Baiamonte G. 2018. Advances in designing drip irrigation laterals. Agric. Water Manage. 199:157-74.

Bisconer I. 2011. Benefits of using pressure compensating (PC) micro-irrigation emission devices. American Society of Agricultural and Biological Engineers Annual International Meeting 2011, ASABE 20117:5698-5713.

Bisconer I., Wolfram B. 2014. A guide for selecting subsurface drip irrigation (SDI) laterals in field crops. pp 3785-3794 in American Society of Agricultural and Biological Engineers Annual International Meeting 2014, ASABE.

Bombardelli W.W.A, Camargo A.P. de, Frizzone J.A., Lavanholi R., Rocha H.S. da. 2019. Local head loss caused in connections used in micro-irrigation systems. Rev. Brasil. Engen. Agríc. Ambient. 23:492-8.

Borssoi A.L., Vilas Boas M.A., Reisdoorfer M., Hernandez R.H., Follador F.A. 2012. Water application uniformity and fertigation in a dripping irrigation set. Eng. Agr. 32:718-26.

Boswell M.J. 1984. Micro-irrigation design manual. James Hardie Editions.

Capra A., Scicolone B. 1998. Water quality and distribution uniformity in drip/trickle irrigation systems. J. Agric. Eng. Res. 70:355-65.

dos Santos J.W.F. Reis L.S., Dos Santos Dias M., de Assis da Silva F., de Oliveira Santos J.P. 2022. Efficiency and uniformity of a subsurface drip irrigation system in sugarcane crops. Rev. Agric. Neotrop. 9:e6829.

Ferrarezi R.S., Geiger T.C., Greenidge J., Dennery S., Weiss S.A., Vieira G.H.S. 2020. Microirrigation equipment for Okra cultivation in the U.S. Virgin Islands. HortSci. 55:1045-52.

Howell T.A. 2003. Irrigation efficiency. In: T.A. Howell (Ed.), Encyclopedia of water science. Marcel Dekker Inc., New York, NY, USA, pp. 467-472.

Mendoza C.J., Carbonell J.A., Lasso J.J. 2019. Technique characterization and hydraulic performance of perforated hose microirrigation system for sugarcane in Colombia. ASABE Annual International Meeting 1900792.

Merriam, J.L., Keller, J. 1978. Farm irrigation system evaluation: a guide for management. Utah State University, Logan, UT, USA.

Petroselli A., Romerio D., Santelli P., Mariotti R., Di Giacinti S., Casini L., Testa C. 2021. Assessing sprinkler systems performance employing a novel experimental benchmark. J. Agricult. Engine. 52:1172.

Prado G., Bruscagin R.R., Tinos A.C., Bortoletto E.C., Mahl, D. 2021. Iterative calculation of local head loss coefficient of emitters in lateral lines. Brazil. J. Agric. Environ. Engine. 25:291-6.

Rajan N., Maas S., Kellison R., Dollar M., Cui S., Sharma S., Attia A. 2015. Emitter uniformity and application efficiency for centre-pivot irrigation systems. Irrig. Drain. 64: 353-61.

Saretta E., de Camargo A.P., Botrel T.A., Frizzon J.A., Koech R., Molle B. 2018. Test methods for characterising the water distribution from irrigation sprinklers: Design, evaluation and uncertainty analysis of an automated system. Biosyst. Engineering 169:42-56.

Sarker K.K., Hossain A., Murad K.F.I., Biswas S.K., Akter F., Rannu R.P., Moniruzzaman M., Karim N.N., Timsina J. 2019. Development and evaluation of an emitter with a low-pressure drip-irrigation system for sustainable eggplant production. Agri. Engine. 1:376-90.

Santelli P. 2018. Impianti di irrigazione a goccia per le colture agrarie – progettazione, metodi e tecniche. Dario Flaccovio Editore.

Solé-Torres C., Lamm F.R., Duran-Ros M., Arbat G., Ramírez de Cartagena F., Puig-Bargués J. 2021. Assessment of microirrigation field distribution uniformity procedures for pressure-compensating emitters under potential clogging conditions.

Trans. ASABE. 64:1063-71.
Testezlaf R. 2011. Irrigation: methods, systems and applications. UNICAMP, Campinas, SP, Brazil.
Vilaça F.N., Camargo A.P. de, Frizzone J.A., Mateos L., Koech R. 2017. Minor losses in start connectors of microirrigation laterals. Irrig. Sci. 35:227-40.
Zhang L., Merkley G.P., Pinthong K. 2013. Assessing whole field sprinkler irrigation application uniformity. Irrig. Sci. 31:87e105.