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DOUBLE LATERAL DESIGNED FOR OPERATING UNDER SINGLE LINE CONDITIONS IN IRRIGATED CITRUS PLANTATION IN BRAZIL

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ABSTRACT

The world largest citrus plantations are located in Sao Paulo State, Brazil. Some of them are irrigated by drip systems, especially when it is expected a rising in prices from orange market or, for the local reality of production, when the plants are in the initial stages of development. By projecting the irrigation for the later stages, the systems are generally designed to support two laterals per row of trees, aiming to greaten the wet bulb diameter and hence the water necessity of these trees. However, it has been checked in the practice of the farms that, from the same doubled line design, there is an implementation of one single line in the initial stages, given that the water requirements are smaller and it is possible to reduce costs. This work reveals that, before adopting this idea, it is essential to simulate the possible occurrences, especially under situations of laterals lying on some degrees of declivity. Simulations were done for conventional and compensating emitters. The pressure variation is affected in both of cases under accentuated declivities (i.e., 5% or 7,5%) and there are possibilities of ruptures for laterals with compensating emitters under these conditions.

KEY WORDS: irrigation, orange, Brazil, drip systems, simulation

RESUMO

O Estado de São Paulo possui as maiores plantações de laranja do mundo. Parte delas é irrigada por sistema de gotejamento, especialmente quando se visualiza um cenário de aumentos de preço da laranja no mercado ou quando os pomares apresentam-se em seus estádios iniciais de desenvolvimento. Quando projeta a irrigação para estádios posteriores dos pomares, faz-se geralmente a adoção de linhas laterais duplas por rua de plantio, visando-se ampliar o diâmetro do bulbo molhado e atender a vazão requerida pelas plantas. Porém, tem-se verificado na prática, com o mesmo dimensionamento das linhas duplas, a implementação de uma única linha lateral

somente para os estádios iniciais, posto que se almeje reduzir custos e que as necessidades hídricas são menores. Este trabalho revela que, antes da adoção deste critério, é fundamental simular possíveis ocorrências em laterais posicionadas em certos graus de declive. A variação de pressão é afetada para ambos os casos sobre declives acentuados (ex.: 5% our 7,5%) e existem possibilidades de rupturas de linhas com autocompensantes nessas condições.
UNITERMOS: irrigação, laranja, Brasil, gotejamento, simulação

INTRODUCTION

Drip irrigation systems have been continuously increasing in terms of world area and number of system choice, especially in places where water is scarce. These systems present as the main characteristics the suitability of saving large volumes of water and improve the irrigation potential efficiency (Oster & Wilkens, 2003). Consequently, it is possible to expand the world irrigated area due to reduction in irrigation volume itself and installed required power per unit of area.

Sao Paulo State (Brazil) has the world largest area of citrus production, being some of them provided by the technologies of drip irrigation systems (Zanini et al., 1998). These irrigated areas also tend to increase either as the orange prices rise or when new areas are planted, where small plants normally require water supply in order to boost plant development (Nascimento et al., 2010), given that rain regimes might be sufficient in depth but not well distributed. In adult citrus plantation rows, drip systems are generally implemented contemplating two lateral lines as an alternative to greaten the surrounding wet area on surface (i.e., wet bulb diameter) of the orange trees. However, in young plantations the owners often prefer to implement only one single line in order to reduce costs during the first year, given that citrus canopies are still quite small and water requirements in terms of wetted area are fully or even better reached by using one single line (Coelho, 2007).

As the citrus plantation irrigation systems are designed to operate with two lateral lines in the later stages of the plantation (i.e. from the second year on), the consideration of this design along with the implementation of an individual line could raise the pressure inside the pipes like manifolds throughout irrigation mesh, as the original project would be designed to achieve twice as much discharge and hence would require greater pressure inside the lateral and even the irrigation subunit. Thus, the pressure may reach nominal value of pressure or even do higher than it, eventually resulting on a decreasing of PVC or polyethylene lifetime, or in extreme cases, in a rupture along the irrigation mesh.

Intending to show the possible occurrences inside the laterals when this practical criterion does exist, this work analyses a computer simulation of pressure performance throughout laterals of drip irrigation systems under different conditions of soil slope and considering two kinds of emitters, firstly based on conventional drippers and then on compensating ones, in both cases designed to operate with double lateral lines but initially operating with single laterals on field.

MATERIAL AND METHODS

The current simulation work was run through computer worksheets. Initially, two subunits were planned, one for conventional emitters and the other for compensating ones, setting a diameter value for laterals and "telescopic" manifolds, both subunits initially operating with double laterals. Further, the pressure values fluctuation throughout this irrigation system was simulated assuming a single lateral line in operation.

It was initially assumed as a design criterion a maximum discharge variation of 10% (Keller & Bliesner, 1990) for the conventional emitters. For the case of the compensating drippers, it was adopted 10 m as a minimum operation pressure to verify the discharge compensation and 40 m as the maximum pressure due to the nominal pressure of the line (NP). The Christiansen coefficient was used for reducing discharge along them whereas in the manifold cases the design was done in a step-by-step way.

Rectangular subunits were designed assuming a citrus plantation spaced 3 x 7 m, planted to achieve the magnitude of 4.5 mm day^{-1} of evapotranspiration values. In adherence with this assumed magnitude, Cruz et al. (2005) have found somewhat between 0.4 and 8.4 mm day^{-1}, respectively, for citrus at the maturity and flowering stages in Piracicaba, Sao Paulo State, Brazil, and 1,271 mm during for a whole year. This value can be extrapolated to ~3.48 mm day^{-1} of real evapotranspiration of plants. Additionally, it could be extrapolated to ~4.35 mm day^{-1} if the value is divided by 0.8, which is a robust magnitude for drip irrigation project-efficiency, according to the efficiency values provided by Allen (1992). For example, the multiplication of plant area (3 x 7 m) by the value of 4.5 mm day^{-1}, then divided by 24 h day^{-1}, led to a projected and rounded source-point discharge of 4.0 L h^{-1} for conventional emitters.

The dripper spacing was 1.3 and 1.1 m for the conventional and compensating emitters, respectively. The localised pressure losses regarding to the emitter insertion and to the connexion were considered as 0.5 m and as 0.7 m, respectively, both in terms of pipe length. The final subunit areas were planned as 3.36 ha (210 x 160 m) and as 9.24 ha (210 x 440 m) for conventional and compensating emitters, respectively, highlighting that the former has been designed to provide 160 m for each lateral and the latter 440 m, both being fed by a manifold underground point (noddle). From this corollary the manifold length was calculated as 210 m, as a result.

The conventional emitters were projected to discharge 4.0 L h^{-1} (levelled lateral with 13.7 mm of diameter) and have presented the following traditional functional form relationship between discharge (q, L h^{-1}) and pressure (H, m):

$$q = 1.325 \cdot H^{0.48} \qquad (1)$$

The compensating emitters were projected to discharge 3.5 L h^{-1} (levelled lateral with 13.7 mm of diameter) and have shown the following relationship between lateral length (L, m) and the required pressure at the beginning of it (Hi, m) to prompt the discharge compensation along length:

$$Hi = 5.103 \cdot e^{0.0082L} \qquad (2)$$

For both conventional and compensating emitters, the simulation was run by considering flat subunits (slope = 0) and also declivity slopes of -2.5%, -5.0% and -7.5%. Uphill slopes were not contemplated because there is no gain of potential energy involved in these slopes, as one intention of this study is to provide an idea of eventual ruptures that can occurs along pipelines when there is a contrast between energy gain from downhill slopes and natural energy losses from friction. The maximum allowed water speed was 3.5 m s^{-1} on the design of manifold whereas from this value it was designed the "telescopic" manifold, which has shown different combinations of diameters according to the different slopes throughout its length. For simulations purposes, it was considered that all subunits have the same dimensions and have pressure regulators at the beginning of each, besides the condition of two subunits working simultaneously in case of single lines operation option, trying to keep constant flow rate and pressure at pump station.

RESULTS AND DISCUSSION

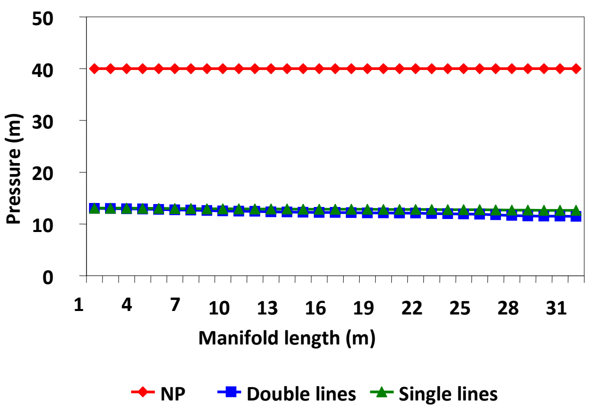
1. Conventional emitters

By observing Table 1 it is noted that the pressure variation decreases when the subunits designed to work with double line (levelled slope) are submitted to operate with a single line, improving the system uniformity. This event occurs because the friction losses are decreased into manifold line as the discharge is reduced. In fact, friction was reduced 77% while discharge was done in 50%, whereas minimum pressure has risen from 10.27 m to 11.43 m, when considering the same value of maximum pressure on the subunit (equal to initial pressure), according to the generated data.

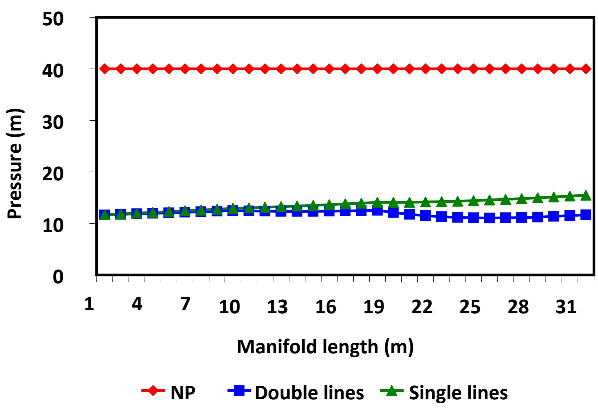
Table 1. Values of pressure at the beginning of subunit (Hi), pressure variation (ΔH), maximum pressure (H max), minimum pressure (H min) and friction losses into manifold (Hf) observed on the subunit when operating with both double and single lateral lines.

Slope (%)	Double line					Single line				
	Hi (m)	ΔH (%)	H max (m)	H min (m)	Hf (m)	Hi (m)	ΔH (%)	H max (m)	H min (m)	Hf (m)
0	13.07	21.14	13.07	10.27	1.7	13.07	12.44	13.07	11.43	0.4
-2.5	11.50	21.53	12.54	9.84	5.5	11.50	32.45	15.48	10.45	1.5
-5.0	11.50	22.01	13.49	10.52	9.3	11.50	46.87	19.97	10.61	2.5
-7.5	15.00	22.22	18.90	14.70	15.0	15.00	47.00	27.90	14.80	4.1

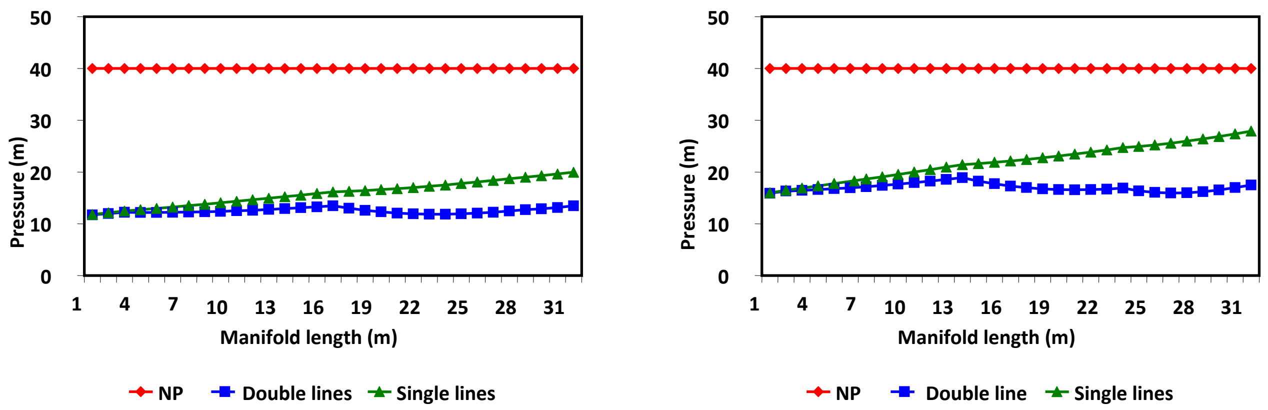
All simulated declivities have presented a reduction around 73% of friction losses of manifold; prompting an increasing of 23% on maximum subunit pressure if a declivity of 2.5% is considered or even bigger, 48%, if a declivity of 5% or 7.5% is considered. Figure 1 highlights the performance of pressure profiles along manifold for all studied slope situations by considering conventional emitters.



(a)



(b)



(c) (d)

Figure 1 – Pressure performance along manifold considering conventional emitters and the slopes (a) levelled; (b) -2.5%; (c) -5.0%; and (d) -7.5%. NP: Nominal pressure of pipes.

According to traditional concepts, for subunits designed under uniform declivity slopes, it is not possible to achieve the same results of those under non-uniform declivities because there is an energy gain come from potential energy as a consequence of an increasing in elevation (Detomini & Frizzone, 2008). It is then necessary to generate higher friction losses by reducing the manifold diameter in order to obtain a pressure variation in consonance with the design criteria. When the irrigation system works based on single lines on the simulation, the existing friction is presumably not sufficient to compensate the

Table 2 the generated data set is released for the simulation contemplating compensating emitters. In such system the design criterion is no longer based on pressure variation, but on minimum and maximum pressure of the system, which both should reach not only the discharge compensation point of emitter but also the nominal pressure of lateral line.

From the generated data set it is implied that even if a decreasing of 73% in friction losses occur into the manifold, it would not occur a variation in terms of emitters discharge due to minimum pressure value be higher than the minimum value for verifying the compensation (10 m). However, in a declivity of 5% the maximum

potential energy gain, then the maximum pressure of the entire subunit and the pressure variation becomes higher.

Nevertheless, when declivity levels are assumed as shown in Figure 1 (b), (c) and (d); the raising pressures can be even greater, which would increase the pressure variation over the pre-determined limits. Additionally, the greater is the declivity, the larger is the gap between pressures of single and double line systems at the final of manifold line.

2. Compensating emitters

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pressure is reached in the final portion of manifold whereas, if considering the declivity of 7.5%, the maximum pressure is easily attained so it makes the manifold susceptible to rupture in any portion of it.

The Figure 2 highlights the pressure performance along manifold length with compensating emitters, which outlines the same pattern of that one already shown for conventional emitters. It might be noted from Figure 2 (d) that near to distance 20 there is a coincidence between pressure reached and nominal pressure, indeed, the rupture may occurs from this point on. As verified from simulation for conventional drippers, the greater is the declivity, the more is the gap between pressures of single and double line systems at the final of manifold line.

Table 2. Values of pressure at the beginning of subunit (Hi), maximum pressure (H max), minimum pressure (H min) and friction losses into manifold (Hf) observed on the compensating emitters of the subunit when operating with both double and single lateral lines.

Slope (%)	Double line				Single line			
	Hi (m)	H max (m)	H min (m)	Hf (m)	Hi (mca)	H max (m)	H min (m)	Hf (m)
0	32.0	32.0	10.0	1.43	32.0	32.0	11.0	0.38
-2.5	31.8	31.8	10.3	6.24	31.8	35.68	11.3	1.64
-5.0	31.0	33.4	10.5	8.94	31.0	39.49	10.6	2.48
-7.5	31.0	34.4	10.6	14.58	31.0	43.50	10.8	3.96

To make assumptions about the rising pressures along the irrigation mesh as a function of the level of emitters clogging associated with engine-pump rotation, Faria et al. (2002) has simulated that a magnitude of 50% of clogging generated about 80% of the whole irrigation mesh presenting pressures higher than the original threshold pressure class of pipes when rotation was 1,750 rpm. When this was turned to 2,100 rpm, the percentage of mesh that reached pressures higher than the mentioned class was 98%. Moreover, the authors suggested that the reduction of engine-pump rotation consists of an efficient method to reduce irrigation net pressure in case of a particular necessity.

Presumably, the simulation figure of 50% on system clogging can represent the obstruction and is somewhat analogous of operating with one single line per row of tree so long the hydraulic system has been designed to work with two laterals. Thus, if there is no valve or other “intelligent” device regulating pressure variations, one could make use of the rotation reduction method as long as the pressures are monitored and do not provoke large discharge variations.

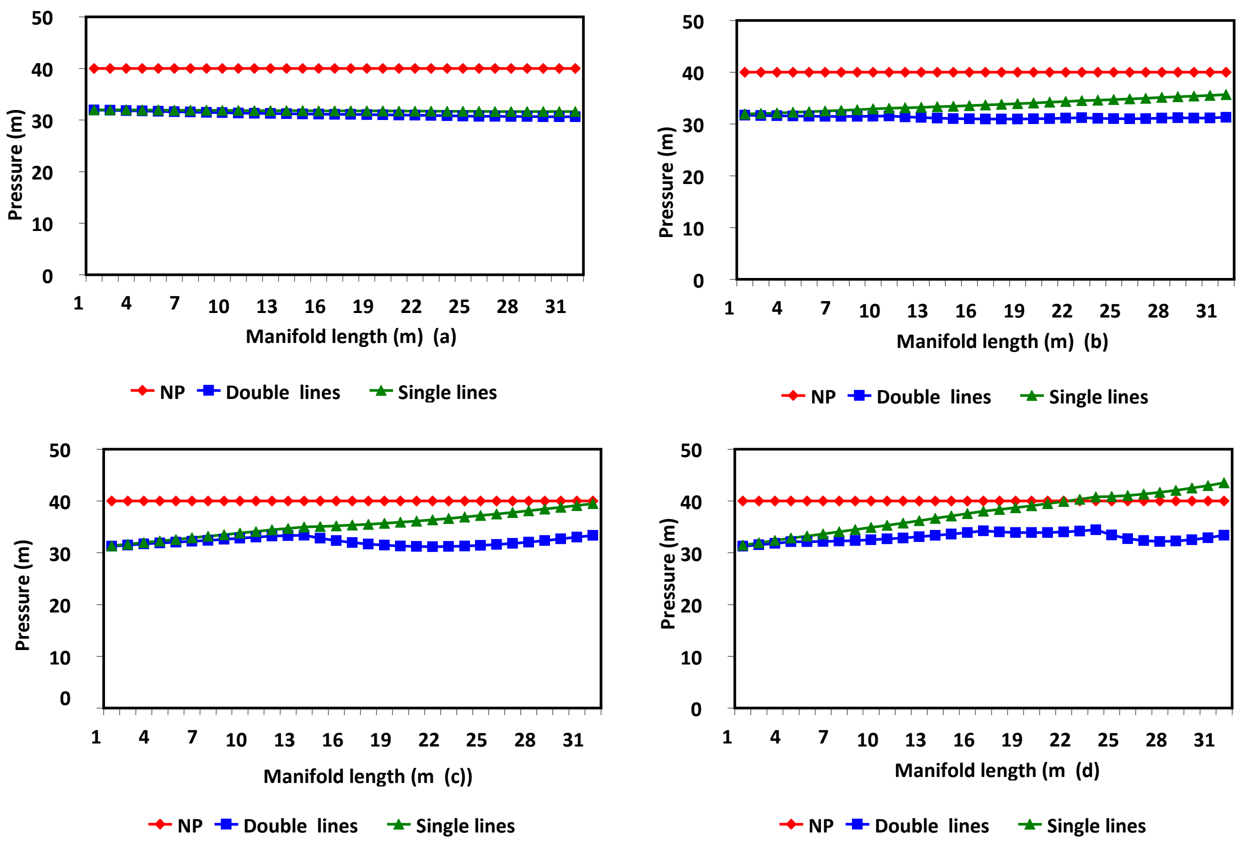

Figure 2 – Pressure performance along manifold considering compensating emitters and the slopes (a) levelled; (b) -2.5%; (c) -5.0%; and (d) -7.5%. NP: nominal pressure.

In terms of irrigation concepts applied to practice on citrus plantation of Sao Paulo State, Brazil, the increasing of pressure and pressure variation on manifold that occurs as a result of opting to use one single lateral on plantation rows, regardless of using double lines, contributes to decrease uniformity discharge emitters and hence eventually to decrease orange productivity, given that the consequent reducing wet area fraction in some cases may lead to insufficient water supply and then to increase flowering aborting percentage followed by the insufficient fruit production, as pointed by Coelho (2007). This process would be of main importance in case of an eventual farmer decision of maintaining the single lateral operating throughout all stages of the plantation due to, for example, particular economic issues. Even in case of adding the second line on later phenological stages of citrus, some plants can be negatively affected in both growth and development during the initial stages when they are submitted to one single lateral, then resulting in future production decreases. This would be actually a hypothesis made from practical observations on field and that could be scientifically tested in future works.

As shown in this work, when conventional emitters operate on double lines, but initially do it on single lines, their performance is influenced by greater downhill slopes. It is important to highlight that pressure at the beginning of lateral depends on the lateral length on field, although special attention to compensating design is required under single line operation and slope conditions to avoid overcoming nominal pressure of pipes on field.

Despite of being complex to conciliate irrigation economical analysis with aspects such as environment and income distribution, which are both essentially related to public policies, the economic interpretation fulfils a central role not only because it provide the basis for support decisions, profits and losses, but also because incorporates criteria about water use and promotes social welfare (Hellegers, 2006). Therefore, the best trade-off between productivity losses and single line operation should be performed in order to estimate the optimal feasibility of doing the latter option and then surely support this widespread and frequent decision among orange growers, although simulating the former option is not only such a difficult task of modelling but also a challenge to experiment of fields. Otherwise, encouraging entrepreneurs to improvise their own lower-cost microirrigation systems might not be the best recommendation.

CONCLUSION

The evaluation of pressure performance throughout drip systems is extremely important in irrigation designs because the pressure variation above the critical value reduces the discharge uniformity of such systems when operating with conventional emitters, although pressure variation inside manifold can occur for pipelines with both conventional and compensating. It is possible that a rupture in pipeline can occur, especially for single lines with compensating emitters under accentuated declivities (i.e., 5% or 7,5%). Hence, when the design is done assuming two laterals operating on downhill slopes, a previous hydraulic study should be done if there is an intention of maintaining only one line operating afterwards.

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