PLANNING UNIFORM SPRINKLER IRRIGATION IN PLANTATIONS WITH FLEXIBLE PLASTIC TUBES

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Solid-set sprinkler systems in plantations and orchards are becoming increasingly popular. This results from labor shortage and the demand for better control over irrigation water. Often, pressure or flow regulators are also incorporated in systems to further increase application efficiency. A number of commercial regulators are available. Recently, small diameter, flexible plastic tubes have come into use, and these replace common risers as a means of conveying water to sprinklers. Plastic tubes, when properly planned, present an alternative low-cost and efficient method of regulating pressures along laterals. The method is described and discussed in this paper.

INTRODUCTION

Solid-set sprinkler systems are characterized by stationary plastic laterals and low flow-rate sprinklers (discharging from 60 to over 200 l/h). Quite frequently such systems are also provided with automatic metering valves that shut off when a pre-set volume of water has been delivered.

Plantations designed for solid-set sprinkler systems ae commonly divided into plots that are irrigated as single units. In a typical design, a submain is placed along the center of the plot and laterals branch off to both sides. Efficient water application, according to common practice, requires that relative pressure-head variations within a plot be limited to 20% (Christiansen 1942). However, the "20% rule" is arbitrary and sometimes a figure of 30% is used.

The limitation imposed on pressure-head variations within plots can result in large diameters for laterals, particularly if these are long. To keep diameters reasonably small, pressure or flow regulators are introduced. Commercial regulators are generally installed in sprinkler risers or inside sprinkler inlets.

Recently, a number of firms have introduced small diameter, flexible plastic tubes that replace common risers in conveying water to sprinklers. Such tubes can also be used to regulate pressures to a desired level at all sprinklers along a lateral. This is done by selecting appropriate tube lengths corresponding to varying pressure heads. If, in addition, submains are designed properly, efficient and uniform water application can be expected.

The method of regulating pressures by means of plastic tubes was investigated and results are reported and discussed. The equipment described henceforth pertains to that of one particular firm ("Ein-Tal" Co. Ltd.) that was co-sponsor in the present study.

EQUIPMENT

Figure 1 depicts the equipment and its main components. A short plastic connector is inserted in a bore, pierced in the lateral wall (lateals are 16, 20 or 25 mm). The two ends of a plastic tube are respectively entered into the connector and into a plastic "head." The latter has an additional inlet for a stabilizing peg and a 1/2" threaded top for connection to the sprinkler.

Plastic tubes are 4 mm in diameter and have a standard length of 0.6 m. For the purpose of pressure regulation, tubes several meters long, at intervals of 30 cm, are available. Long tubes are made into spools in order to minimize any interference with field work.

PRESSURE VARIATIONS IN LATERALS

Tube lengths vary with pressure heads available at outlets (connectors) along a lateral. The distribution of pressure heads is affected by lateral diameter and slope, number and spacings of outlets and the pressure head and flow rate of the selected sprinkler. In this paper, level laterals only are treated. However, the method is also successfully adapted to sloping laterals.

An expression is developed to evaluate varying pressure heads at outlets. Starting at the last outlet downstream (1) the pressure head is given by

$$H_1 = H_s + H_k \quad \ldots\ldots (1)$$

where

H_1 = pressure head at the last outlet downstream (m);
H_s = pressure head of the selected sprinkler (m); and
H_k = head loss in a standard tube 0.6 m long (m).

Proceeding towards the first outlet upstream (n) pressure heads at subsequent outlets are computed by adding up the head loss in successive pipe-sections between adjacent outlets. This head loss, assuming outlets are spaced S meters apart, is evaluated from

$$H_f = K\,Q^{1.76} \quad \ldots\ldots (2)$$

where

H_f = head loss in a soft polyethylene pipe (m);
$K = \dfrac{8.323 \times 10^4\, S}{D^{4.76}}$
D = inside diameter of pipe (mm); and
Q = flow rate in pipe (m³/h). (Israel Institute of Standards 1969).

Since all sprinklers discharge a constant flow rate Q_s along a pressure-regulated lateral, Q in equation 2 takes on values of Q_s, $2Q_s$ and up to $(n\text{-}1)\,Q_s$.

It can be simply shown that the expression for pressure head H_m at the m^{th} outlet is given by

$$H_m = H_1 + K\,Q_s^{1.76}\,T_m = H_1 + H_f(m) \quad \ldots (3)$$

where

$T_m = 1 + 2^{1.76} + \ldots\ldots + (m\text{-}1)^{1.76}$;
$m = 1, \ldots, n$; and
$H_f(m)$ = cumulative head loss to outlet m(m).

Computed pressure heads H_m are reduced to a constant value H_s, which is the head of the selected sprinkler. This is achieved by selecting appropriate tube lengths, for which head losses are known. For a level lateral, tubes start with the standard length downstream. Moving upstream tubes increase in length with pressure heads.

The term $H_f(m)$ in equation 3 can be further simplified. If $H_f(t)$ is the total head loss in a lateral then, assuming the first spacing upstream to be $S/2$, the ratio $H_f(m)$ to $H_f(t)$ is given by

$$\frac{H_f(m)}{H_f(t)} = \frac{H_m - H_1}{(H_n + H_{n+1})/2 - H_1} \quad \ldots\ldots (4)$$

from which

$$H_f(m) = \frac{2T_m}{T_n + T_{n+1}}\, H_f(t) \quad \ldots\ldots (5)$$

where

$$T_n = 1 + 2^{1.76} + \ldots\ldots + (n-1)^{1.76}.$$

The ratio $2\,T_m/T_n + T_{n+1}$ is dependent on n only and tables can be easily prepared. Table I shows values of the ratio for $n = 10$.

The head loss $H_f(t)$ in a lateral can be computed by first assuming the inlet discharge to flow downstream and then multiplying by a factor F, depending on n.

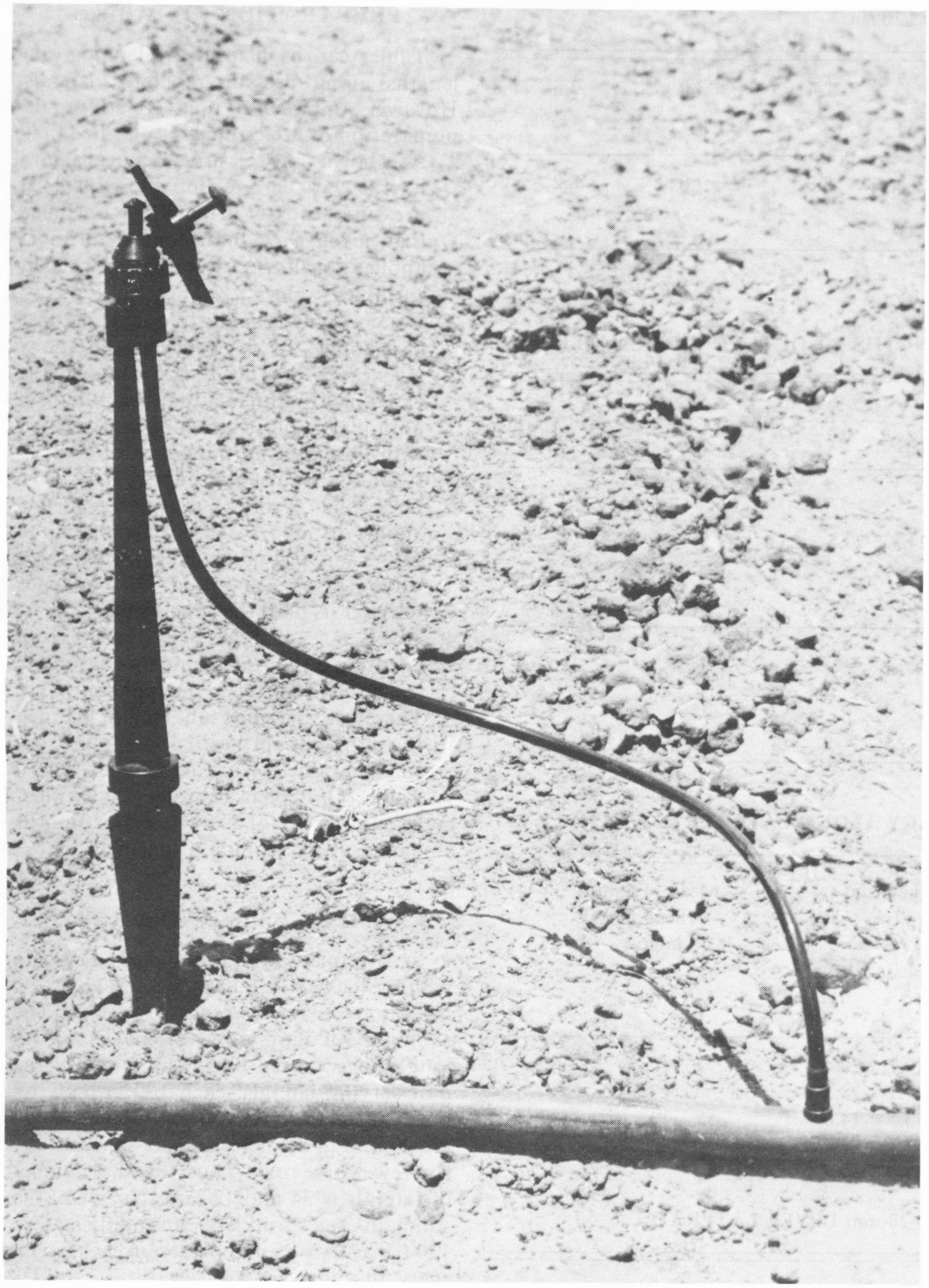

Figure 1. "Ein-Tal" equipment with standard plastic tube.

TABLE I. VALUES OF $2T_m/T_n + T_{n+1}$ FOR n = 10

Outlet no.	10	9	8	7	6	5	4	3	2	1
Ratio	0.86	0.63	0.45	0.30	0.19	0.11	0.05	0.02	0.00	0.00

TABLE II. VALUE OF H_k FOR A STANDARD TUBE

Q_s (l/h)	70	100	120	140	160	180	200	220
Hk (m)	0.9	1.7	2.2	2.9	3.6	4.5	5.5	6.5

Nomographs and slide rules simplify the procedure.

Equation 5 can be used to quickly obtain values for $H_f(m)$. The term $H_f(t)$ in the equation also indicates in practice whether pressure regulation is required.

The pressure head required at lateral inlet H_u is derived from

$$H_u = H_1 + H_f(t) \quad \ldots\ldots (6)$$

To evaluate H_1 the head loss H_k in a standard tube (0.6 m long) must be known. Table II shows values for H_k at various flow rates.

HEAD LOSSES IN PLASTIC TUBES

Head losses in tubes of varying length were evaluated in a laboratory over a range of flow rates. Table III presents head losses in tubes up to 3.6 m long for Q_s = 120 l/h (for pressure regulation tube lengths are actually available at intervals of 30 cm). Long tubes, made into spools, do not produce any changes in head losses.

EXAMPLE 1: PLANNING TUBE LENGTHS

A soft polyethylene level lateral, 20 mm in diameter is planned for 10 sprinklers spaced 10 m apart. The selected sprinkler applies 120 l/h at H_s = 20 m. Relative pressure-head variations along the lateral are to be limited to 20%.

Total head loss in the lateral $H_f(t)$ is evaluated as 6.9 m. This is in excess of the allowable 20% and pressure regulation is required. Using Table I in conjunction with equation 5, values of $H_f(m)$ are computed. These are substituted in equation 3 and, using H_1 = 20 + 2.2 = 22.2 m, pressure heads H_m result, as shown in Table IV, row 2.

To plan tube lengths, H_s = 20 m is subtracted from all H_m values and results are compared with Table III. Tube lengths are recorded in Table IV, row 3. Finally, a pressure head H_u = 22.2 + 6.9 = 29.1 m is required at the lateral inlet.

ACCURACY OF THE METHOD

The lateral in the above example was placed on a level field and a pressure head H_u = 29 m was applied upstream. Measurements of pressure head were then made at selected sprinklers, as shown in Table V, row 1. It is evident that pressure regulation is very effective.

Several additional laterals, both level and sloping, were planned for pressure regulation and tested for accuracy. The efficiency of the method was verified in all cases (this was also true after experimenting for over 2 yr under extreme climatic conditions). Maximum pressure-head variations observed in single tests were limited to 1.5 m.

A lemon plot was also planned using tubes varyig in length from 0.6 m to 3.0 m at intervals of 60 cm. During the irrigation season, pressure heads were measured at

TABLE III. HEAD LOSSES IN TUBES FOR Q_s = 120 l/h

Tube length (m)	0.6	1.2	1.8	2.4	3.0	3.6
Head loss† (m)	2.2	3.4	4.6	5.8	7.0	8.2

†Head loss in connectors is included.

TABLE IV. PRESSURE HEADS AND TUBE LENGTHS AT OUTLETS IN EXAMPLE 1

(1)	Outlet no.	10	9	8	7	6	5	4	3	2	1
(2)	Computed pressure heads at outlets (m)	28.1	26.5	25.3	24.3	23.5	23.0	22.5	22.3	22.2	22.2
(3)	Planned tube lengths (m)	3.6	2.7	2.1	1.5	1.2	0.9	0.6	0.6	0.6	0.6

TABLE V. RESULTS OF TESTS FOR ACCURACY ALONG LATERAL IN EXAMPLE 1

	Pressure head at lateral inlet (m)	Measured pressure heads at selected sprinklers (m)					Mean pressure head in lateral (m)
		10	8	6	3	1	
(1)	29.0	20.2	20.8	19.8	19.7	20.4	20.2
(2)	40.0	28.0	28.3	27.4	27.1	28.3	27.8
(3)	20.0	13.7	14.1	13.5	13.5	14.0	13.8

TABLE VI. PLANNED TUBE LENGTHS FOR A 20-mm LEVEL LATERAL

S	Outlet no.																	
(m)	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
10						6.6	5.4	4.2	3.6	2.7	2.1	1.5	1.2	0.9	0.6	0.6	0.6	0.6
8					6.6	5.4	4.8	3.9	3.0	2.4	1.8	1.2	1.2	0.9	0.6	0.6	0.6	0.6
6			7.2	6.0	5.1	4.2	3.6	3.0	2.4	1.8	1.5	1.2	0.9	0.9	0.6	0.6	0.6	0.6
5		7.2	6.0	5.1	4.2	3.6	3.0	2.4	2.1	1.8	1.5	1.2	0.9	0.6	0.6	0.6	0.6	0.6
4	7.2	6.0	4.8	4.2	3.6	3.0	2.4	2.1	1.8	1.5	1.2	0.9	0.9	0.6	0.6	0.6	0.6	0.6

several locations. Although the plot was triangular and of undulating topography, practically all sprinklers performed within a 15% range of the mean pressure head. Results would be expected to improve had tubes been planned at length intervals of 30 cm.

An important feature of the method is that any changes in pressure head at lateral inlets bring about proportional changes at all sprinklers. This is seen in Table V, rows 2 and 3. Thus, accuracy of the method is retained regardless of pressure fluctuations at field inlets. This stands out particularly when inlet pressure heads drop to a level at which some common regulators stop functioning properly. However, automatic metering valves must be provided to control the application of correct water requirements.

PREPARATION OF TABLES

Tables can be helpful in planning tube lengths along pressure-regulated laterals. However, a number of points relative to the preparation of tables must be clarified first.

1. As shown above, pressure heads in a lateral vary proportionally with inlet pressure heads. It is therefore concluded that, given D, n and S, one set of tubes applies to all H_s values of a particular sprinkler.
2. For constant D, n and S, one set of tubes also applies to all Q_s discharged at any given pressure head H_s. This can be explained by the fact that head losses in both plastic pipes and tubes vary closely with flow rates to the power of 1.76.
3. It follows from 1 and 2 above that, given D, n and S, one set of tubes in fact applies to all Hs and corresponding Q_s values for various available sprinklers. A value Q_s = 120 l/h at H_s = 20 m is selected to plan the tube lengths.
4. Given D, S and Qs, it is evident from equation 3 that the cumulative head loss to the m^{th} outlet is independent of n. Therefore, the same tube lengths planned for a maximum desired n apply to all smaller values of n.

Table VI depicts tube lengths (with a maximum 7.2 m) for a level lateral, 20 mm in diameter, at five common spacings.

EXAMPLE 2: PLANNING A PLOT

A level plantation is designed to comply with the "20% rule". The plot is 200 m X 100 m and trees are spaced 6 m X 5 m. The submain (of hard polyethylene) is 100 m long and is placed along the center of the plot serving laterals, each 100 m long, on both sides. Laterals (of soft polyethylene) are 20 mm in diameter and are spaced every 6 m (every tree row). Thus, the total number of laterals is 34 and 17 on each side of the submain. Ten sprinklers, each applying Q_s = 120 l/h at H_s = 25 m, operate on each lateral every 10 m (every two trees).

Using nomographs, a head loss of 6.9 m is evaluated along a lateral. Exceeding the allowable (5 m), this necessitates pressure regulation. A look at Table VI reveals that the following tubes are to be used (see also example 1 above): 1 X 3.6 m, 1 X 2.7 m, 1 X 2.1 m, 1 X 1.5m, 1 X 1.2 m, 1 X 0.9 m and 4 X 0.6 m. Substituting H_s = 25m, H_k = 2.2 m (see Table II) and $H_f(t)$ = 6.9 m in equation 6 a pressure head H_u = 34 m is required at the lateral inlet.

The submain is also planned as a multiple-outlet pipe, with inlet-flow rate of 34 X 10 X 0.12 = 40.8 m³/h. A diameter of 75 mm is selected and the head loss is 3.5 m. Consequently lateral-inlet pressure heads along the submain vary from 34 m downstream to 37.5 m upstream.

It has been established that pressure heads H_s in laterals vary proportionally with pressure heads at inlets. Therefore, H_s in the first lateral upstream is evaluated from

$$H_S = 37.5 \times \frac{25}{34} = 27.6\ m$$

Thus, values of H_S between extreme laterals vary by 2.6 m. Also, pressure heads along a lateral are assumed to vary by 1.5 m at the most, relative to H_S. Therefore, pressure-head variations over the whole plot are limited to 4.1 m. This satisfies the "20% rule" with 0.9 m to spare.

The pressure head required at field inlet is 40 m, including local head losses. However, the system will operate efficiently if available heads vary from 40 m.

CONCLUSIONS

A method of pressure regulation in laterals by means of plastic tubes of varying length was described and discussed. Uniform water application can be expected if tube lengths and submain diameters are planned properly, as shown above.

The method of pressure regulation as presented has a number of advantages. These are summarized below.

1. The equipment is simple, low-cost and with relatively large passages of flow that diminish the risk of clogging.
2. Pressure regulation is accurate and effective irrespective of pressure fluctuations at field inlets.
3. Pressure-regulating tubes can be used to place sprinklers at varying heights above the ground and thus protect young, growing plants against frost or severe heat.
4. Pressure-regulating tubes can be used to operate sprinklers at any desired distance from trees. This may become important when using mini-sprinklers (one or two per tree) that only partially wet the soil surface.
5. The method can also be successfully adapted to greenhouses, small vegetable tracts, gardens and lawns.

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