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Full Length Research Paper

Lateral-pipe layout design in fixed-pipeline sprinkler irrigation systems

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The lateral pipes in traditional fixed-pipeline sprinkler irrigation systems are usually the terminal pipes and are configured in a single-pipe longitudinal arrangement without further branching. All of the sprinkler heads are evenly distributed along each branch. However, conventional systems have a high-density sprinkler lateral-pipe layout, which leads to increased costs for fixed pipeline sprinkler irrigation systems. To lower the density of the pipeline layout and decrease the associated cost, we proposed a new type of lateral-pipe layout. Half of the original branches in a conventional layout were alternately removed, but the positions of the sprinkler heads on the original branches remained unchanged. The new layout was compared with the conventional design according to the lateral-pipe layout density and the amount of pipe material that was required. The results indicate that the new layout reduced the density of the lateral pipes.

Key words: Irrigation, lateral pipe, layout, cost efficient.

INTRODUCTION

Sprinkling is an important method of agricultural irrigation and had its beginnings in the early part of the 20th century. Sprinkler irrigation is an adaptable means of supplying all types of crops with frequent and uniform applications of irrigation over a wide range of topographic and soil conditions. Sprinkle irrigation can be partly or fully automated to minimize labor costs, and systems can be designed to minimize water requirements. Sprinkle irrigation can be broadly divided into set and continuous-move systems. In set systems, the sprinklers remain at a fixed position while irrigating. The set systems include periodic-move systems and fixed systems. A fixed sprinkler system has enough lateral pipe and sprinkler heads so that none of the laterals need to be moved for irrigation purposes after being placed in the field (Bliesner and Keller, 2001). Therefore, the pipeline layout is an important factor in the cost of the irrigation system.

Extensive research has been conducted on pipeline layouts in irrigation systems and has primarily focused on the optimization of the pipe networks. Optimization methods used include graph-theoretic methods (Xuezhen et al., 1995), linear programming (Throcharis et al., 2005; Lei and Luo, 2010), analytic hierarchy processes (Liu et al., 1999), artificial neural networks, and genetic algorithms (Zhou and Lin, 2001).

Some researchers have conducted comparative studies on the investment, energy consumption and operating costs associated with various types of pipeline sprinkler irrigation systems, including Rodríguez et al. (2009), Moreno et al. (2010), and Theocharis et al. (2010, 2005).

Some researchers have conducted studies on the design of irrigation networks under special conditions of wind and water supply. Zapata et al.（2007）introduced a contribution to the design of collective pressurized irrigation networks in solid-set sprinkler-irrigated windy areas. Dobersek and Goricanec (2009) developed the

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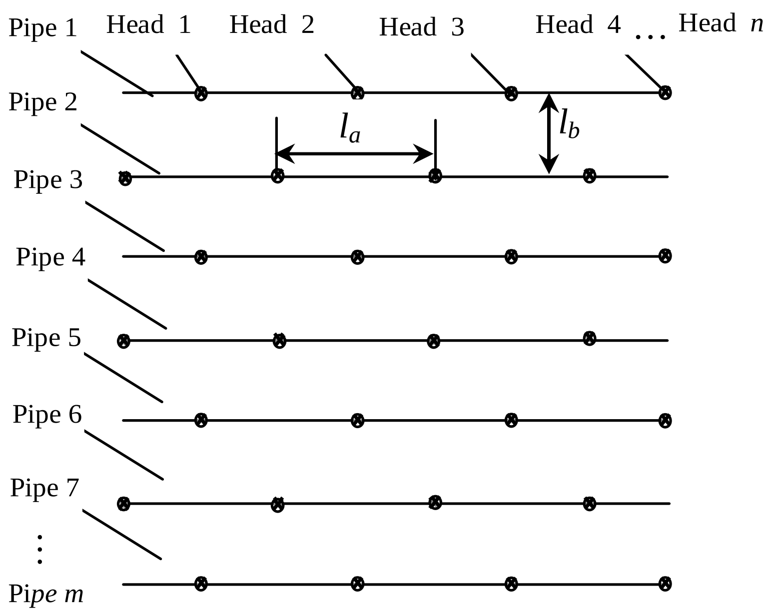

Pipe 1, 2, 3, …, *m*: Lateral pipes numbered 1, 2, 3, …, *m*;
Head 1, 2, 3, …, *n*: Sprinkler heads numbered 1, 2, 3, …, *n*
l_a: spacing interval between the sprinkler heads
l_b: spacing interval between the lateral pipes

Figure 1. Conventional lateral layout.

optimization of pipe network with hot water is presented.

Most research mentioned above based on a pipe layout with sprinkler heads set all ways along the lateral. In this study, in order to reduce the investment of pipeline, we proposed a new lateral-pipe layout with the sprinkler heads set alternatively along the lateral. The comparison of investment for this design was done with a conventional pipeline layout.

MATERIALS AND METHODS

Lateral-pipe layout design

In a conventional fixed pipeline sprinkler irrigation system, the lateral pipes are usually the terminal pipes and are configured in a single-pipe longitudinal arrangement without further branching. The sprinkler heads are all evenly distributed on each branch, as shown in Figure 1. This arrangement is a high-density sprinkler lateral-pipe layout, which may contribute to the high costs associated with fixed-pipeline sprinkler irrigation systems.

Figure 2 shows a diagram of the modifications to the lateral-pipe layout of the original fixed-pipeline sprinkler irrigation system. Pipes 2, 4, 6, … (pipes in even number) from Figure 1 were removed from the original arrangement of the fixed-pipeline sprinkler system (for those arrangements with more lateral pipes, the even numbered lateral pipes are removed), and pipes 1, 3, 5, 7, …, (pipes in odd number) remained. The sprinkler heads that were on the removed pipes in even number were retained, and their positions were not altered. One end of the short perpendicular pipes that were added was connected to the sprinkler heads on pipes in odd number; the other ends of these short pipes were connected to the corresponding sprinkler heads that had been disconnected from pipes in even number. The ends of these short pipes were connected to the corresponding sprinkler heads that had been removed from pipes in even number. This layout design changed only the connections of the water-supply pipes in the irrigation system, and the original sprinkler head layout remained unchanged. The objective of the new layout was to reduce the lateral-pipe layout density in a fixed pipeline sprinkler irrigation system and therefore decrease the setup-cost of the system.

Comparison of lateral-pipe layout densities

Mathematical inference was used to demonstrate that the proposed lateral-pipe layout decreased the pipe layout density. The lateral-pipe layout density was calculated from the total length of the lateral pipes and short perpendicular pipes within a certain controlled irrigation area.

The lateral pipes in the conventional layout were designated as pipe A, the horizontal pipes in the new layout (the layout design of the lateral pipes in Figure 2 is used as an example) were called pipe B, and the perpendicular short pipes were called pipe C. Therefore, as for half of the lateral pipes have removed, the amount of pipe A is double that of pipe B.

The number of lateral pipes in the conventional layout was set as m (m = 1, 2, 3, …), the number of sprinkler heads on each lateral pipe was set as n (n = 1, 2, 3, …), the spacing interval between the sprinkler heads was l_a, and the spacing interval between the lateral

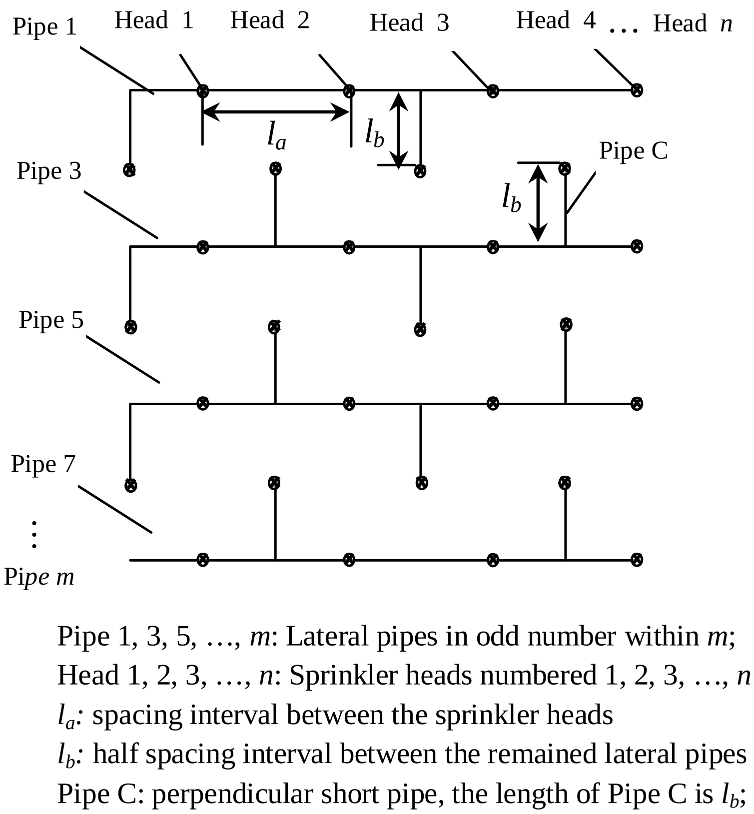

Figure 2. New lateral layout.

pipes was l_b. When the number of sprinkler heads and the span of the sprinkler arrangement were determined, l_a and l_b were calculated, and m and n were then determined after the shape and area of irrigated land were chosen.

For the fixed-pipeline sprinkler irrigation system, the length of each lateral pipe is $(n\text{-}1)l_a$. Therefore, the total length of pipe A, L_A, within a certain controlled irrigation area was determined as the following:

$$L_A = m(n-1)l_a \tag{1}$$

In the same controlled irrigation area, half of the total lateral pipes will be remained. Therefore, the total length of pipe B, L_B, was determined as the following:

$$L_B = \tfrac{1}{2}m(n-1)l_a \tag{2}$$

The pipe C will be installed on each remained lateral pipe in the middle position of two sprinkler heads. Therefore, the number pipe C is n-1 in each remained lateral pipe. The length of each pipe C is l_b. The total length of pipe C, L_C, was the following:

$$L_C = \tfrac{1}{2}m(n-1)l_b \tag{3}$$

Within the same controlled irrigation area, the reduction rate, ε, of the total length of the lateral pipes and perpendicular pipes in the new layout, relative to the conventional layout, was calculated as follows:

$$\varepsilon = \frac{L_A - L_B - L_C}{L_A} \times 100\% \tag{4}$$

The total lengths of pipes A, B, and C were introduced into equation (4) to obtain the following:

$$\varepsilon = \frac{l_a - l_b}{2l_a} \times 100\% \tag{5}$$

Comparison of the amount of consumed pipe materials

The amount of pipe materials consumed was determined using the diameter, length, and wall thickness of the pipes, which can be calculated by the following equation:

$$V = L\pi Dd \tag{6}$$

where V is the amount of pipe materials consumed, L is the length of the lateral pipes, D is the diameter of the pipes, and d is the wall thickness of the pipes.

According to the biaxial stress formula of material mechanics (James et al., 2011), the wall thickness of the pipes was calculated as follows:

$$d = \frac{DP}{2[\sigma]} \quad (7)$$

where $[\sigma]$ is the allowable stress and P is the pressure in the lateral pipe. The introduction of equation (7) into equation (6) resulted in the following:

$$V = \frac{\pi}{2[\sigma]} LD^2 P \quad (8)$$

The pipe diameter was determined according to the flow rate in the lateral pipes (Gregory, 2011), and the relationship between these two variables is as follows:

$$D = 2\sqrt{\frac{Q}{\pi v}} \quad (9)$$

where Q is the flow rate in the pipes and v is the flow speed. In addition, according to the flow speed and pressure in the pipes (Gregory, 2011), we obtained the following:

$$v = \sqrt{\frac{2g}{\xi} P} \quad (10)$$

where ξ is the coefficient of resistance for the lateral pipe. Equations (10) and (9) were introduced into equation (8) to obtain the following:

$$V = \frac{2}{[\sigma]\sqrt{\frac{2g}{\xi}}} LQ\sqrt{P} \quad (11)$$

Given;

$$k = \frac{2}{[\sigma]\sqrt{\frac{2g}{\xi}}} \quad (12)$$

Then,

$$V = kLQ\sqrt{P} \quad (13)$$

The above equation indicates that the following factors affect the amount of pipe material consumed: lateral pipe length, flow rate, and pressure.

The lateral pipes in the conventional layout were referred to as pipe A, and the flow rate for this system is the following:

$$Q_A = nq_0 \quad (14)$$

where q_0 is the flow rate of each single sprinkler and n is as described above. The pipes in the new layout were referred to as pipes B and C, and their respective flow rates were defined as shown below.

$$Q_B = 2nq_0 \quad (15)$$

$$Q_C = q_0 \quad (16)$$

The respective pressures in pipes A, B, and C were the following:

$$P_A = np_0 \quad (17)$$

$$P_B = 2np_0 \quad (18)$$

$$P_C = p_0 \quad (19)$$

Where p_0 is the pressure of each single sprinkler and n is as described above.

Equations (1), (14), and (17) were introduced into equation (13) and simplified to yield the amount of consumed pipe material, V_A, for pipe A.

$$V_A = kl_a mn(n-1)q_0\sqrt{np_0} \quad (20)$$

Equations (2), (15), and (18) were introduced into equation (13) and simplified to yield the amount of consumed pipe material, V_B, for pipe B.

$$V_B = \sqrt{2}kl_a mn(n-1)q_0\sqrt{np_0} \quad (21)$$

Equations (3), (16), and (19) were introduced into equation (13) and simplified to yield the amount of consumed pipe material, V_C, for pipe C.

$$V_C = \tfrac{1}{2}kl_b m(n-1)q_0\sqrt{p_0} \quad (22)$$

The increase in the rate of pipe material consumption for the new layout, when compared with the conventional layout, was set as δ.

$$\delta = \frac{V_B + V_C}{V_A} \quad (23)$$

Equations (20), (21), and (22) were introduced into equation (23) and simplified to obtain the rate of increase of the consumed pipe materials δ.

$$\delta = \sqrt{2} + \frac{\sqrt{n}}{2n^2}\frac{l_b}{l_a} \quad (24)$$

RESULTS AND DISCUSSION

When the sprinkler heads were in an equilateral triangular arrangement, we calculated $l_b = \frac{\sqrt{3}}{2} l_a$, which was then introduced into equation (5) to produce a reduction rate, ε, of 7% of the total pipe length, meaning that the lateral-pipe layout density was reduced by 7%. If the number of sprinkler heads on each lateral pipe was set as $n = 10$, the rate of increase of pipe material consumption for the new layout δ, when compared with the conventional layout, was approximately 142.8% , according to equation (24). If the number of sprinkler heads on each lateral pipe was set as $n = 4$, δ was approximately 146.8%.

When the sprinkler heads were configured in an isosceles triangular arrangement, such that $l_a = 2l_b$, the reduction rate, ε, of the total pipe length calculated using equation (5) was 25%, meaning that the lateral-pipe layout density was reduced by 25%. Therefore, in the new lateral-pipe layout, the reduction rate of the lateral-pipe layout density was greater with increased spacing intervals between the lateral pipes. If the number of sprinkler heads on each lateral pipe was set as $n = 10$, δ was approximately 142.2% according to equation (24). If the number of sprinkler heads on each lateral pipe was set as $n = 4$, δ was approximately 144.5%.

Therefore, the rate of increase, δ, of pipe material consumption for the new layout when compared to the conventional layout, increased both with an increase in the ratio of the spacing interval between lateral pipes to the spacing interval between sprinkler heads and with a decrease in sprinkler heads on each lateral pipe. However, the value of δ only changed slightly with changes in the ratio of the spacing interval between lateral pipes to the spacing interval between sprinkler heads and the number of sprinkler heads on each lateral pipe. The value of δ was always greater than 141.4%, regardless of the number of lateral pipes.

The positive rate of increase, δ , of pipe material consumption for the new layout relative to the conventional layout, was primarily due to the increased number of sprinkler heads on the lateral pipes, leading to a higher flow rate and larger pipe diameter; δ can be lowered by changing the pipe diameter.

CONCLUSIONS

To decrease the pipe layout density and lower the investment cost of fixed-pipeline sprinkler irrigation systems, we proposed a new layout design for lateral pipes. In this new layout, half of the original lateral pipes were alternately removed, and the positions of the sprinkler heads on the original branches remained unchanged. Perpendicular short pipes were added between the sprinkler heads on the remaining lateral pipes and the sprinkler heads that were originally connected to the removed branches to supply water to the sprinkler heads originally connected to the removed branches. The new layout method reduced the lateral-pipe layout density. The rate of reduction in lateral-pipe layout density in the new design increased as the spacing interval between lateral pipes was increased. The new layout design increased the amount of pipe materials used The results of this study provide a new lateral-pipe layout design for fixed-pipeline sprinkler irrigation systems and provide new strategies for lowering the investment cost of pipeline sprinkler irrigation systems.

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