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Full Length Research Paper

Theoretical and experimental study for rectangular spraying

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The use of rectangular spraying can reduce the water and energy requirements in variable pressurized irrigation system. The water application cost can be minimized in rectangular spraying after theoretical analysis. The aim of this study was to achieve rectangular spraying by variable pressures of the pump. Experiments were carried out on a turbo-type whirling sprinkler to determine the spraying effect. Water distribution by the sprinkler was evaluated in an indoor facility. The three-dimensional water distribution figure was drawn using Matrix Laboratory (MATLAB). The result demonstrated that rectangular spraying can be achieved.

Key words: Rectangular spraying, sprinkler, wetted radius.

INTRODUCTION

Sprinkler irrigation is characterized by high potential irrigation efficiency (Clemmens and Dedrick, 1994). In the course of development of sprinkler irrigation technology, a broad range of solutions has been applied to improve irrigation processes from the technical, organizational, and economic point of view. A sprinkler irrigation system represents one of the most common types of irrigation system. In many areas, the water and energy required for irrigation are scarce; hence, sprinkler irrigation systems must apply water with less energy consumption. This generally requires an improvement in the application of water (Martin-Benito et al., 1992).

One of the most important factors in the operation of sprinkler irrigation systems is the spaying effect of the distribution of water over a field. The most common shape is the circular spraying. Non-circular spraying sprinkler was discovered in 1927 by Donald (Donald, 1927). James and La (1952) developed a reaction sprinkler with adjustable rotational speed. Charles (1977) invented a center pivot irrigation system of rectangle spraying. For an historical note on Edwin's discovery (Edwin, 1982). Since Edwin's discovery, the phenomenon has been studied widely, both experimentally and theoretically. Ohayon (2000) realized the automatic control function of flow-rate and pressure in impact sprinkler. Zhu et al. (2002) studied the variable irrigation flow controls. Han (2003) studied the variable rate watering and contour controlled precision sprinkler. Wallender (2007) suggested water-related research on sustainability.

The research of non-circular spraying began 1920s abroad and 1990s in China. It is a new type sprinkler which was developed for avoiding overlapping or leaking in the irregular parcel. However, when the sprinkler was working, either restricting flow or changing the elevation of pipeline was used to change the irrigated wetted radius. There were a few drops for pressure head, and the energy was wasteful. In order to attach the target of saving water and saving energy together, the frequency control technology was brought into the sprinkler irrigation system. One of the main tasks of irrigation research is to find new ways to minimize energy and water use in irrigated agriculture through experimentation.

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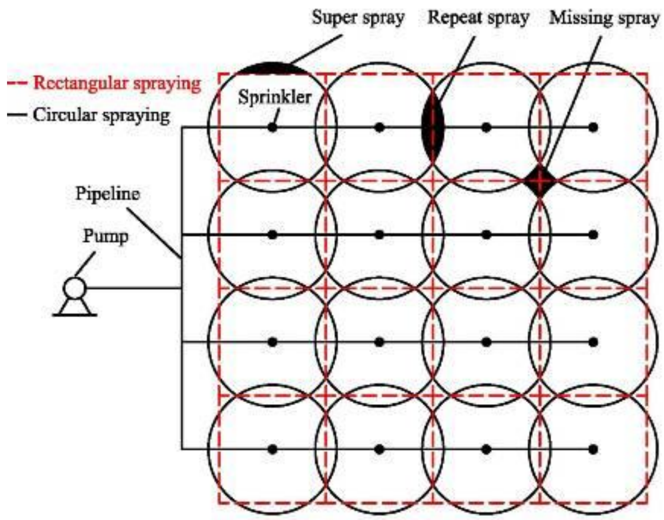

Figure 1. Water applications in circular and rectangular spraying sprinklers.

Figure 2. Frequency inverter.

The objective of this study was to achieve rectangular spraying.

Analysis of water application cost

The precision agriculture has been become the important way of modern agricultural production. According to the characteristics of the agricultural development, the technological system of water-saving precision agriculture should be developed in the near future. Under the conditions of assuring the correct hydraulic performance, the water application cost with sprinkler irrigation includes investment costs (pumping, pipes, and sprinklers), energy, labor, maintenance, and the water cost. Neither labor nor maintenance is taken into account, because they are similar for all the different subunit designs. Some research (Ortega et al., 2004) shows the great influence of the number of sectors and their size on investments costs. On the other hand, they also indicate the small effect of the application rate or uniformity on these costs.

The water application cost in a sprinkler irrigation subunit, understood as the cost of cubic meter of water added to soil for crop use, have been determined as the sum of the investment costs, energy costs, and the water costs. Water application costs in a sprinkler irrigation subunit are conditioned by factors such as sprinkler layouts, subunit size, and working pressure (Tarjuelo et al., 1999). To analyze the design of subunits to minimize the water application cost, it is necessary to consider the influence of those factors (Lunk et al., 2010).

A subunit formed by a pump at one end, some pipelines, and several laterals (Figure 1) has been designed. Circular and rectangular spraying sprinklers were proposed in this work. For the comparisons, the cost of taking water to the inlet of the subunit has been estimated. Pumping costs from the water source, transport water costs for the network of pipes. For the same subunit, the investment and energy costs are similar both for them.

Figure 1 shows the water applications in circular and rectangular spraying sprinklers. As shown in Figure 1, combination of circular spraying sprinklers will arise the problems of super spray, repeat spray, and missing spray. The whole field can be sprayed well in the combination of rectangular spraying sprinklers, and the water application cost can be minimized.

EXPERIMENTS

The experimental setup was designed and constructed at the Indoor Sprinkling Laboratory, Jiangsu University, China (Fraisse et al., 1995). The laboratory is circular with a diameter of 44 m. A centrifugal pump supplied water to the irrigation system from a reservoir maintained at a constant level. The pump was driven by a variable speed motor with control panel (King and Wall, 2000). Figure 2 shows the photo of the common Mitsubishi frequency inverter, typed FR-F740-0.75K～55K-CHT1. The speed of pump was changed by the instruction of the inverter. To minimize pressure variation by the pump, an air vessel and subsequent settling chamber were put in the line between the delivery side of the pump and the bottom of the riser. The frequency inverter was controlled by the virtual instruments (Figure 3).

Figure 3 shows the photo of the virtual instruments, sending out the orders the frequency inverter needed. For the instruments, combined with the hardware, the software was developed in the program of LabView. It contains the front and back panels of data acquisition module, which is shown in Figures 4 and 5, respectively. The sprinkler being tested was the turbo-type whirling sprinkler. The sprinkler had one nozzle 4 mm. The nozzle size was chosen because it is the standard one according to the manufacturer. The collectors were cylindrical and had a sharp-edged round opening of 200 mm diameter and 600 mm height. The single-leg test was conducted, and the center-to-center spacing of the collectors was 1 m in the direction of the radius of the wetted circle. The sprinkler being tested was placed on a riser with an inner diameter of 20 mm and a 1.4 m height above ground and approximately 800 mm above the collector tops. The test duration was 1 h for every pressure (Sharda et al., 2010; Fulton et al., 2005a). The flow rate through the riser (that is, through the nozzle of

Figure 3. Virtual Instruments.

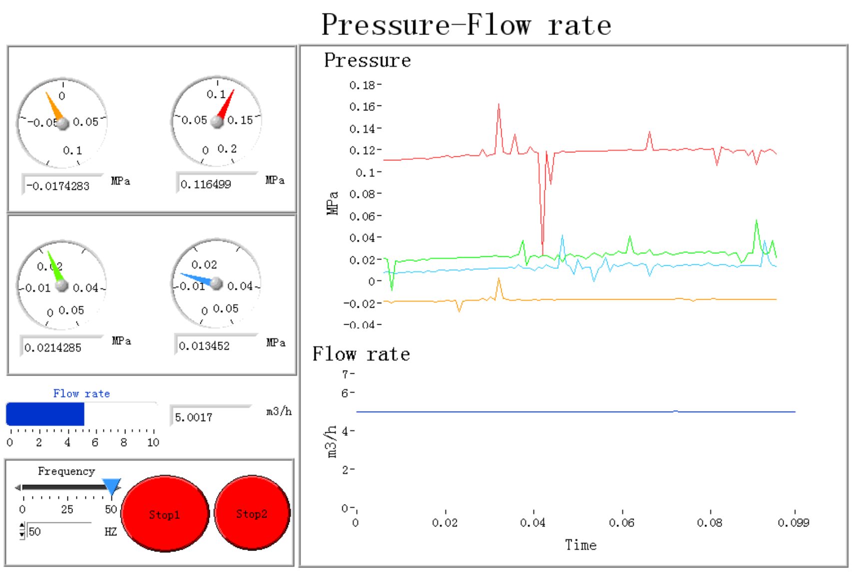

Figure 4. Front panel of data acquisition module.

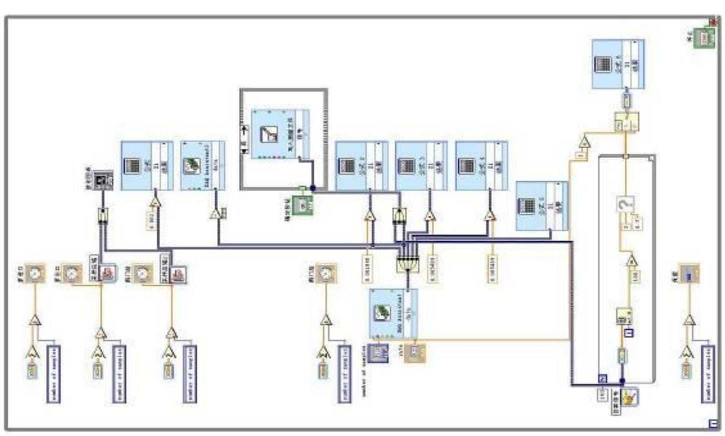

Figure 5. Back panel of data acquisition module

Table 1. Measured data of water distribution.

Degree	Working pressure (kPa)	Flow rate (m^3h^{-1})	Distance from the sprinkler (m)	0	1	2	3	4	5	6	7	8	9	10	11
0°	132	0.61	Depth of water distribution/mm	1.3	1.7	2.6	2.5	2.2	2.1	3.8	0.3	0	0	0	0
25°	146	0.78		1.9	2.3	3	2.5	2.2	1.9	2	3.3	1.4	0	0	0
45°	195	0.87		3.0	3.5	3.8	3	2.7	2.5	2.2	2.3	2.8	2.1	0.3	0

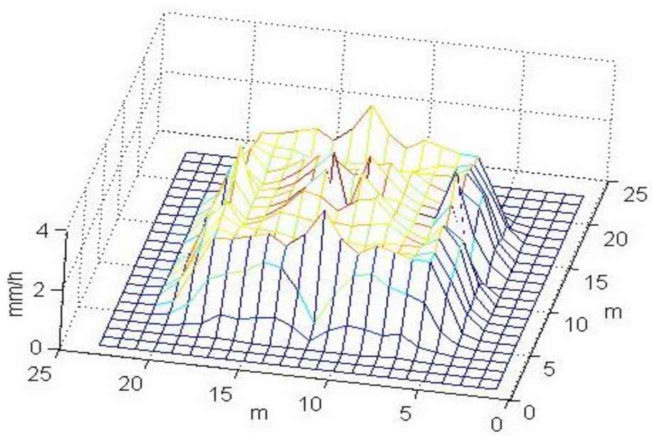

Figure 6. Three-dimensional water distribution of the sprinkler.

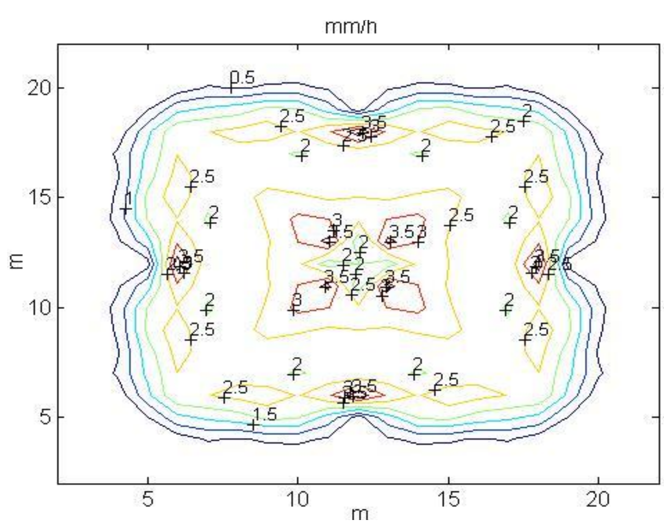

Figure 7. Water distribution contour of the sprinkler.

the sprinkler head) was measured using a calibration tank and stopwatch. The water temperature was measured during the course of the test by a thermometer placed in the main tank. The relative humidity and ambient temperature were also measured during the course of the test. This procedure was chosen to decrease the effect of liquid splashing. To determine the sprinkler water distribution radial profile in no-wind conditions, the following standards were adopted: American Society of Agricultural Engineers (ASAE) S.330.1 (1985); ASAE S.398.1 (1985). A total of 14 useful tests were conducted to study the water distribution of the sprinkler.

RESULTS AND DISCUSSION

The rectangular spraying can be achieved by the experimental setup mentioned above. In the experiment, the maximal wetted diameter for the sprinkler was 10 m, as well as the working pressure for 0, 22.5 and 45° was 132, 146, and 195 kPa, respectively. The catch-can tests were conducted in a radial data for these three working pressure and the tested data was considered to be the radial data of 0, 22.5 and 45°, respectively. Table 1 shows the water depths along these pressures by the test. According to the symmetry, the data for 45 to 90° were calculated out using the data for 0 to 45°. At last the data for 90 to 180° and 180 to 360° can be got using the same method. According to the calculating data, three-dimensional water distribution picture was drawn using Matrix Laboratory (MATLAB). Figure 6 shows three-dimensional water distribution of the sprinkler. Figure 7 shows water distribution contour of the sprinkler.

As can be seen from Figures 6 and 7, it can fulfill rectangular irrigation effectively. Any point around the sprinkler can be got easily from Figure 6. The irrigated intensity is shown in Figure 7. A case study shows that MATLAB is reliable for analyzing water distribution in sprinkler irrigation.

Conclusion

The frequency control technology was brought into the sprinkler irrigation system for the first time. Rectangular irrigated area was chosen to illustrate the quantitative result of this study. After experiment, it can fulfill rectangular spraying effectively. Mathematical program was established using MATLAB. Three-dimensional and contour of water distribution were figured out. It supplied a new way for achieving non-circular spraying of the sprinkler.

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