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Performance of Low Energy Water Application Device

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Abstract Considering the overall farming situation in developing countries particularly India it has been observed that the available options of efficient irrigation technologies are unable to cover up small and marginal farm holders due to lack of the applicability and acceptability in terms of their needs, priorities and financial capabilities. This makes imperative to develop a substitute of existing technologies that could be cheap simple and less capital intensive as well as applicable for small farms. This paper discusses the performances of a low cost water and energy efficient device called LEWA which can be used in place of overhead impact sprinklers to irrigate field and row crops efficiently at small farms. LEWA can be operated at an operating pressure range 39 to 98 kPa at its nozzle head, with discharge rate 0.87–1.10 m^3/h, and throw diameter 6–8 m. Since operating pressure at the nozzle head governs overall system pressure and reflects the total cost of the system, size of prime mover pump required and its operational cost; therefore the developed device holds greater promise in development of a cost effective water and energy efficient pressurized irrigation system for small and marginal farmers possessing small and fragmented land.

Keywords Small farm · Water and energy saving · Low energy water application device

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1 Introduction

In developing countries the average farm holding sizes are very small considering the case of India it is 1.18 ha. Most of the land holdings are highly scattered and fragmented; the cropping pattern is based on daily household's requirements such as rice, wheat, pulses and oilseeds etc. In such scenario sprinkler system can be one of the efficient systems of irrigation. However, the major constraint in adoption of sprinkler system by these small holders is the high initial investment cost and high-energy requirement for operations, as the water application cost with sprinkler irrigation includes investment on pumping, pipes, sprinklers, ditches, energy, labour, maintenance and water costs (Romero et al. 2006). This is because of the fact that commercially available sprinklers can be operated over the operating pressure of the range of 147 to 392 kPa at the nozzle head and necessitates high pressure pumps, pipe networks and other system components. Due to high investment cost considerable numbers of farmers have returned to conventional irrigation system due to various problems such as costs of pumping, maintenance etc. (Zibaei and Bakhshoodeh 2008). These constraints lead to develop a cost effective sprinkling device in order to lower overall cost of the irrigation system. The developed device, LEWA (Low Energy Water Application), may encourage small holders to adopt pressurized irrigation system to practice irrigation efficiently.

2 Review

Many attempts have been made earlier to bring the pressure requirement and the capital costs down by developing different kind of sprinkling mechanism for field crops such as perforated pipe systems; hose-fed sprinkler systems etc., operates at pressure as low as 34–68 kPa (Keller and Bliesner 1990). Though these produce relatively uniform water application when the sprinklers are moved in a systematic grid pattern with sufficient overlap, but the systems could not proven practical for irrigating agricultural crops as they are too labour intensive. Low energy Precision Application (LEPA) type micro sprinkler can also be operated at the pressure less than 98 kPa but it is suitable mainly for vegetable, horticultural and ornamental crops rather than field crops (Visalakshi et al. 2002). Koch (2003) tested the performance of low pressure sprinklers manufactured by Senniger and Nelson at recommended pressures from 68 to 137 kPa. It was observed that at the pressure of 68 kPa the oscillation of all the nozzles was very slow, and the droplets were poorly distributed and the wetted patterns were uneven, however it works satisfactorily when pressure exceeds 98 kPa. Hence, realizing the gap in terms of a cost effective water and energy efficient advanced pressurized irrigation technology for small and marginal farmers growing field crops, the ICAR Research Complex for Eastern Region, Patna developed LEWA device, which can be used in place of high pressure overhead sprinkling nozzles (Singh et al. 2009). Singh et al. (2009) also reports that the LEWA device saves energy in the tune of 30–50 percent besides cost of LEWA irrigation system developed with the help of flat hose flexible pipes can be cheaper in cost by 2 to 2.5 times lesser than the similar ranges of sprinkler irrigation systems, which uses HDPE pipeline to irrigate equal area.

3 Developmental Methodology and Concept of LEWA Device

The LEWA is based on the principle of moment of momentum. It is a 'T' shape device where equal sets of holes are placed (in three rows) on the two arms of the 'T', but in opposite direction (Fig. 1). When it is pivoted at the centre with the help of socket and bush arrangement on the riser and water is allowed to flow through the device, a torque is generated which facilitates circular rotation of pipe. The jets ejecting from the pipe break up in the form of droplets due to the rotation. This not only avoids soil erosion as in case of stationary jets but also facilitates more uniform wetting over the irrigated area. Major design parameters considered for development of LEWA device were the: length and diameter of the 'T' shape pipe, number, spacing, diameter and trajectory angle of the holes. To decide the dimension of these design parameters, testing with different combination was undertaken (Singh et al. 2004) and is discussed below:

Length and Diameter of the pipe Different combinations of pipe lengths (10–80 cm) for the device were tried. It was observed that when the length was less than 30 cm, either there was no rotation, or device rotated only up to certain operating pressure and after that it became stand still. This phenomenon occurs due to insufficient couple produced by the discharge coming out from limited number of holes in opposite direction having arm length less than 30 cm. The same is also been observed when pipe diameter is less than 25 mm. When device length was increased from 30 to 50 cm and diameter 25 mm (with increased number of holes) with hole diameter of 1.5 mm, it resulted in increase discharge and facilitated smooth rotation of the device. At arm lengths higher than 60 cm the discharge of the device was much higher than desired level and imbalance in circular rotation were observed. After various experimentations it was observed that 45 cm length and 25 mm diameter of the device was the most appropriate combination.

Fig. 1 LEWA device along with rotating mechanism

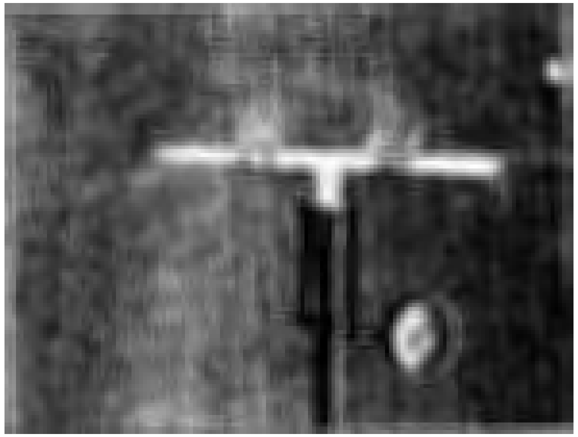

Table 1 Design configuration of developed LEWA device

Length of rotating arms	40 cm
Number of holes	28 (14 each side)
Diameter of holes	1.5 mm
Hole arrangement	3 rows
Trajectory angles of holes	37°, 23°, and 9°

Number, Spacing, Diameter and Trajectory Angles of Holes The number, spacing, diameter and trajectory angles of the holes have direct impact on discharge, radial pattern of water distribution, radial throw, and rotation of the device. The experiment showed that 14 to 16 numbers of holes (each side) are appropriate for 45 cm long device having 25 mm diameter for desired discharge (suiting to the soil properties of testing area). The overall discharge of LEWA device has been kept 10 to 20% higher than the infiltration rate of the soil of testing location to facilitate its use in rice also. Hole to hole spacing of 0.5, 1, 1.5, 2, 2.5 and 3.0 cm were tried and found that 1.0 cm was most appropriate for most of the holes placed on the LEWA arm. Hole diameter 1.0, 1.5 and 2.0 mm were tried with different combination, but experimentally 1.5 mm diameter was found most appropriate. Solomon (1990) reported that due to air drag, maximum throw is achieved at the trajectory angle less than 45° and is just over 30°. Most of the sprinkler manufacturers have adopted 27° as "standard" trajectory angle. In case of LEWA initially different sets of holes were placed at different trajectory angles varying from 9° to 37°. The configuration of LEWA device is presented in Table 1 and its schematic drawing is shown in Fig. 2.

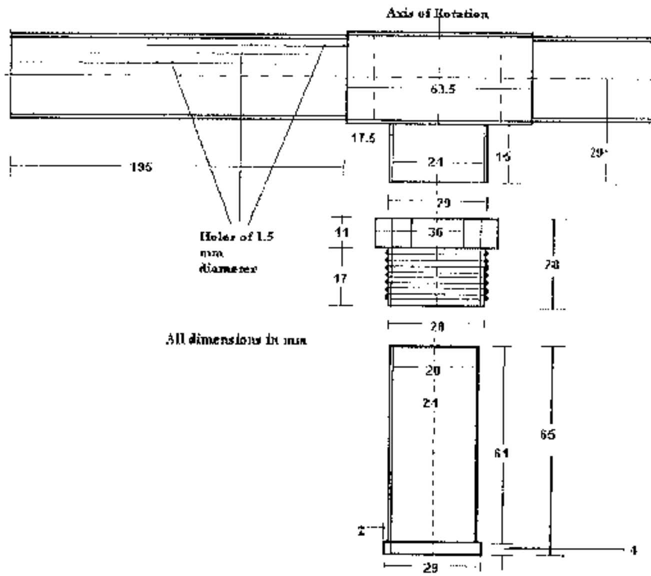

Fig. 2 Configuration of developed LEWA device

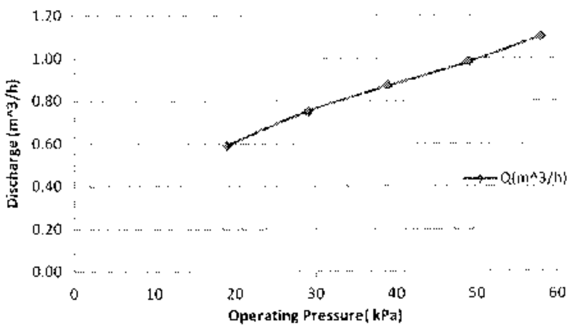

Fig. 3 Head discharge relationship of LEWA device

4 Testing Methodology

To judge the performance of the device, two types of tests were performed. Firstly, 'single nozzle test' for radial water distribution pattern, radial throw, and head discharge relationship. Secondly, 'block test' for determining CU (coefficient of uniformity). The entire testing was performed in an indoor laboratory as per the standard guidelines. Two commercially available sprinkler nozzle were also tested (one single nozzle impact sprinkler and other wobbler) to compare the performance of LEWA. Catch cans used in the testing were of 16.5 cm diameter and 15 cm height. The single nozzle testing of LEWA was undertaken by placing first catch can 20 cm away from the riser and then other in series while in case of single nozzle impact sprinkler and wobbler the same catch cans were placed at an interval of 50 cm starting the first catch can after a gap of 20 cm from the riser. Before start of each 'single nozzle' test, discharge of all the sprinklers were measured by collecting the volume of water coming out of the sprinkler in a 20 liter bucket for at least three times. A pressure Gauge was mounted 15 cm below the sprinkler on the riser to ensure the desired operating pressure at which the sprinkler is to be tested. The grid incase of block test was of 50 × 50 cm and riser heights were 1 m in all the cases. The distance between two sprinklers in 'block test' was 6 × 6 m. All the risers in case of 'block test' were equipped with pressure gauge which was mounted 15 cm below the sprinklers. The test duration for 'single nozzle' test was for 1 h, while in case of 'block test' it

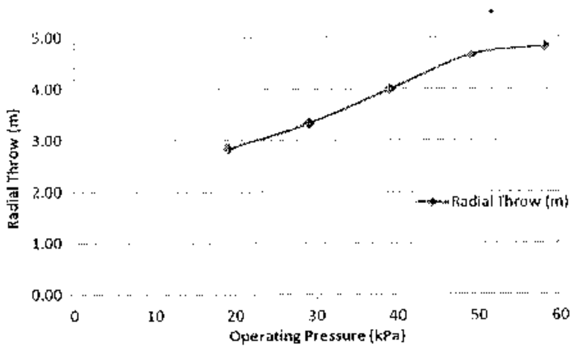

Fig. 4 Effect of operating pressure on radial throw of LEWA device

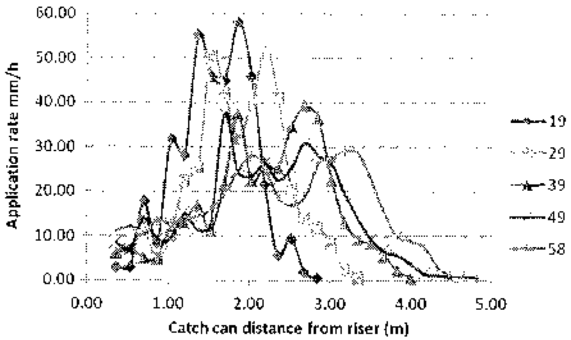

Fig. 5 Radial water distribution pattern of LEWA at varying operating pressure

was 30 min each. All the tests were performed in controlled condition and repeated three times to minimize any error.

5 Result and Discussion

5.1 Testing Performance of LEWA Device

LEWA device was tested with design attributes mentioned in Table 1 for various performance. The testing revealed that the discharge of LEWA varied between 0.59 and 1.10 m^3/h and wetted diameter varies from 6 to 8 m with operating pressure ranges from 19 to 58 kPa (Figs. 3 and 4). It is observed that the relationship between discharge (Q) and operating pressure (P) is governed by liner equation $Q = 0.0036P + 0.0991$ with $R^2 = 0.995$, whereas the relationship between radial throw (R) and operating pressure (P) is given by $R = 0.0538P + 1.8172$, with $R^2 = 0.973$. Figure 5 shows the radial water distribution pattern of LEWA device at an operating pressure 19, 29, 39, 49 and 58 kPa. It was observed that when the LEWA device was operated below 39 kPa the depth of water applied near the nozzle was more which creates unwanted ponding leaving outer periphery of wetted area dry. But at operating pressures of 39 kPa and above better distribution of water is observed. The radial water distribution pattern also reflects shift of peak water application towards outer periphery as operating pressure increases. The overall observation showed that the recommended optimum pressure for LEWA is 39 to 58 kPa. The catch values from block tests at different operating pressures reveals that the Christiansen Uniformity (CU %) increases as the operating pressure increases. The different CU values estimated for 39, 49 and 58 kPa of operating pressure is 54%, 62% and 67% respectively (Table 2 and Fig. 6). The average application rate shows decreasing trend with increase in operating pressure during the testing (Fig. 7).

Table 2 Uniformity (CU%) observed of LEWA device

Operating Pressure (kPa)	Av. application rate (mm/h)	Uniformity (CU %)		
		Min	Max	Av.
39	16.56809	52	56	54
49	14.86048	59	65	62
58	15.55801	62	72	67

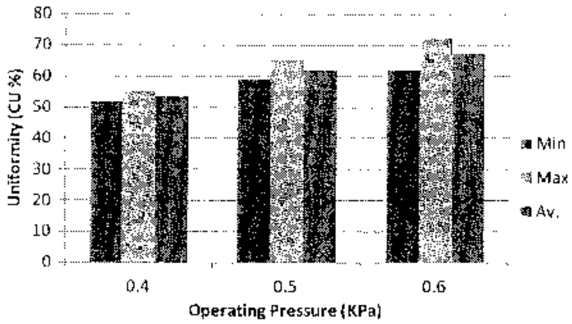

Fig. 6 Surface uniformity (CU %) of LEWA at varying operating pressure

5.2 Testing Performance of Single Nozzle Impact Sprinkler

Figure 8 depicts the head discharge relationship of single nozzle impact sprinkler. It was observed that discharge of the sprinkler varied from 0.39 to 0.72 m^3/h over the operating pressure range of 98 to 294 kPa. Observing the pattern of radial throw with the operating pressure (Fig. 9) it is observed that the radial throw varies from 6.9 m at 98 kPa to 9.0 m at 294 kPa. A significant change in radial throw is observed over the operating pressure range of 98 to 147 kPa whereas the rate of increase slows down considerably when the operating pressure increases beyond 245 kPa. Observing the pattern of radial water distribution pattern (Fig. 10) of impact sprinkler, it was observed that higher depth of water is applied from riser to mid of the radial throw distance when the operating pressure is below 147 kPa whereas more uniform water application with greater depth of applied water towards periphery is observed as the operating pressure ranges between 147 to 245 kPa. These observations reflect that an operating pressure of 147 to 245 kPa is optimum for the impact sprinkler under the test.

The 'block test' was undertaken to estimate the uniformity at 6 × 6 m and 12 × 12 m of impact sprinkler spacing. It was observed that at 6 × 6 m spacing the uniformity (CU values) is over 75%. The CU values estimated were 78.5, 87.6 and 90.6 percent at 98, 147 and 196 kPa of operating pressure respectively. This indicates that the optimum operating pressure for the impact sprinkler under test at 6 × 6 m

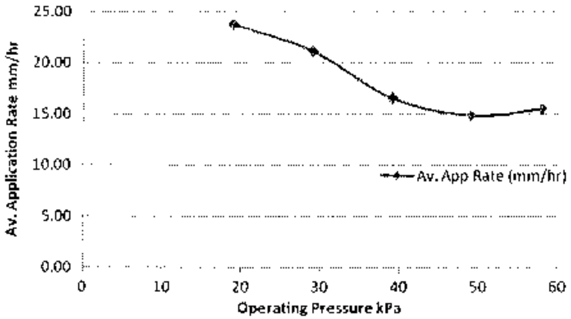

Fig. 7 Trend of av. Application rate of LEWA at varying operating pressure

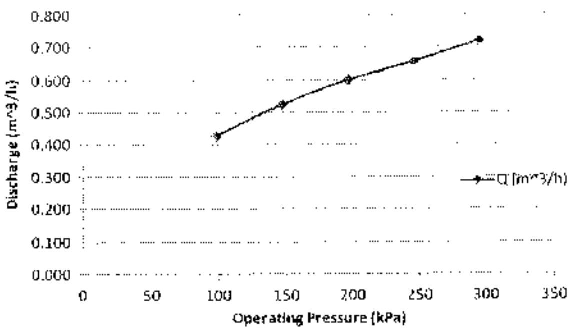

Fig. 8 Head discharge relationship of single nozzle impact sprinkler

spacing ranges between 98–147 kPa, but once the spacing is increased beyond 6 × 6 m the operating pressure need to be increased to achieve desired uniformity. The CU values observed when sprinklers are placed 12 m apart was 58.4% and 60.09% at 147 and 196 kPa of operating pressure respectively, however, the CU values increases above 70% when operating pressure ranged between 245 to 294 kPa at same spacing. This indicates that if one desires to operate the impact sprinkler under the test at 12 × 12 m spacing the operating pressure must be in the range of 245 to 294 kPa.

5.3 Testing Performance of Wobbler

Figure 11 shows head discharge relationship of Wobbler. The relationship shows an increasing trend as the operating pressure increases. The discharge varies from 0.19 to 0.25 m^3/h as the operating pressure ranges from 49 to 98 kPa. Figure 12 indicates huge variation in radial throw of Wobbler as the operating pressure increases from 78–98 kPa. This indicates that, for wider coverage and optimum performance the optimum pressure of Wobbler is 98 kPa or more. Figure 13 reflects that radial water distribution pattern of Wobbler have almost same pattern when operated at different operating pressures. The radial water distribution pattern indicates higher depth of water application near the riser and sharp decrease in depth of applied water over the wetted area towards periphery of throw.

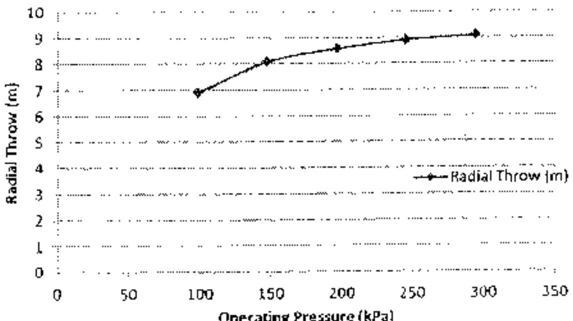

Fig. 9 Effect of operating pressure on radial throw of single nozzle impact sprinkler

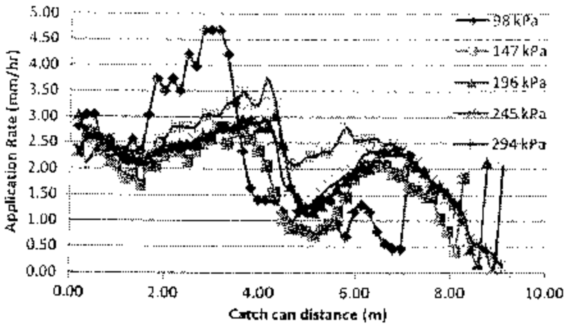

Fig. 10 Radial water distribution pattern of single nozzle impact sprinkler at varying operating pressure

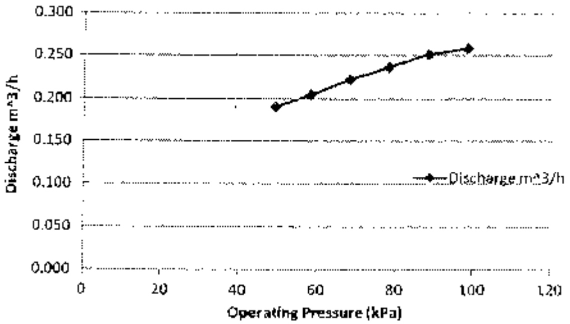

Fig. 11 Head discharge relationship of wobbler

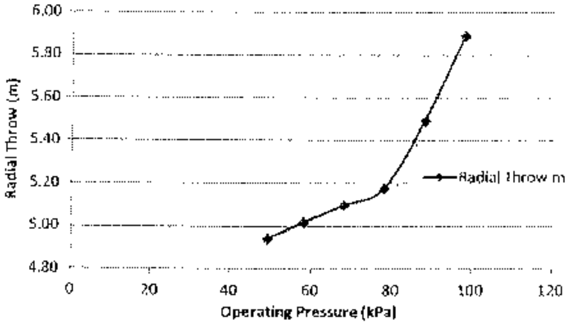

Fig. 12 Effect of operating pressure on radial throw of wobbler

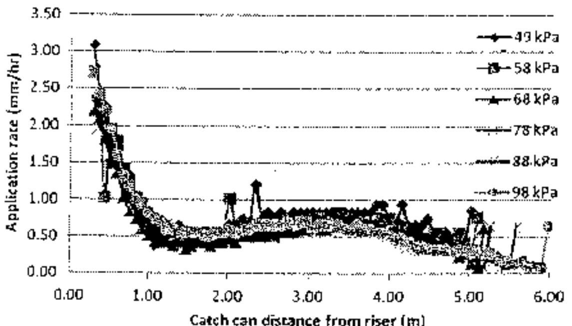

Fig. 13 Radial water distribution pattern of wobbler at varying operating pressure

6 Summary and Conclusions

Currently available options in terms of efficient irrigation technologies to growers in countries like India lacks in technical and economic viability restricting their wide adoption. Majority of the growers who comes under medium, small and marginal categories still forced to practice surface methods of irrigation incurring not only huge wastage of water but also diesel and electric energy used for pumping. LEWA device which can operate satisfactorily at an operating pressure ranging between 39–58 kPa in comparison to impact sprinkler and wobbler which required operating pressure range of 98–294 kPa and 98 kPa respectively to operate satisfactorily, opens an opportunity to use low pressure rating pipe network and other system component which are cost effective too. With this proposition, 'LEWA Irrigation System' will provide an opportunity to wider set of farming community to adopt efficient irrigation systems as per their need and priority in crop production. The concept of 'LEWA Irrigation System' can be a boom for not only in context to Indian farming community but many Asian and African countries where similar situation prevails.

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