Irrig Sci (1993) 13:183–187

Irrigation
Science

Lateral and longitudinal wetting patterns of very low energy moving emitters

I. Amir[1], **J. Dag**[2]

[1] Faculty of Agricultural Engineering, Technion – IIT, Haifa 32000, Israel
[2] Ministry of Agriculture – Afula Extension Service Office, Afula, Israel

Received: 22 May 1992

Abstract. A set of experiments was conducted to investigate the wetting contours obtained under very low pressure (10–15 kPa) moving emitters. Nine different instantaneous application rates (IAR) were applied by three types of emitters: open-end pipe, short (5 m) and long (10 m) perforated pipes and for three water amounts. Results show that high IAR increase the uniformity of the wetting pattern and its width, and decrease the depth. On the other hand, high IAR increase water ponding on soil surface and, consequently, water runoff. The results of wetting patterns under moving emitters are in a good agreement with those for source-point stationary emitters.

Uniformity of soil water distribution is one of the most important factors of irrigation efficiency. Uniformity of moving irrigation systems is composed of two elements: 1) lateral uniformity – which is measured at right angles to the traveling direction, i.e., along the boom of the machine; and 2) longitudinal uniformity – which is measured along the direction of travel. Lateral uniformity is dependent of the type of emitters, distance between emitters, pressure head at the inlet of the emitter and elevation of the emitter above crop canopy. A detailed analysis of the effect of these factors on surface distribution patterns can be found in Amir and Alchanatis (1992). Sometimes, however, uniform distribution over the entire irrigated area is not the most efficient pattern, especially for small row crops, such as carrots, or during the early growing stages of crops, such as cotton. In these cases, due to the limited root zone, more water is required close to the crop whereas the rest of the area should receive less water or none at all. A coefficient to evaluate the uniformity of strip patterns was suggested by Amir et al. (1992). Many publications present data regarding surface uniformity and distribution patterns (Thooyamany et al. 1987; Kincaid et al. 1987).

The longitudinal uniformity depends mainly on the control system of the machines. Two basic methods are used for the control systems: 1) adjusting the speed of the machine to the inlet discharge in order to maintain the required amount of water along the entire traveling path. The control system checks frequently the water amount and the distance of travel and compares the actual amount of water applied to the required amount for the irrigated area defined by the width of the machine and the measured distance. Then, the speed of the machine is changed depending on the comparison between the actual and the required water amounts; 2) applying the required amount of water for a predetermined distance e.g. 1 m. In most machines, in both control methods, the adjustment of the speed or the applied amount of water is carried out when the machine stops while the emitters continue to operate. This, obviously, reduces the longitudinal uniformity of water application.

Another trend in moving irrigation machines is the use of very low pressure emitters – VLPE (<30 kPa) – in order to save energy and to reduce wind draft, evaporation and leaf diseases (Farbman et al. 1979; Lyle 1981). In this respect, Amir et al. (1984) examined the application patterns of very low pressure moving emitters: open-end and perforated pipes.

This experimental work was aimed at studying the wetting patterns in the soil under moving VLPE i.e. a) the *lateral* wetting patterns of the above-mentioned very low pressure moving emitters and b) a preliminary observation of the effect of frequent pauses of the machine on the *longitudinal* uniformity. The main variable was the instantaneous application rate, IAR. An additional aim was to examine the effect of topographical slope on water distribution uniformity under various IAR.

Materials and methods

From the literature (Kincade et al. 1969; Keller and Bliesner 1990) and supported by our experience, one of the most significant factors dominating soil-water patterns of the VLPE, is the IAR. It is defined as the discharge divided by the wetted area, (which is the

---

Correspondence to: I. Amir

product of the distance of travel and the interval between the emitters). Most of the intervals between rows of field crops are about 1 m; since the emitters should be installed every other row at the most, experiments were limited to just one interval between emitters, 2 m. Consequently, two polyethylene pipes, 2 m apart, were connected to a boom dragged by a cable operated by a tractor. The irrigated area had a lateral topographical slope of 2%. The soil was grumusol, heavy clay soil, in the Jezreel Valley of Northern Israel.

The experimental setup, (Fig. 1), included 9 blocks, each one was for a combination of one type of emitter pipe and one water amount. The emitter pipes were:

OEP (Open End Pipe) – without any device at the pipe end; 25 mm diameter.

SPP (Short Perforated Pipe) – 5 m length, with 5 holes of 11.2 mm diameter. (Total area of 5 holes equals the cross-sectional area of open-end pipe).

LPP (Long Perforated Pipe) – 10 m length, with 10 holes of 8 mm diameter.

The effect of the frequent pauses of the movement of the machine on soil-water uniformity was examined by experiments in which the movement of the boom was stopped every 1 m for 15 s (to simulate regular motion of irrigation machines in the field).

Immediately after irrigation, the irrigated area was covered by a dark plastic sheet to prevent evaporation. Four days after irrigation, 90 cm width, lateral (6 m length) and longitudinal (10 m length) trenches were dug by a small trencher in each block. The longitudinal trench was dug on the travel path (axis) of one of the dragged pipes. The wetted contours in the trenches were carefully observed and measured.

For the various treatments of the experiments, two factors were calculated: traveling speed, S, and instantaneous application rate IAR. Traveling speed, controlled by the power take off (PTO) of a tractor, was calculated by the following procedure:

The selected application amount of water is the product of M – the desired amount per unit area (m^3/m^2) and the irrigated area Ai, $Ai = W \cdot L$, (m^2), where W and L are the width and length of the irrigated area, respectively. This selected amount of water is to be supplied by the discharge $Q (m^3/h)$ during the time (t): Therefore,

$$MLW = Qt\,. \tag{1}$$

The speed is $S = L/t$, therefore:

$$S = Q/MW \ (m/h)\,. \tag{2}$$

Three predetermined water amounts per area unit were applied: M = 86, 110 and 141 mm or 860, 1110 and 1410 m^3/ha, respectively.

With regard to IAR, one purpose of the work was to examine open-end and perforated pipes as VLPE. The main difference between these types of VLPE is the discharge. The OEP applies the inlet discharge through one hole, while the perforated pipes distribute the inlet discharge through N holes, 1 m apart. The discharge of each hole is, therefore, $q = Q/N$ ($N = 1$ for the OEP, $N = 5$ for SPP and $N = 10$ for LPP).

By definition:

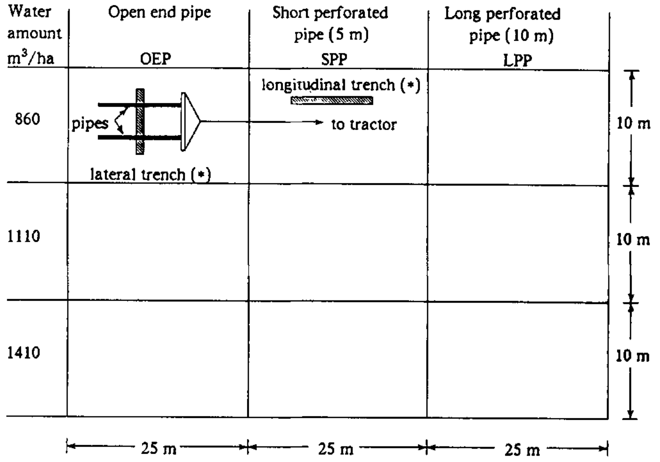
$$IAR = \frac{q}{WL} = \frac{Q/N}{2WL} \tag{3}$$

where: Q/2 the inlet discharge to each emitter pipe; q is the discharge of one hole (out of N); W is the width of irrigated area for each emitter pipe (2.0 m); L is the length of irrigated area (L = 1.0 m as the distance between the holes).

In the experimental setup the inlet discharge was regulated to $Q = 3.44\ m^3/h$, i.e., $1.72\ m^3/h$ for each pipe. Using Eqs. (2) and (3), the values of speed S and the instantaneous application rates IAR, for the three desired application amounts M, were calculated, as presented in Table 1.

Results

The contours of the wetted soil in the lateral cross section are presented graphically in Figs. 2–4 for water applica-



* One trench for every block.

Fig. 1. Experimental setup

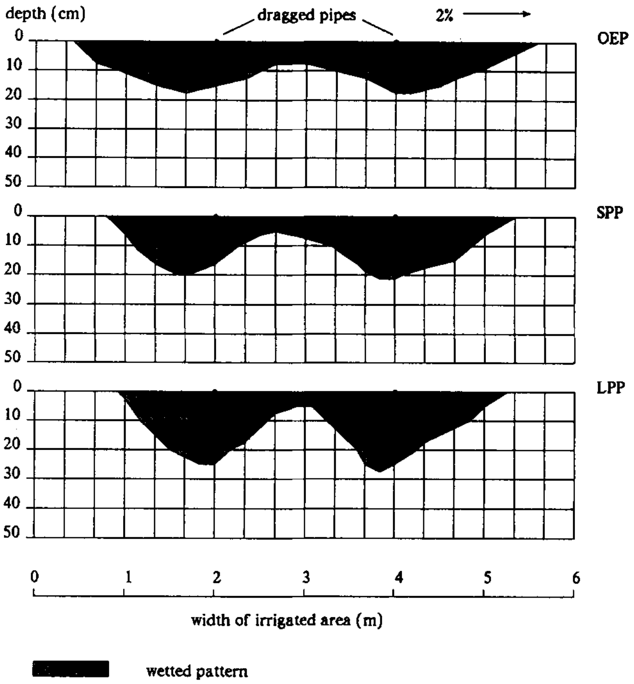


Fig. 2. Lateral wetting patterns for application amount of 860 m^3/ha

Table 1. Speed and instantaneous application rates for the different treatments

Factor		Symbol	Unit	Values		
Application amount		M	m^3/ha	860	1110	1410
speed		S	m/h	10.00	7.75	6.10
Instantaneous Application Rate	OEP	IAR	mm/h	86	111	141
	SPP	IAR	mm/h	17.2	22.2	28.2
	LPP	IAR	mm/h	8.6	11.1	14.1

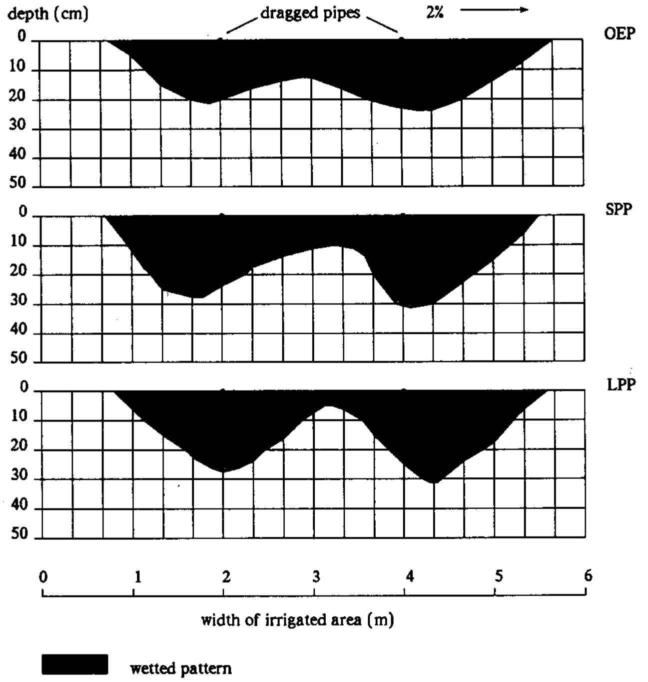


Fig. 3. Lateral wetting patterns for application amount of 1110 m^3/ha

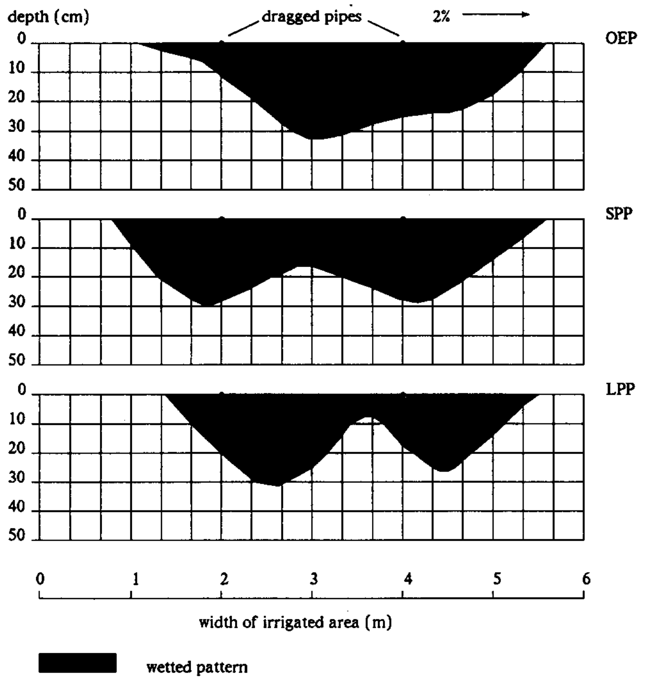


Fig. 4. Lateral wetting patterns for application amount of 1410 m^3/ha

tion amounts M = 860, 1110 and 1410 m^3/ha, respectively. The lines in the figures connect measured points in the trenches taken every 40 cm.

Soil homogeneity has a very significant effect on the wetting contours. Therefore, in order to examine the effect of IAR on the wetting patterns, soil for the various treatments should be homogeneous. The homogeneity of soil (grumusol, heavy clay) was examined by the water content, Wc, and by the size of wetted area for a given water amount. The water content, Wc, defined as the ratio between the volume of the applied water, Vw, to the volume of the wetted soil, Vs, is:

$$Wc=\frac{Vw}{Vs}, \tag{4}$$

The wetted volumes, Vs, were determined by measuring the wetted areas of the cross-sections in the figures, taking into account the scale of the figures and the width of the cross-section, L = 1.0 m.

The amount of water, Vw, (Eq. 4) was calculated by multiplying the surface area of the cross-section, WL, by the selected application amount M, i.e.:

$$Vw = M \cdot W \cdot L \cdot 10^{-4} \text{ (when M is given in } m^3/ha). \tag{5}$$

The values of all Wc were tested statistically, showing that soil of all blocks had the same Wc, Wc = 0.3197 = 32%, at 95% level of significance ($\sigma = 0.02$ and coefficient of variation $\sigma/Wc = 0.063$). Also the wetted areas for the same M were not significantly different from each other. Therefore, it was assumed that the soil in all blocks was homogeneous.

Discussion

Lateral wetting contours (Figs. 2–4)

Figure 2 clearly shows that the contour of the wetted soil varies as a function of IAR for the same application amount M = 860 m^3/ha.

The lateral dispersion of water is largest for the open-end pipe with the highest discharge and IAR. Because the wetted volume is the same for all cases, the depth of wetted soil is smallest. Furthermore, especially for the OEP, the wetted soil pattern is symmetrical, that is, no runoff occurred during irrigation. Such a symmetry of the wetting contours was not achieved under larger application amounts as presented in Figs. 3 and 4, where the wetting patterns are skewed. The uniformity achieved, especially under the open-end pipe, results in an important possibility of effectively controlling irrigation depth and uniformity with very low pressure emitter system. As IAR decreases, the uniformity also decreases. The wetting patterns approach a typical shape of a stationary point-source emitter as in the model of Schwartzman and Zur (1985) [Keller and Bliesner (1990), p. 455]. That model provides empirical equations, according to which width increases and depth decreases with emitter's discharge for a given soil:

$$Z = K1 \cdot Vw^{0.63} \cdot (Cs/q)^{0.45} \tag{6a}$$

$$W = K2 \cdot Vw^{0.22} \cdot (Cs/q)^{-0.17} \tag{6b}$$

where: Z is the depth of the wetting contour; W is the width of the wetting contours, measured at 30 cm below soil surface; K1 and K2 are constants; Vw is the volume of the water applied; and Cs is the saturated hydraulic conductivity of the soil.

Farbman et al. (1979) also present similar results for stationary drip laterals of various drippers on various soils. Similar behaviour of discharge-depth-width relationships were achieved in our experimenets with moving emitters. The similarity was determined quantitatively by comparing the powers of the discharge q of Eqs. (6a) and (6b) with the calculated ones using the results of the experiments. The calculations were carried out using Fig. 2, for $M = 860\ m^3/h$, in which widths and depths of the wetting contours were eliminated by equating the following pairs of contours: OEP-SPP, OEP-LPP and SPP-LPP. The calculated powers for the wetting contour depth of the three pairs were: -0.32, -0.37 and -0.45, respectively, (compare to -0.45 of Eq. (6a) for stationary point-source emitters). For the width of the contours, the powers were: 0.16, 0.16, 0.18, which are the same for the point-source stationary emitters (0.17 in Eq. 6b). This agreement calls for further investigations of the depth and the width of wetted contours under moving point-source low-pressure emitters.

Figures 3, and 4 generally show the same wetting fronts as in Fig. 2. Because the soil is homogeneous, the depths of the wetting fronts are obviously greater than in Fig. 2, due to the higher application amounts. The contours of the wetted soil in Fig. 3 and in particular in Fig. 4 are not symmetrical. The wetted soil pattern of the right hand emitter pipe is wider and shallower than the pattern of the left hand one. Under the OEP (uppermost curve) with the largest IAR, a significant amount of water was diverted to the right due to runoff as had been observed while carrying out the experiments.

From the results it can be seen that IAR is an important factor in the pattern of soil-water distribution. High IAR increases uniformity, as well as width of irrigated area, and decreases depth. High IAR, however, increases water ponding, when it exceeds soil water intake rate, thus increasing the possibility of runoff. IAR, therefore, can be used as a decision variable in controlling soil water patterns under very low pressure moving emitters. It certainly can improve irrigation efficiency. This possibility is especially important because it enables one to save water when irrigating small crops (e.g. carrots) or other field crops, e.g. cotton, in their early growing stages.

Longitudinal wetting contour (Figs. 5–7)

Another set of measurements was carried out to study the longitudinal wetting contours. A 90 cm width trench was excavated on the axis of one of the pipes. Also, in this trench the contours of the wetted soil were observed and measured every 40 cm on both walls of the trench.

From the Figs. 5–7, three main features can be seen:

1) The contours are fairly straight lines, indicating that the soil-water longitudinal pattern is uniform. Here, again, the larger the IAR the smoother the line. The deviations are not regular and therefore they cannot be explained by the frequent pauses in the pipe movement.

2) The higher the IAR the closer the contours of the two walls to each other. This is obvious as the distance between the two lines in the figures is the distance between the two walls, 90 cm apart, in the lateral direction. Therefore, as in the lateral cross-sections, the higher the IAR the more uniform the wetting pattern. The IAR of the OEP in Fig. 7 for $M = 1410\ m^3/ha$ is again exceptional because of water runoff.

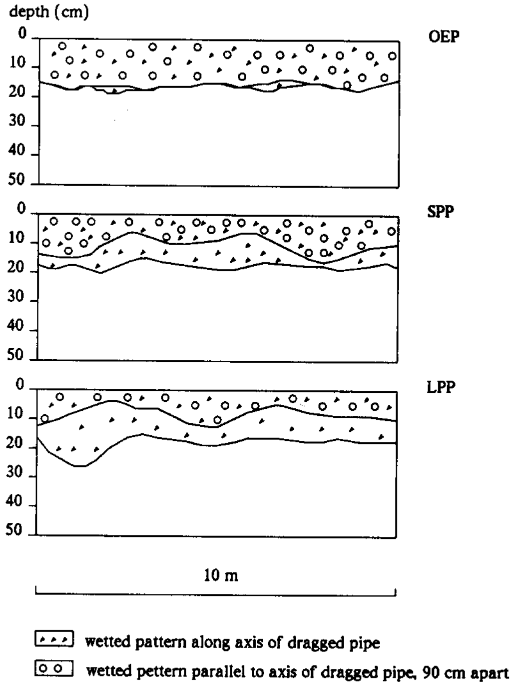


Fig. 5. Longitudinal wetting patterns – for $860\ m^3/ha$

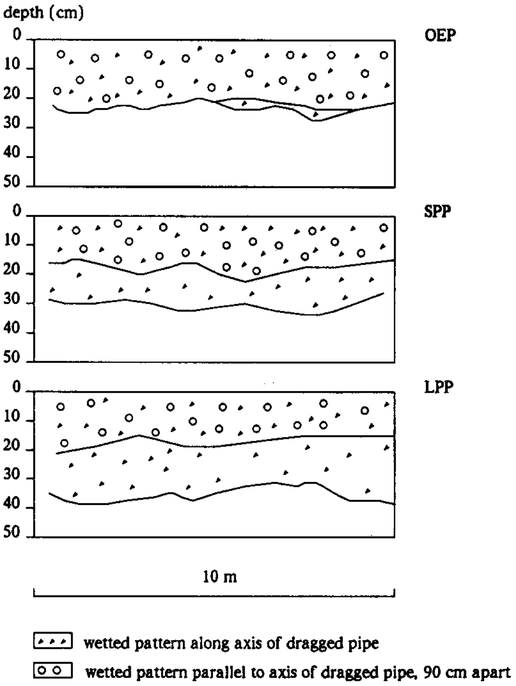


Fig. 6. Longitudinal wetting patterns – for $1110\ m^3/ha$

3) As already mentioned, the effect of the frequent pauses on uniformity cannot be clearly seen in the figures. This indicates that the 15 s stop every 1 m is too small to affect uniformity under the conditions of the experiments (the time to move treatments). As this aspect is very important for moving irrigation systems further investigations are called for.

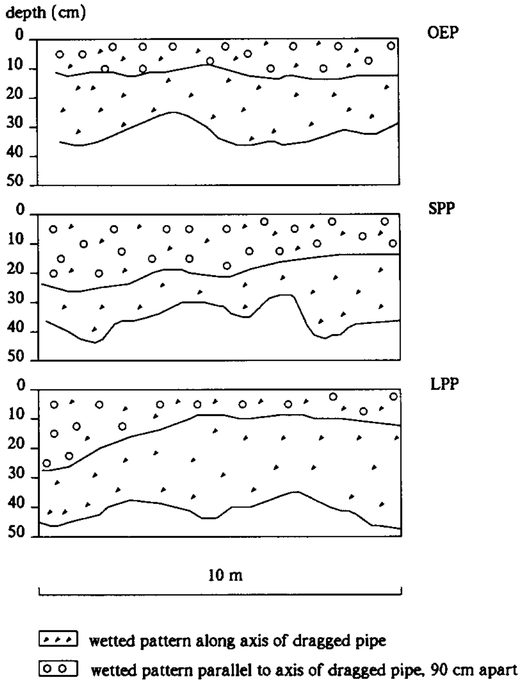


Fig. 7. Longitudinal wetting patterns – for 1410 m^3/ha

Conclusions

A set of experiments was carried out to investigate the effect of IAR on very-low-pressure moving emitters: open-end and short and long perforated pipes. From the results, it can be concluded that:

1) High IAR increases lateral dispersion, increases the width and decreases the depth of soil irrigated.

2) High IAR increases uniformity but also the possibility of water runoff.

3) Resulting from conclusions 1 and 2, is the fact that IAR, when properly controlled, can be used as one of the decision-variables in water application to achieve desired wetting profiles in the soil, both for uniform as well as for strip application. Such a control can be used to significantly improve irrigation efficiency.

4) The effect of the discharge on the width and depth of the wetting contours of moving low pressure moving emitters is similar to that point-source stationary emitters.

5) The longitudinal uniformity is fairly insensitive to frequent short pauses, at least under the conditions of the experiments.

References

Alchanatis V, Amir I (1990) A pattern fit coefficient for water distribution. Irr Drainage Systems 4:29–36

Amir I, Alchanatis V (1992) Procedure for predicting and designing moving sprinkler application patterns. Irrig Sci 13:93–98

Amir I, Dag J, Farbman M (1984) On moving irrigation. Technion P.N. 344. Faculty of Agricultural Engineering (Hebrew)

Farbman M, Dag J, Manor G, Sadan J, Uri J (1979) Moving drip system for field crops. Technion Rep. P.N. 300. Faculty of Agricultural Eng., Haifa, Israel (Hebrew)

Keller J, Bliesner RD (1990) Sprinkle and trickle irrigation. An AVI Book, New York, pp 455–456

Kincaid DC, Heermann DF, Kruse EG (1969) Application rates and runoff in center pivot sprinkler irrigation. Tran ASAE 12:p 790

Kincaid DC, Busch JR, McCairn I, Nabil M (1987) Evaluation of very-low-pressure sprinkler irrigation and reservoir tillage for efficient use of water and energy. Final Report US Dept. of Energy. Contract DE-17179-86 BP62961

Lyle WM, Bordovsky JP (1981) Low energy precision application (LEPA) irrigation system. Trans ASAE p 1241

Schwartzman M, Zur B (1985) Emitter spacing and geometry of wetted soil volume. J Irr Drainage Eng ASCE 112:242–253

Thooyamany KP, Norum DI, Dubetz S (1987) Application rates and uniformity under center pivot sprinkler irrigation system using spray nozzles. CSAE 29:149–154