Irrigation Systems Evaluation in Desert Farming[1]

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Abstract

Scarcity and misuse of fresh water pose a series and growing threat to sustainable development and protection of environment. Egypt and other countries in the region are classified among countries close to, or already facing water-stress conditions. Improving the efficiency of on-farm water use specially in the newly reclaimed areas is vitally needed for sustainable agriculture development.

Evaluation of the existing irrigation systems was carried out in 101 desert farms representing four areas namely; South Tahrir, El-Bustan, Sadat and Wadi El-Natron. These areas vary in the main source of irrigation water (Surface and groundwater), dominant modern irrigation systems (sprinkler and drip), and the type of settlers (small holders old graduates, new graduates, and investors). The evaluation of sprinkler irrigation systems included 21 fixed systems, 22 hand-move systems and 9 side-roll systems addition to 49 drip irrigation systems.

The sprinkler systems were evaluated in the field by determining the uniformity coefficient (UC), distribution uniformity (DU), and the potential application efficiency of the low quarter (PELQ) whereas drip irrigation systems were evaluated in the field by determining the emission uniformity (EU) and the application efficiency (AE). Results showed that most of the sprinkler and drip irrigation systems throughout the study area are performing poorly. Design and operational causes for poor performance are discussed and measures to improve desert irrigation systems efficiencies are presented.

Introduction

Water, more than land, is the major constraint to agricultural expansion in the deserts of Egypt. The River Nile is the most important source. It supplies Egypt with almost all of its water requirements. Egypt's current share of the Nile water is 55.5 billion cubic meter per year. The total net effective rainfall is insignificant; and in the context of the Nile basin, ground-water is not an additional resource since it is recharged from the Nile water. With limited quantities of water, the agriculture sector will have less water available to it than at present. Therefore, it is imperative to use and manage available

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water resources with maximum efficiency at present and in the future. This is particularly true in the new desert areas which are characterized by coarse textured soils and where water is often over-used and miss-used.

Sustainable agriculture requires not only competitive yields but also competitive production costs and conservation of limited resources. Thus, constraints to production include not only conditions which decrease production, but also those which increase costs or deplete resources. Water is a limited resource in irrigated agriculture. The systems, energy, and labor required for irrigation are substantial production costs.

The possible continued degradation of the natural resource base, i.e., the land, water, and environment, under intensive crop production systems in which at least two irrigated crops are grown in a year is the main concern with regard to irrigation systems' sustainability. In many areas, large quantities of water is lost through the irrigated areas. Low irrigation efficiency or the non-uniform application of water in many irrigation systems often causes deep percolation in excessive quantities. Much of this water reaches and raises the water table. This process disturbs the natural hydrological balance in the area. when the water table reaches within about 2 m from the soil surface, the upward capillary movement of the groundwater, which often contains soluble salts, begins to add salts to the crop root zone, creating potential salinity problems. Continuous rise of the water table creates waterlogging and lowers the productivity of the land.

The objectives of evaluating the irrigation systems in desert farming are: (1) To determine the efficiencies of the systems as they are being used; (2) to determine how effectively the systems can be operated and whether they can be improved; (3) to obtain information that will assist in designing other systems and (4) to obtain information to enable comparing various methods, systems, and operating procedures.

Methodology

Evaluation of the existing irrigation systems was carried out in 101 desert farms representing four areas namely; South Tahrir, El-Bustan, Sadat and Wadi El-Natron. These areas vary in the main source of irrigation water (Surface and groundwater), dominant modern irrigation systems (sprinkler and drip), and the type of settlers (small holders old graduates, new graduates, and investors). The evaluation of sprinkler irrigation systems included 21 fixed systems, 22 hand-move systems and 9 side-roll systems addition to 49 drip irrigation systems.

Irrigation uniformity for sprinkler irrigation systems are evaluated by measuring the application depths with catch cans. Trickle systems measure the emitter discharge for evaluating irrigation uniformity. Field evaluation tests were conducted in accord with: ASAE Standard S 330.1 (ASAE, 1990), Merriam et al. (1983), and Merriam and Keller (1978).

A common way to evaluate sprinkler uniformity is the Christiansen's Uniformity Coefficient (CU), a statistical representation of the catch pattern, when expressed as a percentage, it is calculated by:

$$\mathrm{CU} = \left[1 - \frac{\textbf{Average deviation from mean depth caught}}{\textbf{Mean depth caught}} \right] \times 100$$

To achieve high values of uniformity, close sprinkler spacing are usually required. In general, the closer the sprinkler spacing, the more expensive the system costs. Griffin (1978) reported that most agricultural sprinkler applications require a uniformity coefficient of at least 80 percent for market acceptance. Low uniformity coefficient values often indicate an incorrect combination of sprinkler size, operating pressure, and spacing. The pattern of drops falling from sprinklers was determined by measuring the depths of water caught in small containers. The above definition requires that each catch can represent the depth applied to equal areas. The sprinkler flow rate was obtained by filling a known volume container in a measured time. A loose fitting section of hose was slipped over the nozzle to deflect the stream into the container. The sprinkler pressure was measured using a pressure gauge with a pitot tip, which was placed directly in line with the center of the jet flow.

Distribution uniformity (DU) indicates the uniformity of infiltration throughout the field and expressed as follows:

$$\mathbf{DU} = \left[\frac{\textbf{Average low quarter depth caught}}{\textbf{Mean depth caught}}\right] \times 100$$

The distribution uniformity is often applied to sprinkler and trickle irrigation systems. The average low quarter depth of water infiltrated is the lowest one-quarter of the measured values where each value represents an equal area. For sprinkler and trickle irrigation, the depth infiltrated is presumed equal to the depth applied or caught on the surface if there is no runoff. The DU is useful indicator of the magnitude of distribution problems. A low DU value indicates that losses due to deep percolation are excessive if adequate irrigation is applied to all areas. Although the concept of a low DU is relative, value less than 67 percent are generally considered as unacceptable.

Potential application efficiency of low-quarter (PELQ) is the efficiency that is obtainable when the average low-quarter (LQ) depth of irrigation water infiltrated just equals the desired management allowed deficiency (MAD) and is expressed as:

$$\mathbf{PELQ} = \left[\frac{\textbf{Average low - quarter depth of water caught} = \textbf{MAD}}{\textbf{Average depth of water applied}}\right] \times 100$$

The average depth applied was obtained by dividing the sprinkler flow rate over the area served by single sprinkler (sprinkler spacing). Low PELQ values indicate design problems. The water that goes to excessive deep percolation, surface runoff, wind drift, and spray evaporation would tend to decrease the irrigation application efficiency.

The PELQ is always a little lower than the DU of a sprinkler irrigation system because the average water applied (which is the denominator for PELQ) is larger than the average water caught (which is the denominator for DU). The numerator for both PELQ and DU is the average low quarter depth of catch. The difference between the average water applied and the water caught or received is an approximation of losses due to evaporation and wind drift plus loss of water due to some of the area's being ungauged and some evaporation from the gauge cans.

The emission uniformity of drip systems can be determined in the field by the following equation:

$$\mathbf{EU} = \frac{\textbf{minimum rate of discharge per plant}}{\textbf{average rate of discharge per plant}}$$

Drip irrigation has significant advantages over other techniques in minimizing or preventing water loss because leakage from the delivery system is negligible. Evaporation is minor as water is not discharged in the air, as with sprinkler irrigation, or left on the soil surface as with surface irrigation methods. Only a small fraction of the soil surface is wet. Therefore, the only considerable water loss in drip irrigation is deep percolation. With drip irrigation it is always very difficult to determine the soil moisture deficit in the field because of the small soil moisture variations which occur in the wetted soil before and after irrigation. Therefore reasonable deep percolation will be taken as 10 percent of the amount of water applied. The application efficiency (AE) is therefore: AE = 0.9 EU.

The emission uniformity (distribution uniformity) of new drip irrigation installations may be close to 90 percent, but it usually decline appreciably with continued use. A more typical value of about 80 percent should be considered. Only the EU can be measured by evaluations so the AE (PELQ) must be estimated. Since the SMD cannot be measured, but is estimated.

Results and Discussion

The data obtained from the field evaluations of hand-move, side-roll, and fixed sprinkler systems for the area under study were analyzed and performance parameters were calculated. Figure 1, the frequency distribution of the uniformity coefficient for the sprinkler systems (hand-move, side-roll, and fixed), shows that 15.4 percent of the sprinkler systems were in the acceptable limits of CU (about 80 percent CU) and 30.7 percent of the systems showed very poor CU (below 60 percent CU). The system with the highest CU's was the side-roll, in which 22.2 percent of the systems had CU's greater than or equal to 80 percent. Lower uniformity coefficients were found for the hand-move system, in which 36.3 percent of the systems had CU's less than 60 percent. The maximum frequency of occurrence for the three systems was between 60 and 70 percent.

Table 1. Frequency of the distribution uniformity (DU) for sprinkler systems.

DU %	Hand-move		Side-roll		Fixed		Total	
	#	%	#	%	#	%	#	%
< 50	9	40.9	1	11.1	7	33.3	17	32.7
50 - 60	5	22.7	4	44.4	7	33.3	16	30.8
60 - 70	4	18.2	2	22.2	4	19.1	10	19.2
70 - 80	3	13.6	2	22.2	3	14.3	8	15.4
80 - 90	1	4.5	0	0	0	0	1	1.9
Total	22	100	9	100	21	100	52	100

Table 2. Frequency of distribution of the potential application efficiency of low quarter (PELQ) for sprinkler systems.

PELQ %	Hand-move		Side-roll		Fixed		Total	
	#	%	#	%	#	%	#	%
< 50	8	38.1	3	42.9	9	42.9	20	40.8
50 - 60	7	33.3	2	28.6	5	23.8	14	28.6
60 - 70	1	4.8	2	28.6	6	28.6	9	18.4
70 - 80	4	19	0	0	1	4.8	5	10.2
80 - 90	1	4.8	0	0	0	0	1	2
Total	21	100	7	100	21	100	49	100

As shown in Fig. 2, the hand-move systems in south Tahrir had the lowest uniformity coefficients, in which 22.2 percent of the systems had CU's less than 50 percent, comparing to zero percent of the systems in Bostan.

Hart and Reynolds, 1965 gave more useful meaning to the concept of CU. For example, if a sprinkler system has a CU of 85%, this implies that for each unit of the average application of water received by the crop; 80% of the area would receive 85% of the average application or more, and 20% of the area would receive less than 85%. To apply a net application depth of 1.0 unit of water to at least 80% of the area with a system having a CU of 85%, the average net application (after allowing for wind drift and evaporation losses) must be: 1.0/0.85 = 1.18 units of water. With a CU of only 70 %, an average net application of 1.43 would be required to apply a net depth of 1.0 or more units of water to 80% of the irrigated area. It can be seen that the lower the CU value, the greater the deep percolation losses.

Table 1, indicates that 36.5 percent of the sprinkler systems had DU's equal to or greater than 60%, while 32.7% of the systems had DU's less than 50%. This means non-uniform water application and excessive quantities of deep percolation. Table 2, the frequency distribution of the PELQ for sprinkler systems, shows that only 30.6 percent of the systems had PELQ's equal to or greater than 60 percent, while 40.8 percent of the systems had PELQ's less than 50 percent. As presented in Table 2, the actual average application efficiency of the sprinkler systems ranging between 50 and 60 percent. This low application efficiency causes excessive quantities of water losses. The PELQ is lower than the DU by the amount of the percent of evaporation and wind drift losses, which lies in the range of 10 percent. The application efficiency of low quarter has a direct effect on the amount of water losses. For example, if a PELQ has been improved from 50% to 70% there would be a water saving of 28.6% calculated as follows

$$\textbf{Percent of water saving} = \left(1 - \frac{\text{PELQ1}}{\text{PELQ2}}\right) \times 100 = \left(1 - \frac{50}{70}\right) \times 100 = 28.6\%$$

Major factors responsible for low performance of sprinkler systems included: low operating pressure, leakage, wide sprinkler spacing in related to actual wetted diameter, short riser pipe, non-perpendicular riser orientation, riser vibration (not rigidly supported), mixed sprinklers, worn nozzles, and non-uniform rotation rate of sprinklers. The poor water distribution may be improved by using the correct sprinkler nozzle pressure as recommended by the manufacturer and limiting the sprinkler spacing to 50 percent of the sprinkler wetted diameter to match the prevailing 10 km/hour wind speed.

Figure 3, the frequency distribution of the emission uniformity for drip irrigation systems, shows that 20 percent of the systems had EU's equal to or greater than 80 percent. Forty-four percent had EU's equal to or less than 60%, while 36 percent of the systems were between 60 and 80 percent. Thirty-six of the drip systems, which was the maximum frequency of occurrence, had EU's less than 50 percent. It can be said that 20 percent of the drip systems were in the acceptable limits of EU (about 80 percent EU) and 44 percent of the systems showed very poor EU (below 60 percent EU).

As shown in Fig. 4, drip irrigation systems in Wadi-Natron had the highest EU's (>90%), while in Sadat had the lowest EU's (<50%). Sixty-seven percent of the drip systems in Sadat area, which was the maximum frequency of occurrence, had EU's less than 50 percent. It was also observed that 33.3%, 26.9%, and none of the drip systems in Bostan, Wadi-Natron, and Sadat ,respectively, were in the acceptable limits of EU (about 80 percent EU).

Major factors responsible for low emission uniformity included: clogging of emitters, leakage, low operating pressure, mixed and broken emitters, inadequate filtration, insufficient control valves, and lengthy laterals. The study revealed that poor EU was not only due to improper design but also due to inadequate system maintenance with respect to leakage, clogging, insufficient filter capacity and system cleaning. Prevention rather than reclamation, has been the best solution to reducing or eliminating clogging. Preventive maintenance includes water filtration, field inspection, pipeline flushing, and chemical water treatment.

Summary and Conclusion

Results showed that most of the sprinkler and drip irrigation systems are performing poorly. However, the analysis also showed that uniformity coefficients greater than or equal to 80% occurred for 15.4% of the sprinkler systems. Emission uniformities equal to or greater than 80% occurred for 20% of the drip systems. This suggests that high uniformity coefficients and high emission uniformities are possible for properly designed and managed sprinkler and drip systems. Major factors responsible for low performance of sprinkler systems included: low operating pressure, leakage, wide sprinkler spacing in related to actual wetted diameter, non-perpendicular riser orientation, riser vibration, and mixed sprinklers. The poor water distribution may be improved by using the correct sprinkler nozzle pressure and limiting the sprinkler spacing to 50 percent of the sprinkler wetted diameter.

Major factors responsible for low emission uniformity of drip systems included: clogging of emitters, leakage, low operating pressure, mixed and broken emitters, and inadequate filtration. The study revealed that poor EU was not only due to improper design but also due to inadequate system maintenance. Prevention rather than reclamation, has been the best solution to reducing or eliminating clogging. Preventive maintenance includes water filtration, field inspection, pipeline flushing, and chemical water treatment.

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Fig. 1. Frequency distribution of uniformity coefficient for hand-move, side-roll and fixed sprinkler systems.

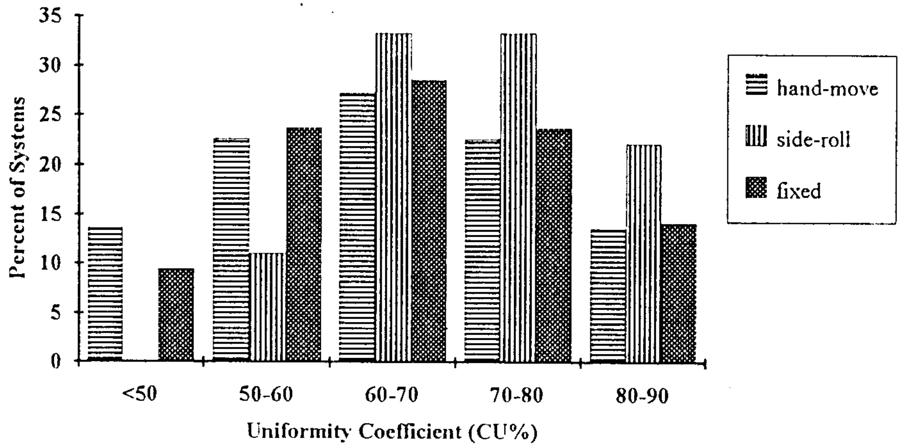

Fig. 2. Frequency distribution of uniformity coefficient (CU%) for hand-move system at Bostan and South-Tahrir areas.

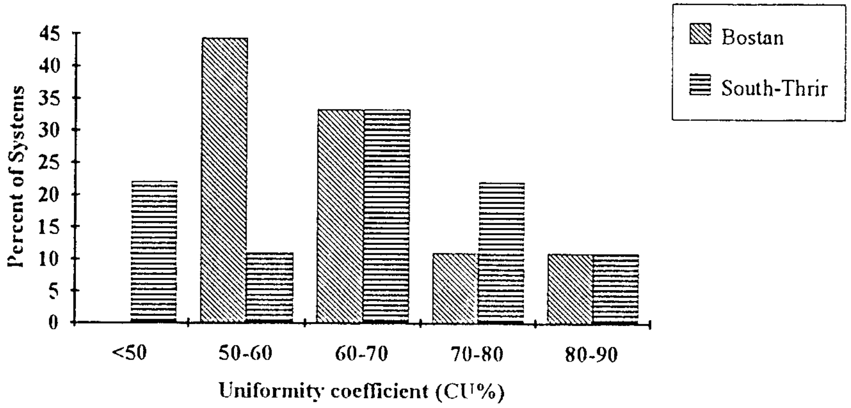

Fig. 3. Frequency distribution of emission uniformity for drip irrigation systems.

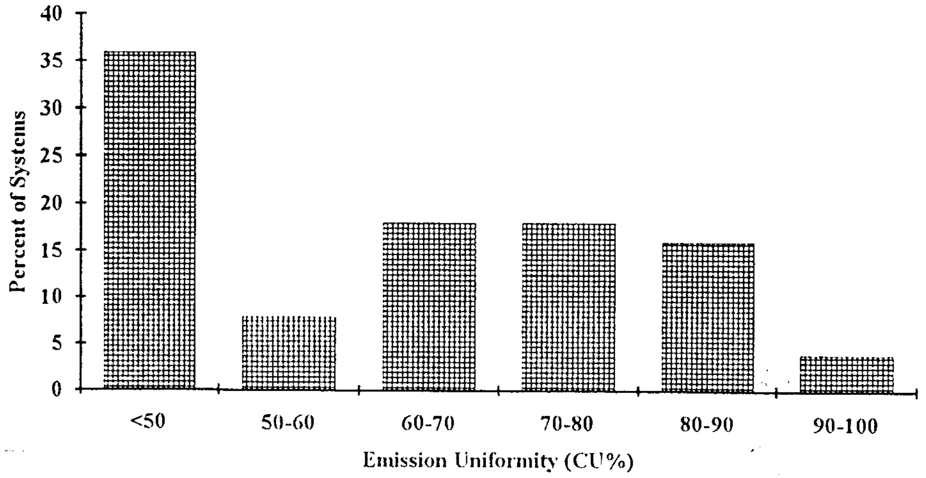

Fig. 4. Frequency distribution of emission uniformity for drip systems at different areas