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A comparative evaluation of three popular irrigation systems for tomato cropping in a semi-arid region of Kenya

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Abstract: *This paper compares the widely used three irrigation systems, viz., drip, sprinkler and furrow, using the data observed in a laboratory farm located in the semi-arid region of Kenya. For these irrigation systems, the total irrigation requirements were 479.50, 610.55, and 783.50, respectively, but with same 428.95 mm of net irrigation requirement (NIR). The respective application efficiencies for the three systems were 89.72%, 70.31, and 54.54%, indicating the drip irrigation system to be more efficient than the others in this study.*

Key words: *water management, drip irrigation, semiarid areas*

INTRODUCTION

Substantial increase in yields of vegetable crops has been observed by adopting the drip irrigation method. The method reduces salt concentration in the root zone when irrigated with poor quality ground water. In comparison with surface irrigation methods, drip irrigation can achieve 90% or more application efficiency, which can hardly be achieved by other methods of irrigation (Michael, 1994).

Bastug *et al* (2006) carried out a study to determine the effects of irrigation on flowering, flower quality, and water use efficiency (WUE) of gladiolus (Gladiolus grandiflorus L.) planted in glasshouse in winter and irrigated by drip irrigation under Mediterranean conditions. It was determined that every mm of water is increasing flowering percentage of gladiolus about 0.3%. Yuan *et al* (2006) evaluated experimentally the effects of different amount of irrigation water on the growth and yield of cucumber under a rainshelter and found the water application due to drip irrigation to be convenient, simple, easy, and cost effective under a rainshelter. The experimental study of Incrocci *et al* (2006) with tomato plants (cv. Jama), grown in glasshouse and watered by conventional drip irrigation or by subirrigation (trough bench system), revealed that subirrigation can be a tool to reduce the water consumption and nutrient runoff in closed-loop substrate culture of tomato conducted with saline water. The effect of irrigation frequency on soil water distribution, potato root distribution, potato tuber yield, and water use efficiency was studied by Wang *et al* (2006). The drip irrigation frequency was found to affect soil water distribution, depending on potato growing stage, soil depth, and distance from the emitter. Şahin *et al* (2005) investigated microbial organisms for use in prevention of clogging in drip irrigation. A total of 25 fungi isolate and 121 bacterial strains were isolated from water samples collected from drip irrigation systems in tomato greenhouses in the eastern Anatolia region of Turkey. The results showed that the antagonistic bacterial strains tested in the genus Bacillus spp (ERZ, OSU-142) and Burkholdria spp (OSU-7) have the potential to be used as anti-clogging agents for treatment of emitters in drip irrigation system. This study demonstrated that antagonistic microorganisms can be utilized for treatment of clogging in drip irrigation systems. A similar greenhouse study was carried out by Rouphael *et al* (2005) during the spring-summer season to determine the influence two irrigation systems (drip and subirrigation) and two nutrient solution concentrations (2.0 and 4.1 dS m_1) on substrate electrical conductivity (ECe), growth, yield, fruit quality (dry matter, carbohydrates, protein, Vitamin C), yield water use efficiency (WUEy) and tissue mineral composition of zucchini squash (Cucurbita pepo L.).

In the dry lands of Kenya, water deficit is the primarily responsible for limiting agricultural yields. If irrigated optimally, these areas have high yield potential because of high solar radiation, favorable day and night temperatures, and low atmospheric humidity conditions that decrease the incidence of pests and diseases compared to areas in temperate zones. To maximize crop yields per unit of supplied water in these dry lands, it is necessary to ensure that maximum of the available moisture is used through plant transpiration and minimum is lost through soil evaporation, deep percolation, and transpiration from weeds. High efficiency of irrigation systems not only increase the crop yield but also ensure the optimum use of available resources. On the other hand, the inefficient use of irrigation water in arid areas is not only wasteful but often leads to salinization of the soil profile. Irrigation systems that are effective and efficient salinity control measures are employed. To this end, it is in order to perform a comparative evaluation of different irrigation systems. Thus, the objective of this paper is to compare the performance of widely used drip, sprinkler, and furrow irrigation systems for their suitability in semi-arid areas of Kenya.

STUDY AREA

The NYS Yatta Agricultural Institute farm (Fig 1) located in semi-arid region (agro-ecological zone 4) of Kenya is selected for the study. It receives an average rainfall of 650 mm per year, which shows a bimodal distribution (Figure 2). The temperature ranges from 12°C to 26°C. The monthly potential evaporation ranges from 115 mm in July to about 160 mm in October with an annual evaporation of 1625 mm. The evaporation exceeds the rainfall in all months except April and November. The major soils in the study area are distinguished as moderately well drained friable sandy clay loams to sandy clays and well-drained friable red to dark reddish brown clays with a tendency to crack on drying. These soils exhibit high infiltration rate, and seepage and percolation losses are quite high forcing many commercial farmers to use drip and overhead irrigation systems, grow drought resistant crops, and undertake ranching activities. Yet, the climate of this zone is best-suited for horticultural production. The soils are hydrologically grouped into group C with effective water holding capacity of 0.14 mm/mm and a minimum infiltration rate of 4.32 mm/hr (Moore, 1979).

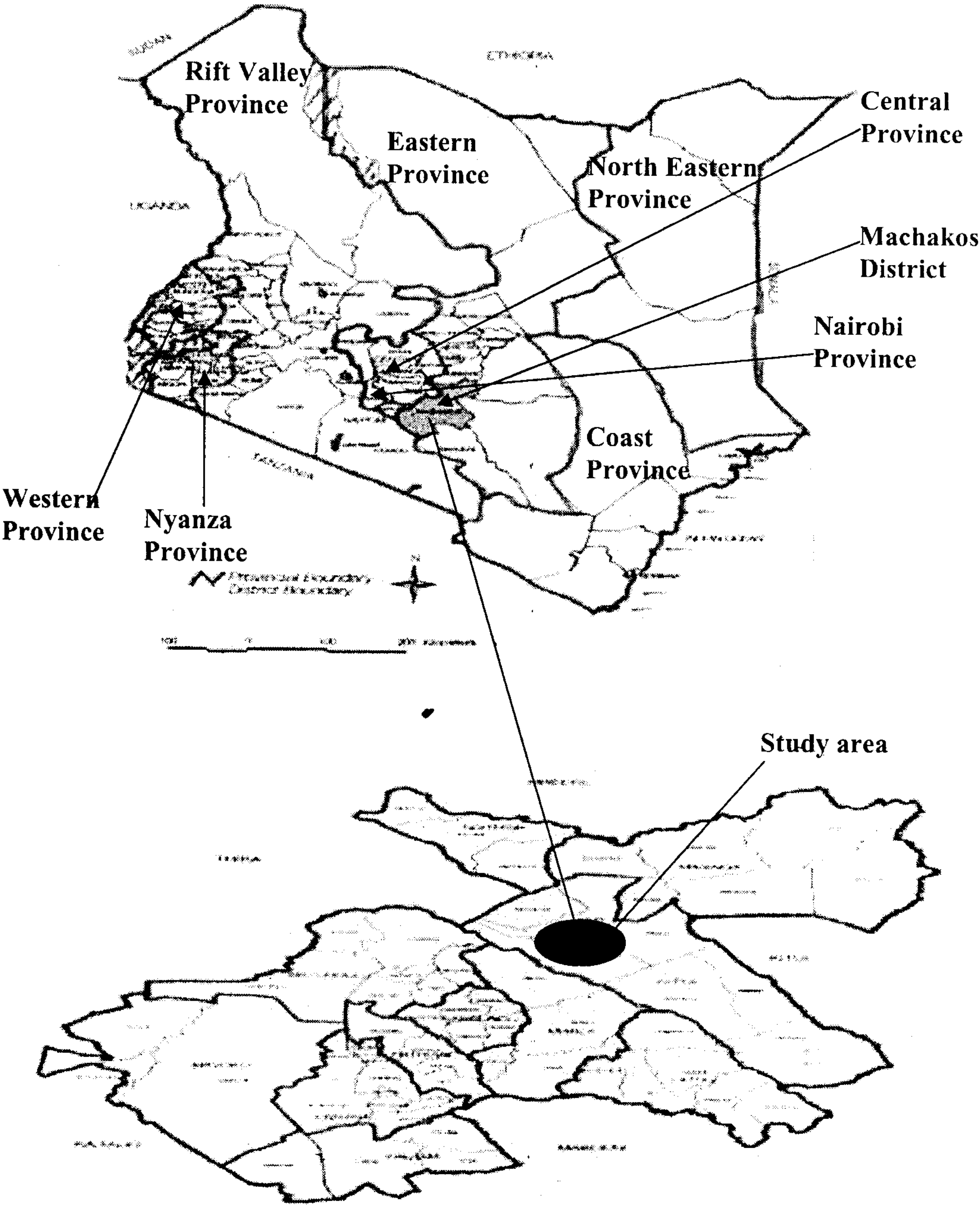

Figure 1. Location map of study area in Kenya

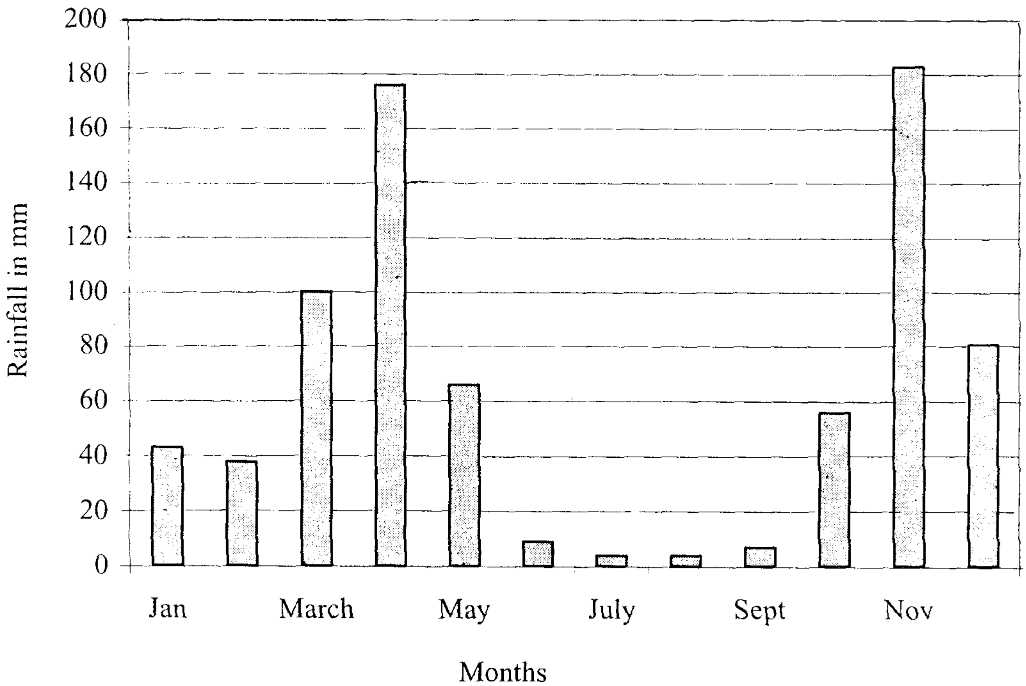

Figure 2. Rainfall pattern in the study area

EXPERIMENTAL SETUP

To evaluate the suitability of irrigation methods for small-scale farmers in the Yatta Plateau, experiments were conducted on a small farm with an area of 500 on Tomato crop in 2001 using drip, sprinkler and furrow irrigation systems. In sprinkler irrigation, the main irrigation facility of the Institute farm was utilized for water supply at the required operating pressure of 15 m. Based on tensiometer observations, the field was irrigated at 4-d interval and the fertilizer was applied manually during the growing period of the crop. In furrow irrigation, water was supplied from the main supply line/pipe and allowed to fill the furrows constructed prior to planting. Irrigation was allowed when the moisture content depleted by 60%. In drip irrigation plastic/polythene lined earthen/dugout small ponds were developed at 1 m above the ground surface to maintain the required pressure of 1 m for emitters. Drip line was laid down as per the spacing between crop rows.

RESULTS AND DISCUSSION

For computation of crop water requirements, crop coefficients (K_c) that represent the evapotranspiration of a crop grown under optimum conditions for optimum production were estimated as the ratio of actual (E_{tc}) to potential (E_{to}) evapotranspiration, i.e. E_{tc}/E_{to}. The evapotranspiration for the twelve months was computed using the Penman-modified method. Table 1 gives the climatic factors considered and the resultant reference/potential evapotranspiration. The highest E_{to} (= 163.65 mm/month) was observed in March, and the lowest (= 100.80 mm/month) in June. Table 2 shows the K_c – values for tomato at different growth stages spanning 170 days. It is seen that the average values of K_c ranged from 0.45 (initial stage) to 1.20 (mid term stage).

Table 1. Evapotranspiration computed using CROPWAT

Month	Temperature Max (°C)	Temperature Min (°C)	Average sunshine hours	Average humidity (%)	E_{to} (mm/month)
January	23.67	12.51	10.6	40	140.12
February	23.36	12.01	10.6	60	126.28
March	25.10	21.01	10.5	50	163.65
April	24.20	21.61	10.1	40	147.0
May	24.61	21.61	10.1	40	144.77
June	1 7.71	7.69	10.0	50	100.80
July	17.42	8.84	10.0	50	102.92
August	17.42	8.43	10.1	40	116.25
September	22.63	8.16	10.3	30	148.50
October	24.86	10.27	10.4	50	154.69
November	21.70	11.15	10.4	50	138.00
December	21.24	12.43	10.6	60	147.25
Average annual evapotranspiration					1630.23

Table 2. K_c values for tomato crop and the respective length of the growth stages

Stage	K_c Range	Average K_c	Number of days
Initial stage	0.4 – 0.5	0.45	30
Crop production	0.7 – 0.8	0.75	40
Mid term	1.1 – 1.3	1.20	60
Late season	0.8 – 0.9	0.85	40
Average length of the growing Season			170

The net crop water requirement or net irrigation requirement (NIR) can be taken as the difference between the crop water requirements and the average effective rainfall (P_e) that represents the rainfall amount stored in the root zone. P_e is computed as:

$$P_e = 0.8P - 25 \qquad \text{if rainfall (P)} \geq 75 \text{ mm/month} \tag{1}$$

$$P_e = 0.6P - 10 \qquad \text{if rainfall (P)} \leq 75\text{mm/month} \tag{2}$$

and

$$NIR = E_{tc} + \text{Seepage or Percolation} - P_e \tag{3}$$

The computed NIR-values are shown in Table 3. Apparently, the highest (122.34 mm) water requirement occurs in May, and the minimum (92.63 mm) in July, and total NIR equals 428.93 mm.

Table 3. Net Irrigation Requirement for 2001

Period→	May	June	July	August	Total
E_{to} (mm)	144.70	100.80	102.92	116.25	-
K_c	1.05	1.20	0.90	0.80	-
Etc (mm)	151.94	120.96	92.63	93.00	460.78
Rainfall (mm)	66.00	9.00	4.00	4.00	-
Pe (mm)	29.60	0.00	0.00	0.00	29.60
NIR (mm)	122.34	120.96	92.63	93.00	428.93
NIR (mm/day)	4.1	4.1	3.1	3.1	
Drip (mm/day)	4.6	4.7	3.5	3.3	
Sprinkler (mm/day)	5.7	6	4.5	4.3	
Furrow (mm/day)	7.1	7.3	6.1	5.8	

As above, the moisture levels monitored by tensiometers were allowed to deplete by 60% for next irrigation. Table 3 compares the different irrigations systems, viz., drip, sprinkler, and furrow. In all the four months (May – August) of drip irrigation, the NIR values were closest with that of the available water, leading to inferring that the minimum losses occurred in this irrigation system. On the other hand, the greatest variation was observed in furrow irrigation, implying the occurrence of maximum losses. Describing the efficiency of the irrigation system as the percent ratio of the amount of water available in the root zone to the amount of water supplied, Table 4 shows drip irrigation system to be the most efficient with efficiency equal to 89.72%, and furrow system the least with efficiency equal to 54.54%. With efficiency of 70.31%, the sprinkler system performed better than the furrow, but poorer than the drip.

Table 4. Comparison of drip, sprinkler, and furrow irrigation systems for 2001

Month	NIR (mm/day)	Drip (mm/day)	Sprinkler (mm/day)	Furrow (mm/day)
May	4.1	4.6	5.7	7.1
June	4.1	4.7	6.0	7.3
July	3.1	3.5	4.5	6.1
August	3.1	3.3	4.3	5.8

Table 5 provides various performance indicating parameters for all the considered irrigation systems. It is seen that, given the amount of water, drip irrigation system allows to irrigate twice and 1.4 times the area irrigable with furrow and sprinkler systems, respectively. The average efficiency obtained with drip irrigation was 89.72% (Table 5) with the highest (93.94%) in August. The average efficiencies for sprinkler and furrow were 70.31% and 54.54%, respectively. Direct evaporation from the soil surface and water uptake by weeds is seen to have reduced because of less soil surface area being in contact with water. Drip irrigation system required less energy than conventional pressurized systems or even no energy for small systems, as in this study. Compared to other forms of irrigation, the labor cost was very low in drip irrigation system because only one person was employed to operate the system when irrigating, lasted for a minimum period of 7 years although some can last longer depending on the quality, and allowed optimum application of nutrients with almost negligible maintenance. In Keny, a small unit of drip irrigation covering an area of 500 m^2 costs $300. Fertilizer costs and nitrate losses are reduced considerably when the fertilizer is applied through the irrigation water (Fertigation). Besides fertilizers, water additives such as herbicides, insecticides and fungicide can be supplied to improve crop production.

Table 5. Efficiencies of drip, sprinkler and furrow irrigation systems used

Month	Drip (%)	Sprinkler (%)	Furrow (%)
May	89.13	71.93	57.75
June	87.23	68.33	56.16
July	88.57	68.89	50.82
August	93.94	72.09	53.44
Average	89.72	70.31	54.54

It was observed in the study that when drip lines were placed close to a row of plants, the root zone tended to be relatively free of salt accumulations, for the salts always accumulate towards the edge of the wetted area. Here, it is noted that salts accumulate in the middle of the root zone in surface irrigated fields. In drip irrigation, the water distribution during infiltration is governed by hydraulic properties of the soil and discharge of emitter. Since the drip can supply water more frequently than others, the irrigation regime leaves a zone of wetted soil with lowered salt content, beneficial for root activity. Furthermore, applying water directly on the soil surface eliminates the opportunity for salts to be absorbed through the leaves, as possible in the most durable sprinkler irrigation. In the furrow system, the construction of furrows is a priory requirement before the crop is grown, and it is very expensive, almost out of reach of many small-scale farmers though its maintenance costs are moderate.

The above most attractive drip irrigation has its own limitations. Its emitters often get clogged, causing poor water distribution along the drip lines and, in turn, affecting the plant growth; requires (a) suitable filters to prevent clogging and (b) more elaborate design than the other methods; and careful management to ensure salts not migrating back to the active root zone. Furthermore, accuracy in water management is essential for irrigating with more water than the plant requirements would result in the loss of most benefits of drip irrigation. Advantageously, since the plant activity is limited to the soil zone wetted by the drip emitter, usually a much smaller soil volume is required in drip irrigation than that wetted by full-coverage due to sprinkler or surface irrigation.

CONCLUSION

With efficiencies of 89.72%, the drip irrigation was the most efficient irrigation system compared to the other sprinkler and furrow systems, required no energy for operation, was more easily manageable than others, and yielded very high fertilization application efficiency. Since water is relatively costly in dry or semi-arid parts of Kenya, it is the most suitable method of irrigation.

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