EVALUATION OF SUBSURFACE IRRIGATION SPACINGS FOR BEAN PRODUCTION

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Subsurface irrigation with 60-, 90- and 120-cm spacings were compared to furrow irrigation with a 60-cm spacing for bean (*Phaseolus vulgaris* L.) yield, yield quality, amount of water use, water use efficiency and soil water distribution. Subsurface irrigation at 60- and 90-cm spacings were comparable to furrow irrigation in bean yield and quality. The 90-cm spacing produced the highest bean yield with no change in quality and had the highest water use efficiency. The 90-cm spacing also resulted in fairly uniform soil moisture content with depth relative to the most active root zone. The average water use with subsurface irrigation was 54.1% of that with furrow irrigation.

INTRODUCTION

Throughout the development of irrigated agriculture, the major concern has been water. As irrigation water supplies become scarce in arid and semi-arid regions, more efficient water application methods become highly important. Standard irrigation methods are particularly wasteful of water in arid lands. A new method which promises a higher water use efficiency is subsurface irrigation.

The subsurface irrigation method used in this study consists of buried perforated pipes through which water is applied to the root zone. Water seeps out and reaches the plant roots through capillary action in the soil. Subsurface irrigation has many potential benefits (Cole 1971) such as saving water, beneficial crop response, labor saving and others. One disadvantage of subsurface irrigation is the high capitalization due to pipe cost and installation expenses (Hagood 1972). Narrower spacings will result in the use of more pipe and a higher cost per unit area to be irrigated and vice versa.

Successful use of subsurface irrigation depends on its design adequacy. Water source, spacing and depth, and flow rate through the buried pipe are important design factors. Many investigators have used subsurface irrigation with different spacings for various crops (Bryan and Baker 1964; Zetzsche 1964; Pohjakas 1966; Zetzsche and Newman 1966; Mitchell and Usherwood, 1967; Anonymous 1968; Hoskyn and Bryan 1969). The depth of installation is determined by the root zone of different crops and tillage operations but the 30- to 50-cm depth is reported to be the most common for shallow-rooted crops (Bryan and Baker 1964; Anonymous 1968; Hoskyn and Bryan 1969; Edlin 1970).

Hoskyn and Bryan (1969) concluded that a 95-cm lateral spacing is preferable to a 190-cm spacing. The appropriate spacing for cotton (*Gossypium hirsutum* L.) and field corn (*Zea mays* L.) was found to be 100 cm (Newman 1965; Mitchell and Usherwood 1967). Mitchell and Usherwood also found that for turf (*Cynodon sp.*) on silt loam soil a 60-cm spacing gave the most uniform growth. Pohjakas (1966) conducted experiments on moisture distribution from laterals with different spacings and a high water application rate. He concluded that satisfactory distribution in the top 120 cm of soil could be obtained with spacings up to and including 150 cm in a sandy loam soil.

Subsurface irrigation has been compared with other standard irrigation methods by different investigators (Edlin 1970; Cole 1971). Cole reported an estimated range of water savings from 25 to 50% for row crops. In another report, it was shown that water saving can be as high as 75% with proper design of the system (Anonymous 1972).

Water is the major concern in development of irrigated agriculture in Iran. The purpose of this study was to compare furrow irrigation and subsurface irrigation at different lateral spacings for bean yield, yield component, quality, and water use efficiency. Soil moisture distribution was also examined for all irrigation treatments used in this experiment.

MATERIALS AND METHODS

Bean plants (*Phaseolus vulgaris* L.) were grown in plots under furrow and subsurface irrigation. The experiment was conducted on a silty loam soil on the Bajgah experimental field at the College of Agriculture located 16 km North of Shiraz, Iran. The physical properties of soil are shown in Table I.

TABLE I PHYSICAL PROPERTIES OF THE FIELD SOIL

Depth (cm)	Texture	Sand	Silt	Clay	Bulk density	Field† capacity	Permanent† wilting point
			%		(g/cm³)		%
0-30	Silty loam	25	48	27	1.66	38	13
30-60	Silty clay loam	8	38	54	1.68	40	18

† Volumetric soil water content.

Furrow irrigation with a 60-cm spacing of furrows and subsurface irrigation with 60-, 90- and 120-cm spacings of the pipe lines were designed and installed on plots 5 X 20 m. On each plot seven rows of bean plants were planted 60 cm apart. Seeds were sown on 15 May 1974 at a rate of 100 kg/ha. The experimental design was a completely randomized block with four replicates.

With furrow irrigation, the seeds were planted in the middle of the ridges. The irrigation water requirement was calculated from the gravimetric determination of soil water in the root zone prior to irrigation. The maximum root depth of 48.6 cm was observed at the time of maximum coverage of the crop. The soil water content was raised to field capacity every 7 days (Table I). An irrigation application efficiency of 0.7 was used in the irrigation requirement calculation (Bahrani and Moayedi 1972). Water was applied to the furrows through siphons from a plastic-lined equalizing ditch located along the experimental plots.

Crop row spacing was 60 cm in all subsurface irrigation plots. (Fig. 1). With subsurface irrigation of 60-cm spacing, seeds were planted in seven rows placed over the water source. On plots with the 90-cm spacing, three out of seven rows of plants were located on the water source and the remaining four rows of plants were placed between the water sources. The distance of plant rows nearest to the water source was 30 cm. On plots with 120-cm spacing, four out of seven rows of plants were located on the water source and the remaining three rows were placed at the midpoint between the water sources.

With subsurface irrigation, water was applied through 17.5-mm i.d. du Pont "Viaflo" porous plastic tubing, (E.I. du Pont de Nemours and Co. Inc., Wilmington, Delaware, U.S.A.) placed 30 cm below the soil surface. Soil water was replenished through micropores in the pipe walls. Subsurface porous pipes were connected to the reservoir through polyvinyl chloride plastic pipe 25.4 mm i.d. The water reservoir provided the system with sufficient head for water flow. The amount of water for each irrigation treatment was controlled by a main valve and recorded with a flow meter. A mercury manometer was used to control the operational pressure head of 200 cm of water (Anonymous 1972). This manometer was placed just after the main valve and before the main flow meter. The volume of water used for each irrigation treatment was carefully recorded for each 7-day interval. Whenever moisture was observed near the soil surface, the flow rate was decreased by the controlling valve.

Soil water content in all the treatments was determined on the 4th day after irrigating the furrows during the growing season by a neutron scattering probe, Model 2651, with scaler rate meter, serial no. 841, manufactured by Troxler Laboratories, Raleigh, North Carolina, U.S.A. With subsurface irrigation, access trubes were installed at 0-, 15- and 30-cm distances from the water source on plots with 60-cm spacing; 0-, 22.5- and 45-cm distances from the water source on plots with 90-cm spacing and 0-, 30- and 60-cm distances from the water source on plots with 120-cm spacing. Access tubes were also placed on the middle of ridges, between the rows and 15 cm from the middle of the furrow. Readings were taken at depths of 30, 45 and 60 cm in each access tube. Soil water content at depths above 30 cm was determined gravimetrically at 0- to 15- and 15- to 30-cm depths, at which depths the neutron probe was not considered reliable.

Evaporation from a free water surface was also measured from a U.S. Class A pan installed near the experimental site.

Plants located on and away from the water source from all the plots were harvested separately at the same time on 2 September 1974. The number of pods per plant, number of seeds per pod and 1,000-seed weight were determined for each irrigation treatment. The protein content of the bean was determined by the Kjeldahl method (William 1970).

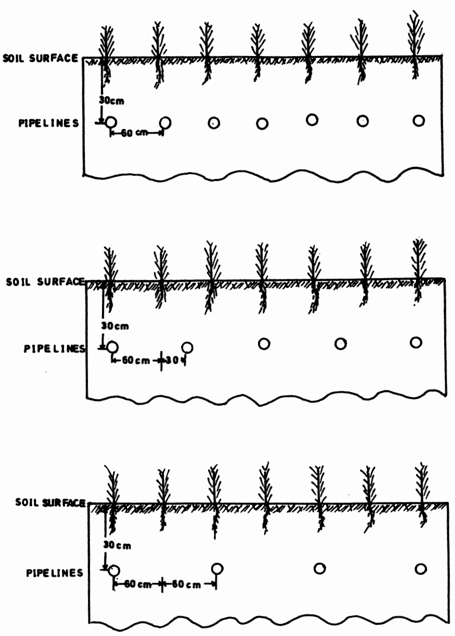

Figure 1. A sketch showing the layout of pipe lines and the crop rows at the various subsurface irrigation spacings.

RESULTS AND DISCUSSION

Crop Production

Bean yield, yield component and quality with furrow and subsurface irrigation at different spacings are shown in Table II. Subsurface irrigation at the 60- and 90-cm spacings produced a bean yield comparable to furrow irrigation. Sichani (1974) reported that subsurface irrigation at a 60-cm spacings resulted in the same yield as furrow irrigation. On the other hand, subsurface irrigation at 60- and 120-cm spacings resulted in significantly lower bean yields than at the 90-cm spacing. The significantly higher number of pods per plant for the subsurface irrigation treatment with a pipe spacing of 90 cm probably caused the higher yield for this treatment (Table II). Since irrigation treatments had no significant effect on vine yield, number of seeds per pod, 1,000-seed weight, or protein content, about the only thing left that may have caused the relatively high yield in the furrow irrigation treatment would be the number of plants per row. This was not recorded. The results of this experiment indicated that with subsurface irrigation, only a 90-cm spacing is preferable to other spacings for bean production.

Water Use

The rates of water use with furrow and subsurface irrigation during the growing season and the evaporation rates from the U.S. Class A pan are shown in Fig. 2. Considerable differences are evident between irrigation treatments. In general, the rate of water use was lower with subsurface than with furrow irrigation. Among the different subsurface irrigation spacings, the 60- and 120-cm spacing showed the highest and the lowest water use during most of the growing season, respectively. During the latter part of the growing season (podding and pod filling), however, the rates of water use with furrow and with subsurface irrigation at the 90-cm spacing were the highest. At this time, the water application rate was consistently decreased with subsurface irrigation at the 60-cm spacing to improve a very minor anaerobic condition in the root zone. This might not have seriously lowered the bean yield because subsurface irrigation at the 60-cm spacings resulted in the same yield as furrow irrigation (Table II). Similar results were reported by Sichani (1974) with no waterlogging in subsurface irrigation.

The total amount of water use during the growing season is shown in Table III. In general, water use was significantly less with subsurface irrigation. The 90-cm spacing, which gave approximately the same yield as furrow irrigation, used only 56.2% as much water. Similar results were

TABLE II. YIELD, YIELD COMPONENT AND QUALITY OF BEANS WITH DIFFERENT IRRIGATION METHODS AND SPACINGS

Irrigation methods	Lateral spacings (cm)	Yield: Bean (kg/ha)	Yield: Vine (kg/ha)	Yield component: No. pods/ plant	No. seeds/ pod	1,000-seed weight (g)	Protein content (%)
Furrow	60	1,604 *ab**	1,930 *a*	18.3 *b***	4.0 *a*	175.2 *a*	22.6 *a*
Subsurface	60	1,027 *bc*	2,040 *a*	21.2 *b*	4.0 *a*	158.3 *a*	25.6 *a*
Subsurface	90	1,731 *a*	2,020 *a*	33.3 *a*	3.7 *a*	160.4 *a*	23.5 *a*
Subsurface	120	742 *c*	2,040 *a*	15.4 *b*	3.6 *a*	151.5 *a*	23.3 *a*

* Significant at 5% level.

** Significant at 1% level. Means followed by common letters are not significant by Duncan's multiple range test.

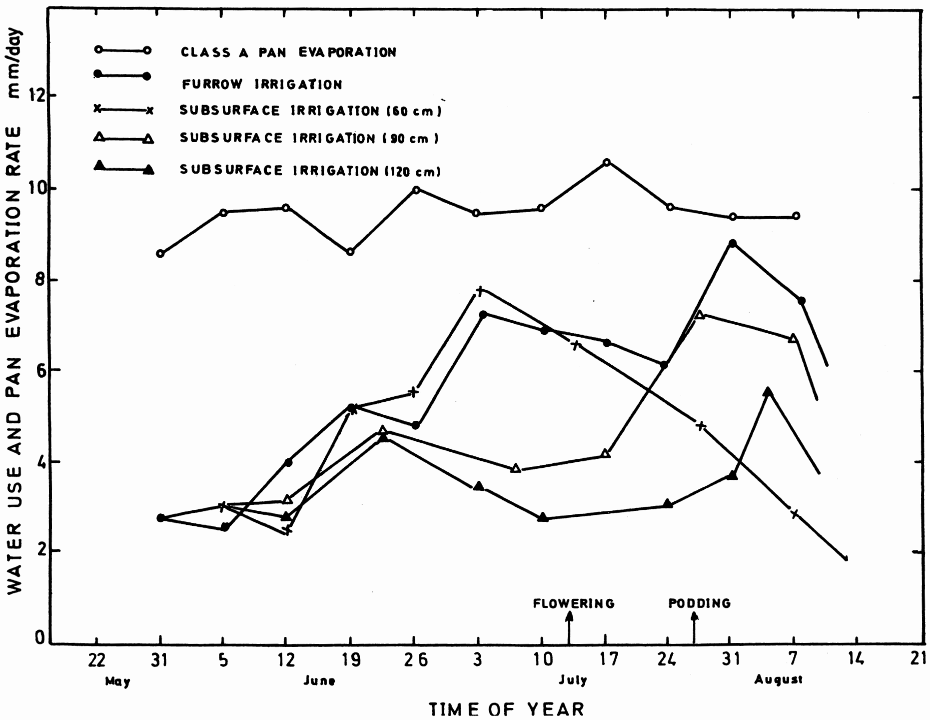

Figure 2. Rate of water use with different irrigation methods and evaporation from a U.S. Class A pan during the growing season.

TABLE III. TOTAL IRRIGATION WATER USE AND WATER USE EFFICIENCY WITH DIFFERENT IRRIGATION METHODS AND SPACINGS

Irrigation methods	Lateral spacings (cm)	Irrigation water depth (cm)	Irrigation water depth %	Water use† efficiency
Furrow	60	61.5 *a***	100.0	0.026 *b**
Subsurface	60	37.6 *b*	61.6	0.027 *b*
Subsurface	90	34.3 *b*	56.2	0.051 *a*
Subsurface	120	27.1 *b*	44.5	0.027 *b*

† Bean yield was used in the calculation.

*, ** Means followed by common letters are not significant at 5% and 1% levels respectively by Duncan's multiple range test.

TABLE IV. VOLUMETRIC SOIL WATER CONTENT AT POINTS BETWEEN THE WATER SOURCES AND AT DIFFERENT DEPTHS WITH DIFFERENT IRRIGATION METHODS AND SPACINGS

Irrigation methods	Lateral spacing (cm)	Distance from water source (cm)	Soil depths (cm) 0-15	15-30	30	45	60
			%				
Furrow	60	0	25.8	29.2	28.8	34.8	35.1
		15			28.5	32.9	34.2
		30			28.7	32.3	34.0
Subsurface	60	0	23.5	27.5	28.4	33.1	34.6
		15			28.3	32.9	34.9
		30			28.9	34.0	35.5
Subsurface	90	0	24.4	28.5	33.7	35.4	36.1
		22.5			29.7	33.8	34.3
		45.0			28.9	33.9	35.6
Subsurface	120	0	23.9	27.8	34.4	36.0	36.2
		30			27.1	32.3	34.8
		60			24.3	31.5	34.7

obtained by Zetzsche (1964) and Newman (1965) for cotton in Texas. They reported comparable cotton yields with 42% less irrigation water. The results in Table III also illustrate the water use efficiency of the irrigation treatments for bean production. The water use efficiency at the 90-cm spacing was twice that of the other irrigation treatments.

Soil Water Distribution

Soil water content measurements are shown in Table IV. Soil water contents at points between the water sources were more uniform at other depths than at 30-cm depth. Since the most important depth is 30 cm, the remaining discussion pertains to this depth. The decrease in soil water content was greater with distance from the water source (from 34.4 to 24.3%) with subsurface irrigation at the 120-cm spacing (Table IV). The soil water content with subsurface irrigation 60 cm from the water source was not favorable for an optimum yield (Vittum et al. 1963). The average bean yield from crop rows 60 cm from the water source was 537 kg/ha compared to 946 kg/ha from rows on the water source. Soil water content at a depth of 30 cm affected the bean yield because the average maximum root depth with subsurface irrigation was 38.2 cm. The results shown in Table IV indicate that the soil water content at 30-cm depth and distances up to 30 cm from the water source was adequate for normal crop growth. Therefore, crop row placement may be possible only at distances up to 30 cm from the water source. This indicates that subsurface irrigation at the 120-cm spacing may be suitable for optimum production for crops with wider row spacings.

CONCLUSIONS

Subsurface irrigation, at pipe line spacings of 60 and 90 cm, was found to be comparable to furrow irrigation for bean production. Considering only subsurface irrigation, bean crop production was the highest at a 90-cm spacing. However, bean quality was not affected by either irrigation methods or spacings in this experiment. Water use was significantly decreased with subsurface irrigation. The highest water use efficiency for bean production was obtained at a 90-cm spacing. Subsurface irrigation at a 90-cm spacing also resulted in fairly uniform soil moisture content with depth relative to the most active root zone. Subsurface irrigation at a 90-cm spacing will result in 33.3% less pipe length per unit area than 60-cm spacings and the cost will be lowered accordingly.

By planting crops that require row spacings wider than 60 cm, at a distance from the water source, subsurface laterals wider than 90 cm could be suggested for optimum crop production.

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