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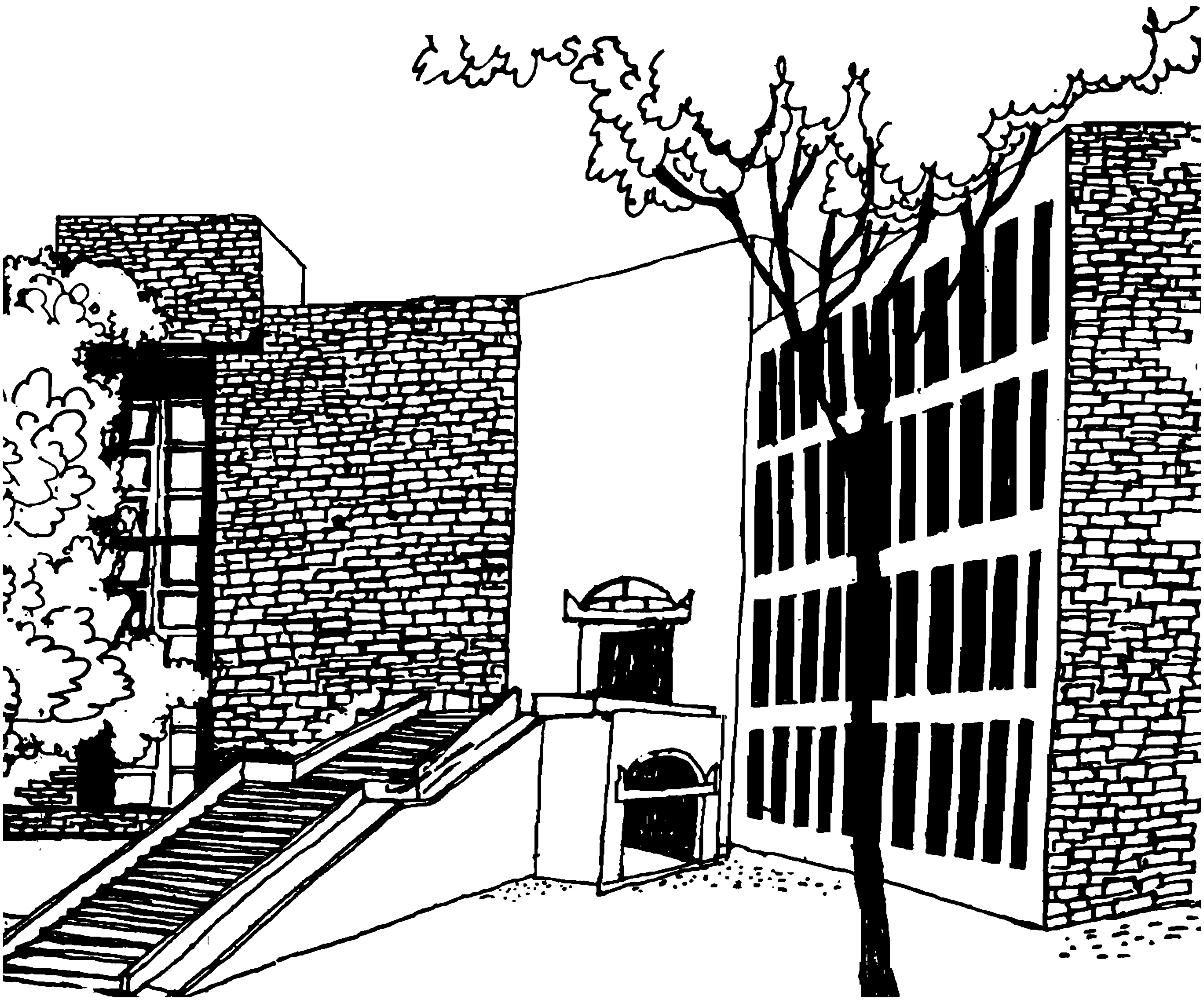

FEASIBILITY OF INTEGRATING SOLAR DESALINATION

By

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Feasibility of Integrating Solar Desalination with Polyhouse in Kutch

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Abstract

In this paper, we examine via simulation, feasibility of using solar stills as partial source of water to irrigate crops inside polyhouses. Need to consider such a possibility arose in the course of our work in Kutch, a region lacking severely in agriculture quality water, besides being hot and extremely arid.

Stills can not, of course, cope with demand from crops in open field. But, analysis suggests, if water requirement is reduced by putting the crop inside polyhouse, distillate blended with local groundwater to increase volume, and blend applied through low-loss microwatering systems, required size of stills reduces sufficiently to warrant trial.

Simulations were carried out for tomato and beet under climatic conditions of Bhuj (Kutch).

Introduction

Kutch is the largest district of Gujarat accounting for 23 per cent of total geographical area of the state. With (Thornwait) moisture index of (-)80, it is extremely arid. Rainfall at Bhuj, its district headquarters averages to just 344 mm, with coefficient of variation as large as 75 per cent. On the other hand, annual pan-evaporation averages to 1840 mm. Day temperatures are high, going up to 45° to 50°C during summer.

Salt affected soils and poor quality groundwater occur widely. Analysis of a sample of 286 wells in Kutch by Bhargava *et al* [1] found that only 18 per cent had (near) agriculture quality water, (EC < 1 dS/m). Thus, agro-climatic conditions in Kutch are indeed harsh from the point of view of conventional agriculture. But it is also a matter of concern that such a large land area should remain unproductive and under-utilized, despite the fact that recent advances in techniques of protected agriculture have helped tackle such problems elsewhere.

Arid areas occur in many other parts of the world. Growing need for food and other products has led to search for technology to make these areas productive. Technologies found useful include microwatering systems [2,3,4,5], plastic mulches, tunnels and greenhouses [6]. We are working on design of a polyhouse with some special features for trial there.

It is clear that in hot, arid areas polyhouse will need effective cooling and shading. In view of shortage of agriculture quality water, desalination facility also appears necessary. Kutch region, especially rural areas also suffer from inadequate and erratic supply of electricity. Mechanisms that depend less on electricity and more on solar energy will be desirable.

In this paper we examine, via simulation, feasibility of basin type solar stills as partial source of irrigation. Evaporation area required (or size) is the key factor on which feasibility rests. We develop estimates of evaporation area needed relative to crop area, at such levels of groundwater salinity as are known to exist in Kutch.

Review of Literature

The idea of mounting a solar still on top of a glasshouse to supply water for irrigation was apparently first proposed by Oztoker and Selcuk in 1971 [7]. Tiwari and Dhiman [8] also considered such a system and developed a mathematical model of glasshouse with still on top. Their aim was to develop a model so that studies on optimization of operational parameters could be done more easily. No mention of actual prototype was made.

Major impediment in making such a system practical is requirement of a rather large basin area. Tiwari and Dhiman stated that daily distillate output of solar still is not sufficient to irrigate an area equal to that of the still. They did not cite the basis of this stipulation, but as we shall see later, this is true under conditions of extremely high salinity. There is need to explore ways to reduce the required size. One way is blending. By increasing the volume of water, blending can help reduce the size of still needed. Moreover, demand for water can be reduced by growing crops in enclosures and further by applying water via low loss microwatering systems.

Basin type solar stills have been installed at several locations in Gujarat to supply drinking water [9]. Due to negligent maintenance, these have largely been abandoned. There is no report of any of these being tried for irrigation. We argue that there may be a better match between demand from plants and supply from stills, since both are driven by a common factor--solar radiation. When it is hot, demand from plants as well as output from stills will be high. Second, whereas demand for drinking water can not be deferred, irrigation can be done periodically. That is, distillate output need not match the demand each day.

In the following analysis, we examine the feasibility of using basin type stills as partial source of water for irrigation under climatic and cropping conditions of Bhuj (Kutch). Merit of this possibility will be judged by basin area required, relative to crop area. Here this is termed still-to-crop area ratio (SCAR). Smaller this (SCAR) value, more promising the possibility. Tomato and beet which are moderately tolerant of salts, are used as examples in simulation. Tomato has very high water requirement, beet relatively less. Analysis is done for open field conditions. An indication is given of likely reduction in SCAR when crop is put inside an encloser, say a polyhouse and water applied via microwatering system. Likely economics of this arrangement is also discussed.

Analysis Procedure

Scheme of analysis is as follows. Assume tomatoes are planted in unit area in open field in Bhuj. Crop is irrigated with water from local well. Quantity of water in well is assumed to be plentiful and its salinity level known. In case salinity level of well water is higher than tomatoes can tolerate, it is blended with distillate produced from stills.

We shall compute daily water requirement of tomatoes, using actual pan-evaporation data of Bhuj and crop coefficient appropriate to its growth stages. Water balance of root-zone is done at 24 hour interval to detect the need for irrigation. When moisture deficit equals a pre-set level, irrigation is done. Each irrigation restores root-zone to field capacity; or to the extent possible if sufficient quantity of the blend is not available. Water given also includes leaching requirement.

Above scheme permits us to compute the basin area needed to meet crop water requirement fully with appropriately blended water. By varying the assumed salinity level of well supply, we obtain a plot of SCAR versus salinity.

Simulation Model

Let

AE	application efficiency (fraction)
CN	curve number
D(t)	deep percolation on day t (mm)
DR	depth of root-zone (m)
EC_c	Crop tolerance to salt level of soil (dS/m)
EC_{iw}	Electrical conductivity of irrigation water (dS/m)
$E_p(t)$	pan evaporation on day t (mm)
ET(t)	evapo-transpiration on day t (mm)
FC	field capacity (mm/m)
I(t)	irrigation water supplied to field during the interval (mm)
IN(t)	water available for irrigation on day t (mm)
K_c	crop coefficient (fraction)
K_p	pan coefficient (0.65)
LE	leaching efficiency (fraction)
LR	leaching requirement (fraction)
M(t)	moisture content of root-zone (mm/m)
MAD	maximum allowable moisture deficiency in root-zone (%)
P(t)	rainfall on day t (mm)
R(t)	run-off on day t (mm)
S	maximum potential retention plus initial abstraction (mm)
t	time (day)
$W_r(t)$	water required to restore the rootzone to field capacity (mm)

Water Balance at Root-Zone

$$M(t+1) = M(t) + \frac{P(t) + I(t) - R(t) - D(t) - ET(t)}{DR} \tag{1}$$

Evapotranspiration

$$ET(t) = K_p * K_c * E_p(t) \tag{2}$$

Daily precipitation (P) and daily pan evaporation (E_p) data of Bhuj used here are for the year 1989, obtained from IMD Pune. For reason of space, only weekly values are shown in **table** 1. Values of crop coefficient are taken from Doorenbos **[10]**.

Run-off

Run-off is calculated using well accepted Curve Number method details of which can be seen in **[11]**.

$$R(t) = \frac{(P(t) - 0.2 * S)^2}{P(t) + 0.8 * S} \tag{3}$$

$$[\ \mathit{if}\ [P(t) > 0.2 * S] \quad \mathit{otherwise} \quad 0\ ]$$

$$S = \frac{25400}{CN} - 254 \tag{4}$$

Factor 0.2 in Equation 3 is impirical estimate of initital abstraction commonly used for agricultural fields. The other factor 0.8 is just its complement. Value of CN used in analysis is 78, which is for row crop and hydrological soil group B under good hydrologic condition. Equation 4 is then used to compute **S**. Using this value and actual rainfall of the day, run-off is computed. Run-off is included here to keep the model general, although during the growth span of crops considered in this analysis (winter months) rains usually do not occur.

Deep Percolation

$$D(t) = (M(t) - FC) * DR \quad [\text{ if } M(t) > FC * DR, \text{ otherwise } 0] \tag{5}$$

Watering Schedule

Irrigation is triggered when

$$M(t) < MAD * FC \tag{6}$$

Leaching requirement for gravity irrigation is given by

$$LR = \frac{EC_{iw}}{5 * EC_c - EC_{iw}} \tag{7}$$

Leaching requirement works out to be 0.15 for tomato and beet.

Assuming that the irrigation losses (inefficiency) is due only to deep percolation, water requirement to restore the rootzone to field capacity, and to meet leaching requirement is given by

$$W_r(t) = \frac{(FC - M(t)) * DR}{AE}$$
$$[If \; LR \leq (1-AE) * LE, \quad otherwise \tag{8}$$
$$W_r(t) = \frac{(FC - M(t)) * DR}{(1-LR) * LE} \;]$$

Irrigation water supplied to field

$$I(t) = W_r(t) \quad [\text{if} \quad IN(t) \geq W_r(t), \quad \text{otherwise} \quad I(t) = IN(t)] \tag{9}$$

Soil has been taken to be clay-loam with field capacity (FC) of 300 mm/m or 30 per cent. Maximum allowable deficit (MAD) has been taken as 50 per cent of field capacity, at all stages of growth. Water balance is done daily.

Distillate Output

Based on long experience in Gujarat, Gomkale **[op cit]** developed following correlation for productivity of deep basin stills.

$$S_p(t) = 4.63 \times 10^{-6} (S_r(t))^{1.545} \tag{10}$$

where

$S_p(t)$ = Distillate output on day t (l/m^2)
$S_r(t)$ = Solar radiation on day t (kcl/m^2)

Expected weekly distillate output from such stills in Bhuj area is shown in the **table 1**. $S_r(t)$ for Bhuj is taken from Mani's Handbook of Solar Radiation Data for India (1980).

Amount of well water to be added to distillate,

$$W_w(t) = \frac{T * S_p(t)}{EC_{wl} - T} \tag{11}$$

where

$W_w(t)$ = Amount of well water (mm)
T = Crop tolerance to salt level of irrigation water (dS/m)
EC_{wl} = Electrical Conductivity of well water (dS/m)

Equation 11 states that the amount of well water in the blend varies inversely with (relative) salinity level of the well water. Higher the salinity or poorer the quality, lower the proportion of well water in the blend. Total blended water used in the entire span of growing season

$$TB_w = \frac{ET_s}{AE} * \frac{(EC_{wl} - T)}{EC_{wl}} + \frac{ET_s * T}{AE * EC_{wl}} \tag{12A}$$

When $LR \leq (1-AE) * LE$, otherwise

$$TB_w = \frac{ET_s}{(1-LR) * LE} * \frac{(EC_{wl} - T)}{EC_{wl})} + \frac{ET_s * T}{(1-LR) * LE * EC_{wl}} \tag{12B}$$

Where

TB_w = Total blended water used in season (mm)
ET_s = Total evapotranspiration of season (mm)

Right hand side of Equations 12A & B have been expressed in the form of two terms, for convenience. First term is the amount of distillate and second the well water that will go to make the total blend used during the season. Note, if EC_{wl} is equal to T; first term vanishes. In other words, well water will be used directly and no distillate will be called for. If a $EC_{wl} >> T$, the second term will become negligible. In other words, blend will contain mostly the distillate.

SCAR and Salinity Level: Simulations

Crop	Tomatoes in open field
T	2 dS/m
Growing season	Standard Week 45 to 9
AE (surface irrigation)	0.65

Root zone is assumed to be at field capacity initially. Water balance of root zone is done at 24-hour interval using Equation 1. Water applied to field (I) at each irrigation is obtained from Equations 8 and 9. Total water applied during the entire season is the sum of all these. For tomatoes, it was 452 mm or 452 litres per square meter of crop area. This includes evapo-transpiration (300 mm), leaching requirement and losses.

In the first run, salinity of well water was kept at 2 dS/m. In this case, all the requirement is met by well water. No distillate is needed. In successive simulations, salinity level of well water was raised in steps of 0.25. Amount of distillate needed to make a suitable blend (for tomatoes EC = 2 dS/m) was obtained from Equations 12A and 12B. The basin area needed to produce this amount is obtained from Equation 10. With salinity of well water at 3 dS/m the basin area came to 0.53 sq.m per square meter of crop.

Figure 1 shows the plot of SCAR versus electrical conductivity of well water for tomato and beet. Simulations for beet were done in the same manner. Beet is slightly more tolerant of salts (T=2.7), has lower water requirement and shorter growing period. Both curves approach limiting values, 1.50 for tomato, 1.20 for beet. These values are reached at very large levels of salinity, upwards of 30 dS/m and therefore not shown in the graph. At these levels, distillate virtually becomes the only source. Most likely, stipulations by Tiwari and Dhiman, mentioned earlier relate to such a situation.

We are not interested in such high levels of salinity. If one could tackle levels up to 4 dS/m, it could be applicable to large part of Kutch. Figure shows that at this level, blending is able to reduce SCAR only marginally to 0.8 for tomato. It is about 0.4 for beet, whose water requirement is much less.

Further reduction in SCAR will be desirable. This can be possible by lowering the water demand. There are many techniques to do this in open field such as mulching etc. More significant reduction occurs when crop is grown inside enclosures. Reduction by 30 to 40 per cent is widely reported in literature. Raman *et al* [12] reported that evaporation inside polyhouse at Navasari, Gujarat was 40% less than open field. This would suggest that when integrated with polyhouse, basin area may need to be only about 60% of that in open field. We shall use this fact in the following analysis.

Economic Feasibility of Stills

Relative crop yield potential due to salinity is given [13] by following relationship

$$Y = 100 - \frac{100 \times (EC_e - EC_c)}{EC_c(0) - EC_c(100)} \qquad (13)$$

Where,

Y	Relative crop yield (%)
ECe	Salinity of soil saturation extract (dS/m), ECe is 1.5 times of ECiw [13]
$EC_c(0), EC_c(100)$	Salinity of soil extract at 0 and 100% yield

Figures in column one of **table 2** show the range of groundwater salinity found in Kutch. Relative crop yield at these levels computed using Equation 13, is shown in column 2. Third column gives the production loss. For instance, with water of EC_{iw} = 3 dS/m, yield will be 80.6% of that with good quality water. Taking the yield in open field (and good water) to be 370 kg/100 m^2, production loss will be 72 kg which at price of Rs.15 per kilogram works out to Rs.1,077 (column 3). Solar still is intended to prevent this loss by providing better quality water blend.

Economic feasibility will have to be judged therefore by comparing its cost with value of production loss. Column 4 shows the required basin area using SCAR values developed earlier. Thus, with well water of EC_{wl} = 3 dS/m, one would need basin area of 53 m^2 in open field cultivation and 32 m^2 in polyhouse. Column 5 gives the annualized cost of still. This includes, cost of capital recovery, annual repairs and maintenance. Pumping cost is ignored because it will be the same for cultivation without the still.

Not expectedly, economics is not favourable in open field, but improves considerably in polyhouse. This is true particularly at higher levels of salinity. The improvement is result of higher yields (greater production loss) and lower size of stills needed for the same area (lower investment).

Columns 6 and 8 show production loss in polyhouse. If only one crop is taken in a year, stills will not be economical except at very high salinity levels. However, it is easily possible to take at least two crops in a year. In that case, stills show significant promise.

Conclusions

In extremely arid areas like Kutch agriculture is handicapped due to shortage of good quality water. Cost effective techniques of desalination need to be developed and integrated with water saving mechanisms such as **polyhouse**. Analysis of such a possibility done via simulation led to following conclusions.

Stills will not be economically viable, even with blending, if cropping is in open field under climatic conditions of Bhuj area. Basin area needed, relative to crop area, does reduce by blending but not enough to make it economical.

When crop is put inside polyhouse and water applied via microwatering system, water demand is reduced and accordingly the size of stills. This arrangement appears economically viable under two conditions:

(i) when salinity levels are greater than 4 dS/m;

(ii) at least two rounds of cropping is done in a year, and the produce is of relatively high value.

When salinity is extremely high, basin area needed is large. Despite this, economics improves. Reason for this, of course, is that yield loss grows non-linearly with increase in salinity level of irrigation water. When salinity is only slightly higher than tolerance threshold of the crop, yield loss is marginal. But after a certain level, further rise in salinity causes much sharper decline in yield.

In view of the above, it does appear worthwhile to build prototypes of polyhouse integrated with solar desalination facility for trial in Kutch.

Table 1

Std WK	Daily Global Insoln during week (kcal/m^{2}d)*	Week's Dist. output (l/m^2)**	Week's Pan Evp. (mm)***	Week's Rainfall (mm)***
1	4262.2	13.1	22.2	0.0
2	4262.2	13.1	23.2	0.0
3	4262.2	13.1	26.4	0.0
4	4262.2	13.1	25.9	0.0
5	4684.3	15.2	28.4	0.0
6	5000.9	16.8	38.0	0.0
7	5000.9	16.8	35.0	0.0
8	5000.9	16.8	38.7	0.0
9	5188.2	17.8	40.0	0.0
10	5328.6	18.5	46.5	0.0
11	5328.6	18.5	40.2	0.0
12	5328.6	18.5	49.0	0.0
13	5418.0	19.0	45.7	3.0
14	5954.6	22.0	57.0	0.0
15	5954.6	22.0	64.5	0.0
16	5954.6	22.0	66.4	0.0
17	5954.6	22.0	76.8	0.0
18	6332.1	24.2	66.0	0.0
19	6395.0	24.6	77.6	0.0
20	6395.0	24.6	70.3	0.0
21	6395.0	24.6	75.5	0.0
22	6066.2	22.7	65.9	0.0
23	5627.8	20.2	79.0	0.0
24	5627.8	20.2	52.4	127.5
25	5627.8	20.2	47.3	0.0
26	5476.0	19.3	55.4	0.0
27	4564.9	14.6	47.2	2.5
28	4564.9	14.6	48.0	1.5
29	4564.9	14.6	38.1	22.2
30	4564.9	14.6	25.8	114.8
31	4493.6	14.3	29.0	0.0
32	4465.1	14.1	34.9	0.0
33	4465.1	14.1	31.2	4.7
34	4465.1	14.1	25.8	102.7
35	4634.2	14.9	25.2	118.1
36	5056.8	17.1	39.6	0.0
37	5056.8	17.1	39.1	0.0
38	5056.8	17.1	36.9	6.8
39	5056.8	17.1	31.5	13.8
40	5100.7	17.3	37.9	13.7
41	5100.7	17.3	35.2	0.0
42	5100.7	17.3	36.8	0.0
43	5100.7	17.3	36.8	0.0
44	4897.7	16.3	39.4	0.0
45	4745.5	15.5	30.9	0.0
46	4745.5	15.5	29.6	0.0
47	4745.5	15.5	25.5	0.0
48	5080.2	17.2	27.3	0.0
49	5916.8	21.8	26.8	0.0
50	5916.8	21.8	21.5	0.0
51	5916.8	21.8	21.2	0.0
52	5916.8	21.8	20.1	0.0

* Mani Anna. Handbook of Solar Radiation Data for India. Allied. 1980.

** Computed using Equation 10

*** IMD, Pune, for year 1989

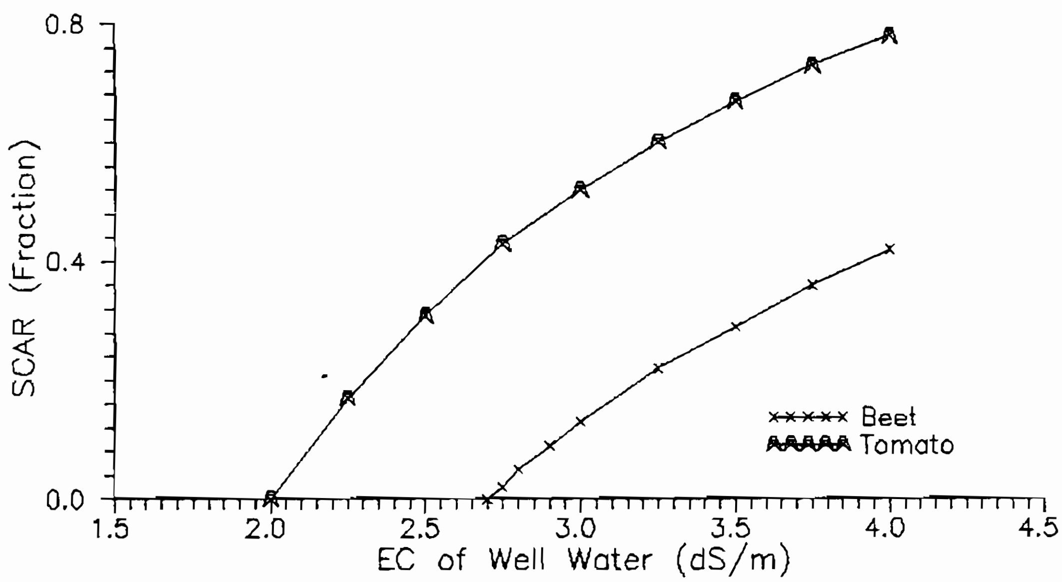
Table 2
Preliminary Economics of Solar Stills as a source of irrigation water

Water quality (dS/m)	Yield Potential (%)	Open field Cultivation			Polyhouse cultivation		
		Prod. loss/ crop (Rs.)	Req. Still Area ($m^2/100m^2$)	Annualized Cost (Rs.)	Prod. loss/ crop (Rs.)	Req. Still Area ($m^2/100m^2$)	Annualized cost (Rs.)
3	80.6	1077	53	5294	2794	32	3176
4	65.7	1905	80	7992	4943	48	4797
5	50.8	2734	104	10389	7093	62	6196
6	35.8	3562	113	11283	9242	68	6796
7	20.9	4390	119	11888	11391	71	7096
8	5.97	5219	124	12387	13540	74	7395

Values used in calculation

Cropped area	100 m^2
ECc (tomato)	2.5 dS/m
Open field (100%) yield	370 kg/100m^2
Polyhouse yield per crop	960 kg/100m^2 **(source [12])**
Sale price	Rs.15/kg
Initial cost of still	Rs.500/m^2
Annual repairs	@ 5% of initial cost
Life of still	20 yrs
Salvage Value	10%
Rate of interest	14% per annum

Figure 1: Size of Still and Quality of Water



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