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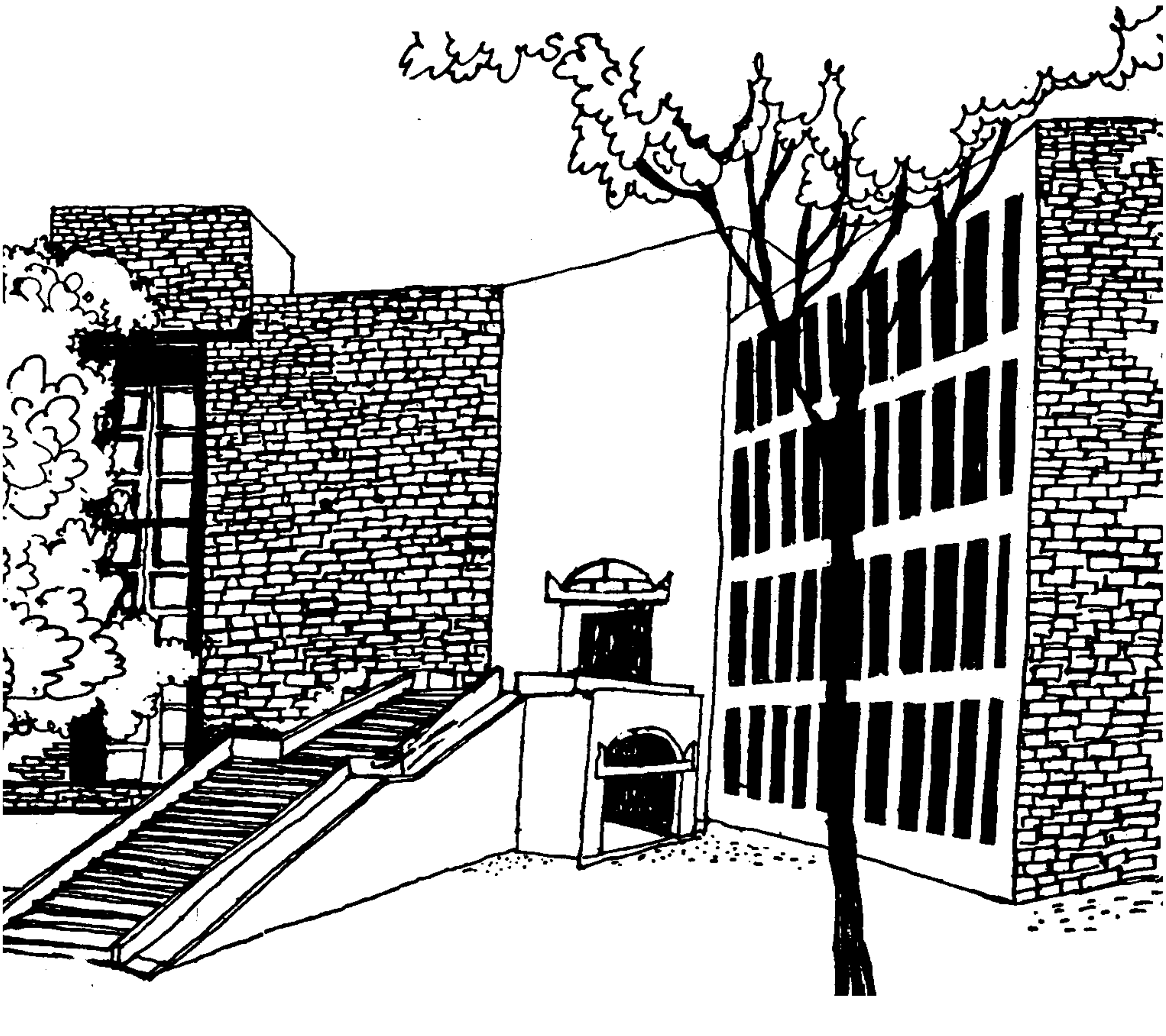

NEED FOR AND POSSIBILITY OF INTEGRATING SOLAR DESALINATION WITH POLYHOUSE IN ARID AREAS LIKE KUTCH

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W P No.1321
July 1996

INDIAN INSTITUTE OF MANAGEMENT
AHMEDABAD - 380 015
INDIA

Need for and Possibility of Integrating Solar Desalination with Polyhouse in Arid Areas like Kutch

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Abstract

Development of agriculture in arid areas like Kutch is impeded because of widespread salinity and scarcity of good quality water. In view of this and the fact that insolation is high, we examine in this paper the possibility of integrating solar stills with greenhouse.

Distillate yield on one hand and water demand from plants on the other are both driven by intensity of radiation. This feature makes the still appealing as a partial source. But, requirement of large evaporation area is a deterrent. Some investigators have reported that one would need a still of same (basin) area as the crop or even more to meet the water demand. This would appear to be true. A considerable reduction in the required evaporation area is therefore needed to make such a scheme feasible.

This matter has been examined here a little more closely than found in literature. In particular, possible reduction by use of blending the distillate with groundwater is analysed. Analysis suggests that if distillate is blended with local water to reduce its salinity to the tolerance threshold of the crop, size of the still can be reduced significantly. Climatic conditions of Bhuj (Kutch) have been used in analysis. Tomato and beet have been used for illustration.

Although, blending offers considerable scope, it is necessary to explore further avenues of reducing the required still size. Use of enclosures (polyhouse for instance) to reduce the crop water demand is suggested as a further important means of this.

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 344 mm. It is very erratic with coefficient of variation of 75 per cent. Annual (pan) evaporation averages to 184 mm. Temperatures vary from 5 C to 28 C in January (Winter) to 25 C to 45 C in June (Summer).

Salt affected soils and poor quality groundwater occur widely. On the basis of a sample of 286 wells in Kutch, Bhargava *et al* [1] reported that only 18 per cent of the sampled wells had water with EC of less than 1 dS/m. That is, those whose water can be used without restriction for a variety of crops.

These are severe conditions. But it is also a matter of concern that such a large land area should remain unproductive and under-utilized.

Arid areas are distributed in many other parts of the world. Growing need for food and other products has led to large scale research to develop technology to make these areas more productive. Some of the newer technologies reported to be effective in tackling the arid areas include microwatering systems [2,3,4,5,6], plastic mulches, tunnels and greenhouses [7]. We visualise great need and potential for their application in arid areas of the state such as Kutch.

With this in view we have initiated work to develop polyhouse with special features to suit the requirement of the region. Such facilities may be used for growing vegetables, medicinal herbs, flowers. These could also be used for raising saplings and propagation of plant material needed by foresters, for re-establishment and afforestation.

Greenhouse design for hot and arid areas will need to have special features such as cooling and shading. Another desirable feature is provision for desalination. This is in view of widespread salinity and scarcity of good quality water. Kutch region, especially rural areas also suffer from frequent interruptions in and deficient supplies of electricity. It will be desirable to take this factor into account in design. Mechanisms that depend less on electricity and more on solar energy will be desirable.

We are interested in integrating solar still with the polyhouse. Evaporation area required is the key factor necessary to examine this possibility. We present an estimate of the evaporation area needed per unit crop area with the quality range of groundwater found in Kutch.

Review of Literature

The idea of mounting a solar still on top of a greenhouse to supply water for irrigation was apparently first proposed by Oztoker and Selcuk in 1971 [8]. They did thermal analysis of such a system. Tiwari and Dhiman [9] considered such a system promising. They also developed a mathematical model of glasshouse with still on top. They sought to improve upon the model of Oztoker and Selcuk by making it less complex so that studies on optimization of operational parameters could be done more easily. No mention of actual prototype was made.

A major impediment in building such a system appears to be requirement of a rather large basin area. Referring to literature, 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 most likely, this does not take into account the possibility of blending. By increasing the volume of water, blending can help reduce the size of still needed.

Basin type solar stills have been installed at several locations in Gujarat to supply drinking water [10]. It is argued here 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 using stored output.

In the following analysis, we shall examine the possibility of using basin type stills as source of water for irrigation under climatic and cropping conditions of Bhuj (Kutch). Merit of this possibility will be judged by still-to-crop-area ratio (SCAR). Tomato and beet are used as illustration crops. Analysis is done for open field conditions. An indication is given also of likely reduction in SCAR when crop is put inside an encloser, say a polyhouse. If blending reduces SCAR significantly below one, we shall proceed further and examine the costs involved which then will enable us to determine the feasibility.

Plan of Analysis

We shall simulate daily water requirement of a moderately sensitive crop (tomato) and a moderately tolerant crop (beet) grown in unit area. Crop water demand is estimated using actual pan evaporation data (of Bhuj) and crop coefficients appropriate to the crop and growth stage. Well water is blended with the daily distillate output to create a supply of water with salinity level equal to the tolerance threshold of the crop. Irrigation water is drawn from this supply when required.

SCAR will be determined through simulation. Quality of well water will be varied to correspond with those found in Kutch. Thus we shall obtain a plot of quality of well water and SCAR.

It is recognized that additional water will be required for use when crops are grown in greenhouse. This will include cooling and cleaning etc. Presently, these requirements are ignored.

We shall do water balance at the root-zone at 24 hour interval. When the moisture content of rootzone reduces to a level equal to the maximum allowable deficit, irrigation will be done. Each irrigation will restore the moisture level of rootzone to field capacity, or to the extent possible if sufficient water is not available. Total water given will include leaching requirement.

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_e	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	recharge capacity (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 was obtained from IMD Pune. For reason of space, only weekly values are shown in **table 1**. Values of crop coefficient are taken from Doorenbos [11].

Table 1

Std WK	Daily Global Insoln during week (kcal/m²d)*	Week's Dist. output (l/m²)**	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	2/5.9	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 by authors
*** IMD, Pune

Run-off

Run-off is calculated using Curve Number method.

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

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

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

Value of CN used in analysis is 78. This is for row crop and hydrological soil group B under good hydrologic condition, is used in analysis. Run-off is included here to keep the model general, although during the growth span of crops considered in this analysis rains usually do not occur.

Deep Percolation

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

Watering Schedule

Irrigation is triggered when

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

Leaching requirement for gravity irrigation is given by

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

Leaching requirement works out to be 0.15 for all three crops considered in this analysis 0.15.

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

$$W_r(t) = \frac{(\ FC - M(t)\ ) * DR}{AE}$$

$$[\textit{If} \quad LR \leq (1 - AE) * LE, \quad \textit{otherwise} \tag{8}$$

$$W_r(t) = \frac{(\ FC - M(t)) * DR}{(1 - LR) * LE}\ ]$$

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 of 300 mm/m or 30 per cent. Maximum allowable deficit has been taken as 50 per cent of field capacity for all crops at all stages of growth. Water balance is done daily.

Distillate Output

Gomkale [10] has given the following correlation for the productivity of deep basin type solar stills. The correlation was developed using several year data on performance of stills installed in Awania village for supply of drinking water.

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

where

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

Weekly distillate output is shown in the **table 1**.

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} = Electric 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. 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 amount of blended water used in a season (mm)

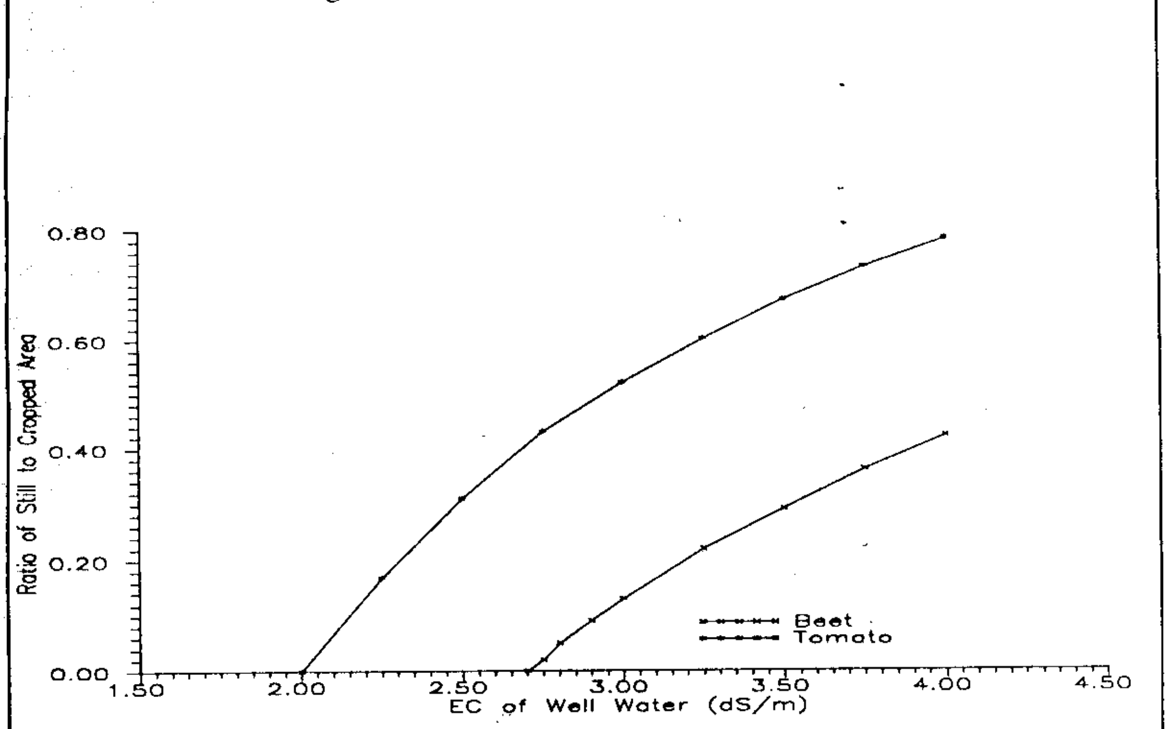
ET_s = Seasonal evapotranspiration (mm)

First term of equation 12A and 12B is the amount of distillate whereas second is the well water. Note, if T is zero, i.e. the crop cannot tolerate any salt, second term of equation 12A and 12B vanish, i.e. no well water will be used. This is what one would intuitively expect. When T is very large, i.e. crop can tolerate direct use of poor quality well water, equations 12A & 12B reduce again to ETs/AE and ETs/(1-LR).LE as intuitively expected.

SCAR and Quality of Well Water

It can be stated at the outset that the size of still required SCAR will depend on crop water requirement, climate of the place and quality of well water. **Figure 1** shows the plot of SCAR versus electrical conductivity of well water for tomato and beet at Bhuj. As expected, poor the quality of well water, larger the required still. Both curves approach a limiting value, 1.55 for tomato, 1.24 for beet. These values are reached when water becomes so poor that distillate virtually becomes the only source. Most likely, this is the value alluded by Tiwari and Dhiman.

Figure 1: Size of Still and Quality of Water



It is seen in the graph that a SCAR of 0.3 will permit use of water as poor as 2.5 dS/m for tomato, and 3.6 dS/m for beet. Whether this is economically worthwhile or not will depend on the investment needed in still of this size and the value of yield loss that it will prevent. This needs further investigation. Presently we consider it worthwhile, if SCAR is no more than about 0.2. This is based on our preliminary enquiries about the likely costs of deep-basin-glass-covered solar stills of the type that have been tried out in Gujarat.

Further Reduction by Polyhouse

Further reduction in size is 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 in water demand has been reported when crop is grown inside plastic greenhouses and tunnels. Reduction of water demand by 30 to 40 per cent is widely reported in literature. Preliminary results available for locations in Gujarat also support this. This would suggest that when integrated with polyhouse, stills may need to be only about 20 per cent the size of crop area.

Salt Accumulation in Root Zone

Use of saline water leads to salt accumulation in soil. Describing spatial and time changes in salt concentration is complex. Presently, we will use summary empirical expressions available in literature, to estimate the level of salinity in rootzone when water of a given EC is used repeatedly.

Ayers and Westcot [6] expression,

$$EC_e = EC_{iw} * X \qquad (14)$$

where,

X = concentration factor (dimensionless)

Concentration factor (X) is tabulated for various leaching fraction on assumed water use pattern of 40-30-20-10. If water of EC_{iw} = 2 dS/m is used repeatedly, EC_e will stabilize at 3.2 as per above equation. In case of tomato, the yield reduction due to this will be very marginal.

Conclusion

In extremely arid areas like Kutch where insolation is high, water scarce and saline, electricity supply unreliable, protected agriculture need to be tried out. We visualize growing facilities consisting of a polyhouse with provision for cooling, shading and solar desalination. The size of desalination facility will depend on crop, climate and quality of groundwater.

In climatic conditions of Bhuj, stills of area equal to about 20 per cent of crop area appear to be adequate to enable growing of tomato and beet in places where groundwater has salinity levels of up to 3 dS/m. Large proportion of wells in kutch would appear to have such a supply.

Establishing feasibility of this configuration will require investigation of cost of stills available and other economic factors.

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