VIABILITY OF IRRIGATION BY POROUS CAPSULE METHOD IN ARID AND SEMI-ARID REGIONS

ADERALDO DE SOUZA SILVA[2], DINARTE AÉDA DA SILVA[3], HANS RAJ GHEYI[4] e EVERALDO ROCHA PORTO[2]

ABSTRACT - This paper presents the results of four field experiments carried out with the objetive of evaluating the feasibility of irrigation by porous capsule method, from 1979 to 1983, at Bebedouro Experiment Station, EMBRAPA-CPATSA, Petrolina, PE, Brazil. The irrigation system consisted of fulcrum of cone shaped porous capsules, interconnected with conduit pipe and installed in the soil at equidistance and 0.10 m deep along contour lines. The hydrostatic pressures studied ($\Delta H = 0.35$ m to 2.8 m) did not significantly influence the crop yield, but influenced, at 0.10 level, the daily water release from porous unit. The mean yields for watermelon (*Citrullus vulgaris* Schard), var. Charleston Gray, for muskmelon (*Cucumis melo* L.) var. Valenciano Amarelo, and for maize (*Zea mays* L.), var. Centralmex, estimated in ton/2,500 units/ha or in cobs/2,500 units/ha, were 28.5, 10 and 17,500, respectively. The water consumption for watermelon, musk melon and maize was, respectively, 60 mm, 60 mm and 100 mm in a deep sandy yellow-red latosol. The cost of the system was US$ 1,677.41/ha.

Index terms: low pressure irrigation, scarce water.

VIABILIDADE DE IRRIGAÇÃO POR CÁPSULA POROSA EM REGIÕES ÁRIDAS E SEMI-ÁRIDAS

RESUMO - O trabalho apresenta resultados de quatro experimentos de campo, com objetivo de avaliar viabilidade do método de irrigação por cápsulas porosas, durante o período de 1979 a 1983, na Estação Experimental de Bebedouro, EMBRAPA-CPATSA, em Petrolina, PE, Brasil. O sistema de irrigação é composto de unidades porosas em forma de tronco de cone, interconectadas com tubos de polietileno (eletroduto), instalados no solo a distâncias equivalentes e a uma profundidade de 0,10 m, em curvas de nível. As pressões hidrostáticas testadas ($\Delta H = 0{,}35$ m a 2,8 m) não influenciaram, significativamente, no rendimento das culturas; entretanto, afetaram, ao nível de 1% de probabilidade, na liberação de água diária, por unidade porosa. As principais produções médias obtidas para melancia (*Citrullus vulgaris* Schard), variedade Charleston Gray; melão (*Cucumis melo* L.), variedade Valenciano Amarelo e milho (*Zea mays* L.), variedade Centralmex, estimadas em toneladas/2.500 cápsulas/ha ou em espigas/2.500 cápsulas/ha, foram de 28,5; 10 e 17.500, respectivamente. O consumo de água para culturas de melancia, melão e milho, de acordo com a descrição acima, foi de, respectivamente, 60 mm, 60 mm e 100 mm, em um latossolo Vermelho-Amarelo, profundo, de textura arenosa. O custo do sistema por hectare foi de US$ 1,677.41.

Termos para indexação: irrigação a baixa pressão, economia de água.

INTRODUCTION

Nearly one third of the land area in the world constitutes the arid and semi-arid zones (Shantz 1956). Such vast areas areas with abundant natural assets have great potentialities for agricultural development. In fact great civilizations are known to have flourished in such regions, but limited water, occasional droughts, unpredictable and/or erratic distribution of rainfall have restricted development of such areas. The key to successful development of these areas lies in either large scale water resources or in efficient use of limited water available.

In the present day context, the increasing cost of energy makes the efficient use of water doubly important, because eficcient use of water automatically improves the efficiency of energy use. However, the equipment necessary for such efficient application and use requires considerable capital investment, beyond the financial capacity of small farmers. Further, relatively higher level of

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2 Eng. - Agr., M.Sc., EMBRAPA/Centro de Pesquisa Agropecuária do Trópico Semi-Árido (CPATSA), Caixa Postal 23, CEP 56300 Petrolina, PE.

3 Eng. - Agr., M.Sc. Assistant Prof. Fed. Univ. of Rio Grande do Norte, Natal, RN, Brazil.

4 Eng. - Agr., Dr. Associate Prof., Dep. of Agricultural Engineering, Fed. Univ. of Paraíba, Campina Grande, PB, Brazil.

management skill required in operation of these equipments and/or small size of farms have hampered the adoption of such techniques.

The real challenge in these regions is to design irrigation systems capable of utilizing available water rationally and efficiently and at the same time be within financial capacity and management skill of small farmers. Undoubtedly, such systems, if innovated, would bring more crop land under irrigation with existing limited water resources and thereby help to increase agricultural production. In this context, a sub-surface method of irrigation consisting of a series of interconnected porous capsules was successfully tested by Silva et al. (1980 b). The method, apart from being simple, automatic and indigenous, is highly efficient and capable of producing a good corn crop with only 10 cm of water.

The present study summarises results of four field experiments conducted at Bebedouro Experimental Farm of EMBRAPA in the State of Pernambuco using this method and evaluates economic feasibility of its adoption in arid and semi-arid regions, particularly on small farms where water is scarce. For a better understanding, a brief description of installation and operation of such a system is also presented.

The suggested irrigation method as shown in Figure 1 A consists of water reservoir, principal supply line, secondary distribution line and porous capsules.

For proper functioning of the system, a constant hydrostatic pressure is required and as shown in Fig. 1 B, a water reservoir of about 250 to 500 l capacity is put between the water tank and the area to be irrigated. A float is installed so as to provide the required water head. Silva et al. (1980 a) reported that for proper functioning of the system, a hydrostatic pressure of as little as 35 cm is enough. However, keeping in view plant growth and other related aspects a pressure of 50 cm was recommeded by them which corresponds to a water release of about 5 l/day/capsule.

The principal supply line is an 1" diameter conduit pipe which links the distribution lines to the water reservoir. Depending on field conditions, the principal line may be superficial or sub-superficial.

The secondary distribution line (conduit pipe Ø= 1/2") consists of a series of interconnected porous capsules installed at 10 cm depth along the contour lines. The experience and preliminary results show that up to a length of 100 m there is no appreciable decrease in hydrostatic pressure. The distance between lines and porous capsules is a function of the nature of crops, soil characteristics and resources (financial and water) available. A spacing of 2 m x 2 m has been successfully used for a variety of crops at CPATSA.

The porous capsules, principal component of the system is a fulcrum of cone shaped container of about 700 ml volume with two opennings at the upper end. These capsules were made using Plaster of Paris moulds with a mixture of locally found minerals, principally consisting of weakly metamorphosed shales, talc and calcite. After moulding and initial drying in shade, the capsules were oven and furnace dried at temperatures of 145 and 1120°C respectively, during a period of 32 h. The procedure in detail has been described earlier by Silva et al. (s.n.t.). The capsules at the end of the drying process presented dimensions as show in Figure 1C, mechanical resistance equal to 5 kg/cm^2, 20%-22% porosity and hydraulic conductivity of 0.0054 ± 0.0007 cm/h under saturated conditions.

For the installation, a well levelled and uniform area is preferred. After ploughing and harrowing, furrows 100 m long and 25 cm deep are opened at desired distance. In case of fields with appreciable slope, these furrows must be opened along the contour lines. Subsequently in these furrows, irrigation lines consisting of porous capsules interconnected at desired distance are installed at 10 cm depth. Each line is connected to the principal supply line originating from water reservoir of constant head. Depending upon the situation, water reservoir may either be connected to irrigation canal, water pump or to another tank.

Once installed, the system works automatically and virtually no care and maintenance is required. Of course, at the beginning, joints and connections are to be thouroughly checked for any leakage. The hydrostatic pressure at different places in the field should also be verified with the help of

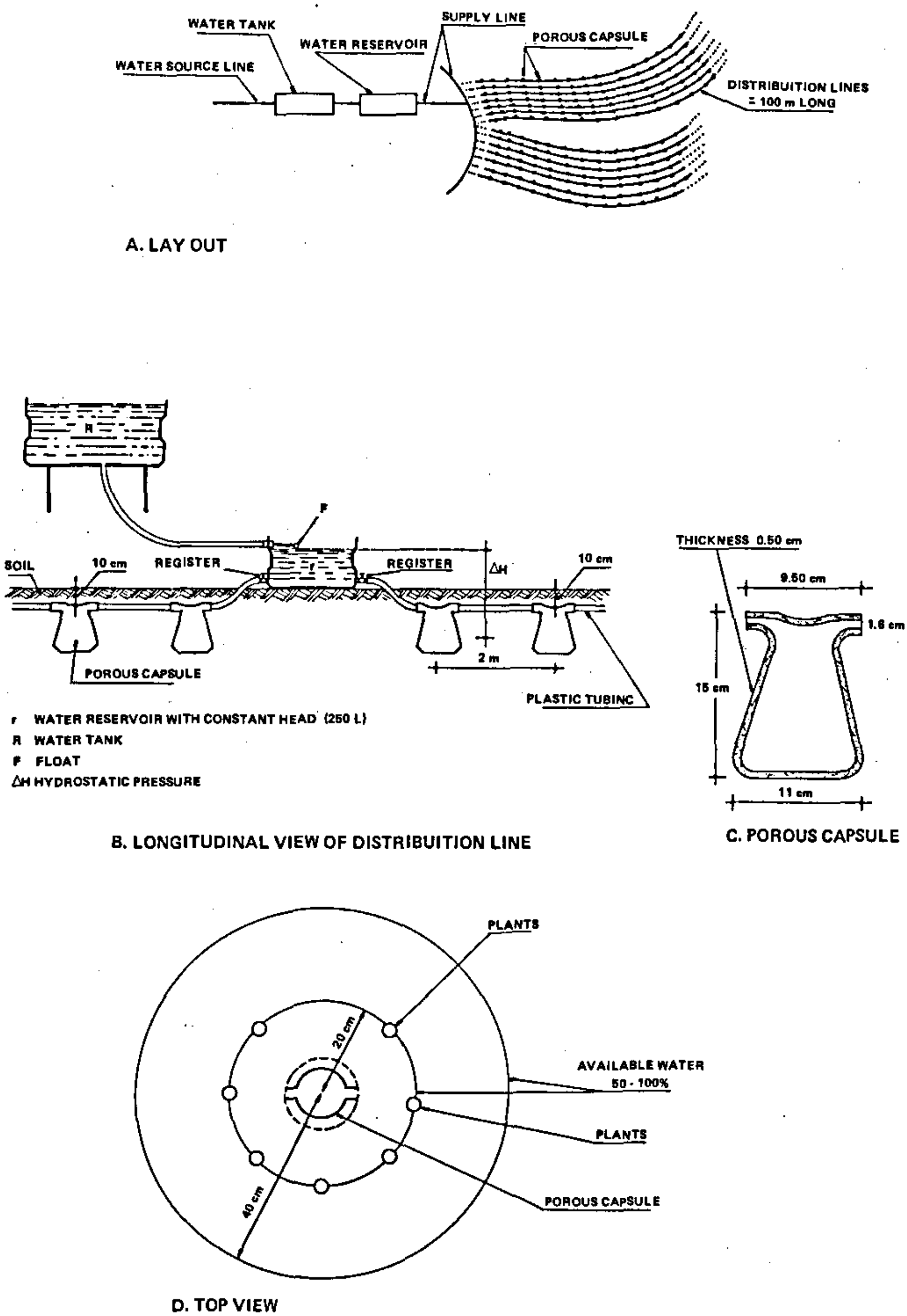

FIG. 1. Schematic of irrigation by porous capsule method.

piezometric tubes. According to Silva et al. (1980 a) the available water content in a radius of about 40 cm around the capsule and up to a depth of 60 cm varies between 50%-100% (volume basis) depending on density and fenological cycle of the crop. For sowing of crops a radius of 20 cm is generally recommended (Fig. 1 D) and for tillage operations a spade is usually used, but between the lines, animal driven light implements may be used without any restrictions. Although, no long term experiment has been conducted to verify durability of capsules and conduit pipe but the experience at Bebedouro Experiment Station indicates that up to a period of three years, except for gradual decrease in water release with time, system do not present any other problem.

The approximate cost of installation and necessary material is shown in Table 1. The other methods of irrigation such as sprinkler, xique-xique (perforated tubes) and drip commonly used for efficient application of water have cost estimates of Cr$ 420,000; 450,000 and 780,000 (1 US$ = Cr$ 135,00), respectively (Cavalcanti 1982). The present system, apart from being efficient, continuous and to give precise application of water, presents the advantage of energy and water economy. The system allows application of irrigation water virtually without any runoff, deep percolation, evaporation and drift losses thereby resulting in high water use efficiency.

MATERIAL AND METHODS

The field experiments were conducted at the Bebedouro Experiment Station of EMBRAPA about 45 km from Petrolina in the State of Pernambuco (9°9'S, 54°22'W, altitude 365.5 m). Average rainfall is about 400 mm and is mostly concentrated in the months of December to April. Mean temperature oscillates between 23° to 28°C and relative humidity during the year is around 68% though values as low as 35% are not uncommon.

The soil of experimental farm is a latosol series of a loamy sand texture and its important physical and chemical characteristics are given in Table 2.

A levelled and uniform area was selected as the experimental site. After ploughing and harrowing, nine furrows 100 m long and 0.25 m deep were opened following contour lines. In these furrows, irrigation lines consisting of 50 porous capsules interconnected at 2 m were installed at 10 cm depth and each line was separately connected to the water reservoir of constant head (50 l capacity) and a water tank (250 l capacity).

TABLE 1. Physical and chemical properties of the soil of Bebedouro Experiment Station Farm[1].

	Depth interval (cm)			
	0 - 15	15 - 30	30 - 45	45 - 60
Physical characteristics				
Sand - %	84	85	78	73
Silt - %	8	7	10	8
Clay - %	8	8	12	19
Bulk density - g/cm^3	1.64	1.66	1.60	1.62
Field capacity - %	10.62	11.73	10.40	11.84
Wilting point - %	2.96	2.75	4.02	5.82
Chemical analysis				
pH (1:2.5)	5.3			
Cation exchange capacity-meq/100 g	2.74			
Base saturation - %	77			
Available phosphorus (ppm)	4.03			
Organic matter - %	0.48			

[1] Data on physical properties reported by Azevedo (1975).

RESULTS AND DISCUSSION

The first experiment was conducted during Sept. 6, 1979 to January 19, 1980 using corn (*Zea mays.* L.) cv. Centralmex as a test crop. The experiment consisted of three hydrostatic pressures (0.35, 0.50 and 0.75 m) and five plant populations (1, 4, 7, 10 and 13) distributed around a capsule in a randomized block design with three replications. Each sub-treatment of plant population consisted of ten porous capsules. On november 28, 1979, 83 days after sowing, at random plants belonging to five porous capsules were harvested for cob collection, the remaining plants were harvested on maturity (January 19, 1980, after 135 days). The results are summarised in Table 3. On the basis of these results Silva et al. (s.d.) concluded that density of seven corn seedlings/capsule is optimum for cob or grain production.

It is worth mentioning that hydrostatic pressure did not show any significant effect on corn yield and mean water release varied from 4.3 to 5.4 l/day/capsule (Silva 1980). Considering a spacing of 2 m x 2 m or 2,500 porous capsules/ha, total water consumption by corn crop will be of the

TABLE 2. Material and installation cost[1] (per hectare) of irrigation by porous capsule method.

Item	Quantity	Unit price[1] Cr$	Total Cr$	Total US$
Porous capsules	2,500	40.00	100,000	740.74
Conduit pipe (Ø = 1/2")	5,000 m	15.00	75,000	555.56
Conduit pipe (Ø = 1")	150 m	30.00	4,500	33.33
Plastic tube	250 m	72.00	18,000	133.33
Connections	50	30.00	1,500	11.11
Araldite[2]	1.5 kg	3,500.00	5,250	38.89
Water reservoir	1	2,200.00	2,200	16.30
Installation cost/ha	400 h	50.00	20,000	148.15
Total			226,450	1,677.41

[1] Price prevalent in Feb. 1982.

[2] High quality fixer for plastic and ceramic.

Observation: Cost of pump in not included. In case it is not possible to irrigate by gravity flow it has to be added in the costs = Cr$ 210,000.00 (US$ 1,555.55). A filter is optional and necessary when irrigation water contains too much material in suspension.

Exchange rate: 1 US$ = Cr$ 135.00
1 ORTN = Cr$ 1,526.66

order of 9cm-11 cm with expected yields of 2.15 t in grain or 17,500 good commercial quality cobs.

The second experiment was conducted during the period February 15 to April 28, 1980, with beans (*Vigna unguiculata* L.) cv. Seridó. The experiment consisted of three hydrostatic pressures (0.35, 0.50 and 0.75 m) and five plant densities (1, 5, 9, 13 and 17) per capsule in a randomized block design with three replications. The results obtained (Table 4) show no significant effect of hydrostatic pressure on bean yields but differences due to plant population were found to be significant at 0.01 level of probability. Though best yields were obtained with highest plant density tested (17 plant/capsule) but spacing between plants (≃ 10 cm) was found to be too little for plant development. A density of nine plants/capsule has been considered as optimum, however results of production due to severe attack of insects and viruses can not be considered normal. In another experiment on a differente site, Pires (1982) obtained yield equivalent to 1.5 t/ha of cv. Pitiúba, which is considered to be more realistic. Depending upon hydrostatic pressure, mean water release/day/capsule was observed to vary from 2.45 to 3.14 l, in other words total water consumption by this method of irrigation for a bean crop may be between 4.5 cm to 5.8 cm.

As hydrostatic pressure did not show any significant effect on yields of corn and beans, for the third experiment only single hydrostatic pressure of 0.5 m was choosen.

The study was carried out during the period of June 13 to September 5, 1980, with the objective to determine optimum plant density of watermelon (*Citrullus vulgaris* Schrad) cv. Charleston gray. The plant densities varied from 1 to 6/capsule, though with not a constant number of replications. The results of production obtained are summarised in Table 5A.

The plant densities tested presented significant differences with respect to mean number of fruits and production/capsule. Taking into consideration, production and mean weight of single fruit, a density of 4 plants/capsule is considered to be optimum. On the basis of mean water release/day/capsule total water use of watermelon by this method is found to be nearly 6 cm with an expected yield of 28.5 t/ha. Araújo et al. (1982) obtained a production of 25.8 and 16.6 t/ha (commercial quality) in modified and traditional croping system of watermelon cultivation, respec-

TABLE 3. Mean number of cobs and corn yield for different treatments and sub-treatments[1].

Hydrostatic pressure (Δ H)	Plant population per capsule					
	4	4	7	10	13	Mean
A. Mean number of cobs[2]/capsule						
0.35 m	1.93	6.00	6.80	6.93	7.00	5.73 A
0.50 m	1.93	5.40	7.47	7.60	7.33	5.95 A
0.75 m	2.33	5.67	6.73	7.73	8.67	6.23 A
Mean	2.07 a	5.69 b	7.00 b	7.42 b	7.67 b	
B. Green matter production - kg/capsule						
0.35 m	1.40	2.36	2.36	2.80	2.76	2.34 A
0.50 m	1.46	2.04	2.50	2.72	3.16	2.38 A
0.75 m	1.16	2.20	2.80	2.80	3.66	2.52 A
Mean	1.34 a	2.20 b	2.55 bc	2.77 bc	3.19 c	
C. Corn yield[3] - g/capsule						
0.35 m	288.8	292.4	837.7	790.0	661.7	684.1 A
0.50 m	258.9	804.3	829.8	732.9	807.9	686.6 A
0.75 m	219.7	541.7	915.7	904.7	876.7	691.7 A
Mean	255.8 a	646.1 b	861.1 c	809.2 c	782.1 c	
D. Dry matter - kg/capsule						
0.35 m	1.13	2.42	2.18	2.54	2.39	1.10 A
0.50 m	1.29	1.77	2.27	2.57	2.88	2.16 A
0.75 m	0.98	1.90	2.52	2.40	3.31	2.22 A
Mean	1.13 a	1.97 b	2.32 b	2.50 bc	2.86 c	

[1] Mean followed by the same letter in a row or column do not differ significantly at p = 0.01 level according to Tukey's test.

[2] Only good commercial quality cobs.

[3] Adjusted to 15.5% moisture content.

TABLE 4. Yield of beans under different treatments and sub-treatments[1].

Hydrostatic pressure (Δ H)	Plant population/capsule					
	1	5	9	13	17	Mean
m				g		
0.35	73.4	181.3	338.3	251.5	409.6	250.8 A
0.50	77.9	261.8	354.9	336.2	337.0	273.5 A
0.75	73.4	265.0	267.1	365.5	390.9	272.4 A
Mean	74.9 a	235.9 b	320.1 c	317.1 c	379.2 c	

[1] Means followed by the same letter in a row or column do not differ significantly at p = 0.01 level according to Tukey's test.

TABLE 5. Yield of watermelon and muskmelon obtained under different plant densities.

	Plant density/capsule					
	1	2	3	4	5	6
A. Watermelon						
No. of capsules[1]	21	124	50	125	57	52
Production/capsule - kg						
Minimum	2.75	2.75	2.75	1.90	1.75	1.50
Maximum	14.90	34.25	19.60	38.65	41.45	31.95
Mean	6.38	10.17	10.68	11.38	10.25	10.85
Mean no. of fruits/capsule	1.8	2.2	2.7	2.9	3.1	3.7
B. Muskmelon						
No. of capsules[1]	30	81	108	90	47	13
Production/capsule - kg						
Minimum	0.65	0.72	1.37	1.18	1.59	2.06
Maximum	5.23	7.33	7.56	9.95	10.59	6.96
Mean	2.77	3.13	3.59	3.91	4.32	3.84
Mean no. of fruits/capsule	2.43	3.01	3.61	3.96	3.13	3.85

[1] Replications.

tively. Although, no detailed studies were made about the commercial quality yield obtained by porous capsule method, but a discount of 25%-30% on that account seems to be reasonable thereby indicating that yields obtained are comparable at least with the traditional system.

Comparing the data on mean water release/day for the three experiments, it is observed that a gradual decrease occurred with time, however such decrease was quite significant (nearly 40%) in the second experiment. From the latter experience with this method of irrigation, it was found that a sharp decrease occurred due to discontinuity of operation from November 28, 1979 (after collection of cobs) to February 14, 1980. Possibly suspended colloidal material in the irrigation water blocked some pores.

The fourth experiment was conducted during the period August 26 to November 3, 1982, with the objective to find out optimum plant density of muskmelon (*Cucumis melo* L.) cv. Valenciano Amarelo and to verify the operation of the system after three years of its installation and continuous use.

It was observed that the system operated normally without any problem except for significant decrease in water release. Hence for the experiment a hydrostatic pressure of 2.80 m was choosen. The plant densities varied from 1 to 6, though without a constant number of replications. The results of production obtained are summarised in Table 5B. On the basis of number of fruits, size and mean production, a density of 4 to 5 plants/capsule may be considered as optimum with a potential yield of about 10 t/ha. The mean water release/day/capsule was observed to be 3.27 l and based on this data only 5.8 cm of water would be necessary for the crop.

In Table 6 the annual returns on the basis of optimum plant density are shown. The experience at CPATSA shows that on a small farm of 1/2 to 1ha, three to four crops can be taken with only 30 cm water. Apart from good returns and water economy, the system presents advantages of precise application of water without any significant percolation, evaporation and drift losses. Another advantage of the system lies in efficient use of nutrients applied to crops. The fertilizers are incorporated in a radius of 10 cm around each capsule at a depth of 3 cm - 4 cm. The water content in this zone seldom exceeds beyond field capacity thereby no loss of nutrient occurs by way of percolation and at the same time weed growth is restricted to a minimum. The limitation of the

TABLE 6. Approximate total annual returns (per hectare) with irrigation by porous capsule method[1].

Crop	Fenological cycle (days)	Production per hectare	Unit price[2] Cr$	Total price
Corn - cobs	83	17,500	8.0	140.000,00
Green matter		6,375 kg	5.0	31.875,00
Beans[3]	74	1,500 kg	60.0	90.000,00
Wetermelon	83	20,000 kg	8.5	170.000,00
Muskmelon	70	10,000 kg	20.0	200.000,00
		Total	Cr$	631.875,00
			US$	– 4,680.6

[1] On the basis of sale at site.

[2] Minimum prevailing prices in Feb. 1982.

[3] Alternatively, bean production may be utilised by the farmer.

Observation: Production cost/ha may vary from Cr$ 30,000 to 40,000/crop/ha.

Exchange rate: 1 US$ = Cr$ 135.00
1 ORTN = Cr$ 1,526.66

method observed so far is the gradual decrease in water release with time. In this connection the recent studies of Castro & Baumgartner (1982) show that mean diameter of pores in a capsule is of the order of 1.35 μm and that 80% of pores have got diameter in the range of 2.36 to 0.42 μm. Hence any clay or silt sized particle in water can easily block the pores, particularly if the system is stopped and allowed to dryness as occurred during November 1979 to February 1980. However, the limitation does not forbid the adoption of the system on small farms in arid and semi-arid regions where water is scarce, because by putting a filter between the source of water and water reservoir, this problem may be solved to a great extent.

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