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Low-Cost Pitcher Irrigation System with Paddy Straw Mulching for Growing Vegetables in Coastal Saline Soils

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The scarcity of freshwater limits vegetable production in the coastal saline zone of the Sundarbans region. Low-cost, locally available, earthen pots (called pitchers) were tested for irrigation of vegetables along with paddy straw mulching (PSM) for soil water conservation. Field experiments were conducted in successive years (2021-22 and 2022-23) at ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town to increase the use efficiency of scarce good quality irrigation water for vegetable cultivation. The eight treatments consisted of: T_1: Conventional check basin irrigation with best available water (BAW) with electrical conductivity (EC_{iw}) of 1.27 dS m^{-1} in 2021-22 and 1.80 dS m^{-1} in 2022-23; T_2: Check basin irrigation with saline water (EC_{iw}: 5.82 dS m^{-1} in 2021-22 and 4.60 dS m^{-1} in 2022-23); T_3: Check basin irrigation with BAW + paddy straw mulch (PSM); T_4: Check basin irrigation with saline water + PSM; T_5: Pitcher irrigation with BAW; T_6: Pitcher irrigation with saline water; T_7: Pitcher irrigation with BAW + PSM and T_8: Pitcher irrigation with saline water + PSM. The experiment was conducted in triplicate in a split-plot design with irrigation methods (check basin and pitcher) as main-plots, the combination of water quality (saline and non-saline) and moisture conservation (PSM and non-mulching) in sub-plots. Clay pitchers of 9.75 liters capacity are buried inside the soil, around which seeds of bitter gourd (*Momordica charantia* L.) were sown. Check basin irrigation was followed as per the treatment. Lowest soil salinity development, higher bitter gourd yield and net return were observed when pitcher irrigation using BAW with PSM was followed. However, during the second year, check basin irrigation with PSM was at par with pitcher irrigation with PSM with respect to yield, net return and benefit cost ratio. The low cost (pitcher) irrigation with PSM was effective for growing vegetable crops with scarce water supplies in farmers' fields in the Sundarbans.

(***Key words:*** *Coastal agro-ecosystem, Earthworm diversity, Organic farming, Soil enzymes*)

To feed the ever-increasing population, food production in India must be doubled to 494 MT by 2050, by intensifying production on existing land (Patel *et al.,* 2019). Productivity can be increased by bringing rainfed areas under irrigation cover. However, water availability for agriculture in India will decline from 78% of total water used today to 68% in 2050 (Sharma *et al.,* 2018). Water scarcity and salinity are the main problems during *Rabi*/summer seasons for agriculture in the coastal areas (Mainuddin *et al.,* 2020). Though rainfall in this region is high, rainwater available in the water harvesting structures is very limited (Bell *et al.,* 2019). Good quality ground water is also scarce and extraction may exacerbate sea water intrusion. Conventional flood irrigation practiced in these regions is labour intensive and results in an inefficient use of scarce water. Hence, improving farm-level water use efficiency in agriculture is a high priority for water resources management (Bassi *et al.,* 2020).

Micro irrigation practices can increase the water productivity, but the initial investment for the resource-poor farmers inhibit large scale adoption. In this regard, the use of earthen pots called pitchers for irrigation by small and marginal farmers with limited water resources is an alternative option. The use of saline water with conservation practices such as paddy straw mulching

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(PSM) may also increase water use efficiency and save precious good quality irrigation water. Keeping these facts in view, a study was conducted under the Australian Centre for International Agricultural Research (ACIAR) funded project on 'Mitigating risk and scaling-out profitable cropping system intensification practices in the salt-affected coastal zones of the Ganges Delta' by Indian Council of Agricultural Research (ICAR)-Central Soil Salinity Research Institute (CSSRI), Regional Research Station (RRS) located at Canning Town in West Bengal, India. The objectives of this study, conducted at Canning Town, during 2021-2022 and 2022-23, were to explore alternative low-cost irrigation methods for improving the productivity of *Rabi* vegetable crops, to efficiently utilize the scarce irrigation water resources and to study the effect of saline irrigation water on soil salinity.

MATERIALS AND METHODS

A field experiment was conducted in the research farm of ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town (Latitude 22º15′N, Longitude 88º40′E, altitude 3.0 m from average mean sea level) during the *Rabi* seasons of 2021-22 and 2022-23. The weather data for the experimental period is given in Table 1.

Table 1. *Monthly weather data during Rabi 2021-22 and 2022-23 seasons recorded at the Meteorological observatory located at ICAR-CSSRI, RRS, Canning Town [Latitude 22^{o}15′ N, Longitude 88^{o}40′E, Altitude (AMSL) - 3.0 m]*

Month	Rainfall (mm)	Evaporation (mm)	Max temp (°C)	Min temp (°C)	Max relative humidity (%)	Wind (km h^{-1})
Nov 2021	3.2	98.0	29.3	19.5	73.3	2.3
Dec 2021	74.6	28.0	25.0	15.4	80.9	2.5
Jan 2022	15.0	30.0	23.6	14.4	83.9	2.6
Feb 2022	71.8	33.9	27.1	16.0	83.4	3.3
Mar 2022	0.0	58.5	33.5	21.8	78.3	5.2
Apr 2022	0.0	60.7	35.1	25.7	86.2	11.3
May 2022	232.2	94.1	26.9	19.6	76.9	8.7
Nov 2022	0.0	57.0	29.8	18.7	79.6	2.2
Dec 2022	0.0	50.0	27.0	15.2	77.6	2.2
Jan 2023	0.0	45.0	26.3	15.0	86.6	3.0
Feb 2023	0.0	72.0	30.1	18.3	86.4	3.7
Mar 2023	38.8	122.0	32.5	21.6	83.2	4.4
Apr 2023	15.8	235.0	36.8	25.1	82.5	5.1
May 2023	85.1	190.0	36.6	25.9	78.7	7.6

The rainfall during the crop growing period (January to April) of both the years was meagre, except in the months of January to February 2022 and March to April 2023 (Table 1). The rate of evaporation increased towards the end of crop growing period during both the years. During 2021-22, the maximum temperature was 23.6 - 35.1°C and the minimum temperature was 14.4 - 25.7°C. The maximum and minimum temperature regimes during 2022-23 were 26.3 - 36.8 and 15.0 - 25.1°C, respectively. The relative humidity was higher (> 78%) and wind speed increased as the crop approached maturity.

There were three phases in this study, in the first phase, study was undertaken to standardize the pitcher irrigation (Plates 1-3). The earthen pitcher of volume 9.75 litres was standardized for depth and quantity of water (Fig. 1).

The release pattern of water from the pitcher to the soil was studied through four treatments, *viz.*, pitcher with a small hole (5 mm diameter) at the bottom

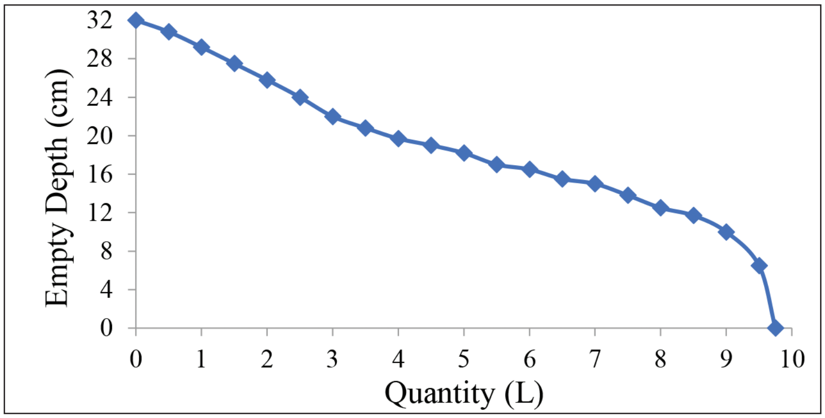


Fig. 1. *Relation between void depth and water volume contained in the pitcher used for irrigation*

and buried in soil to a depth of 35% of the height of pitcher, pitcher with a hole at the bottom and buried in soil to a depth of 70% of height of pitcher, pitcher with a hole at the bottom and buried in soil to a depth of 100% of height of pitcher and pitcher without a hole and buried in soil to 100% of height of pitcher. A more prolonged water release from the pitcher was observed when 100% was placed inside the soil and without making any holes (Fig. 2). This treatment was then used for further study and demonstration of the pitcher irrigation method.

The second phase of the experiment consisted of

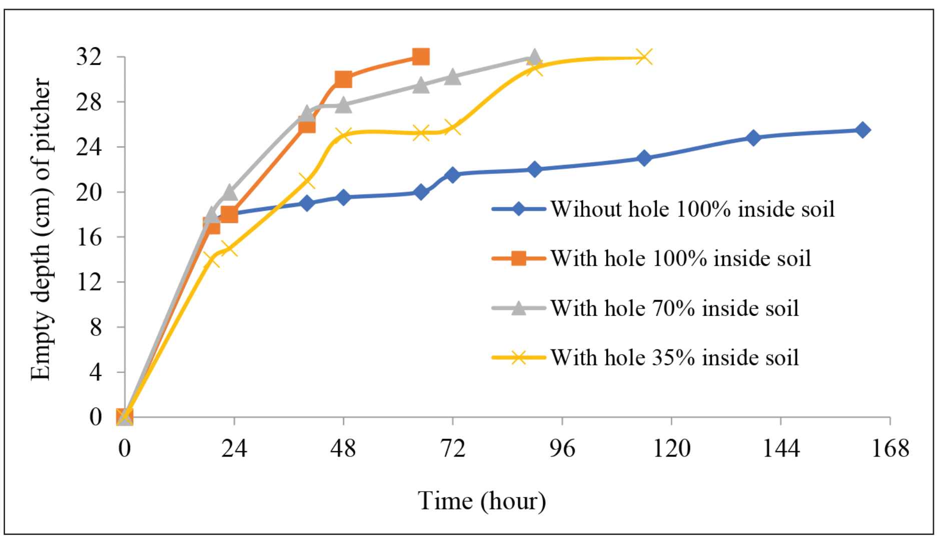
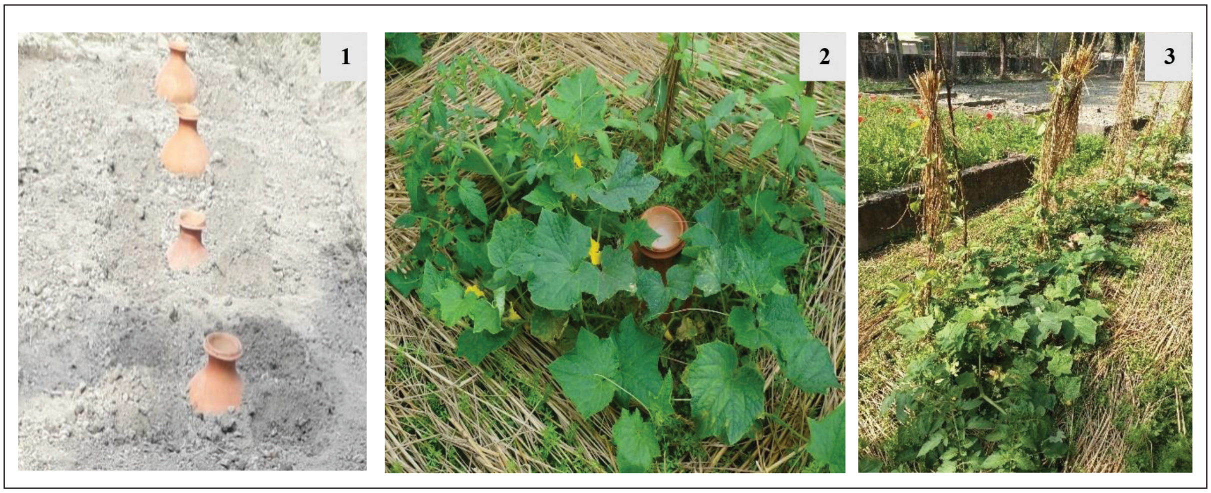


Fig. 2. *Study of water release pattern from earthen pitcher with and without holes placed at different soil depths*

eight treatments *viz.*, T_1: Check basin irrigation with best available water (BAW) with EC_{iw} of 1.27 dS m^{-1} during 2021-22 and 1.80 dS m^{-1} in 2022-23; T_2: Check basin irrigation with saline water (EC_{iw}: 5.82 dS m^{-1}); T_3: Check basin irrigation with BAW + Paddy straw mulching (PSM); T_4: Check basin irrigation with saline water (EC_{iw}: 5.82 dS m^{-1}) + PSM; T_5: Pitcher irrigation with BAW; T_6: Pitcher irrigation with saline water (EC_{iw}: 5.82 dS m^{-1} in 2021-22 and 4.60 dS m^{-1} in 2022-23); T_7: Pitcher irrigation with BAW + PSM and T_8: Pitcher



Plates. *(1) Installation of pitchers to study the effect of ahole in the bottom and depth inside the soil, (2) vegetable crops grown around these pitchers and (3) mulching of paddy straw*

irrigation with saline water + PSM. Eight treatments comprising two irrigation methods (check basin and pitcher), two water qualities (saline and non-saline) and two moisture conservation methods (PSM and non-mulching) were replicated thrice to make a total of 24 plots. The experiment was conducted in split-plot design with irrigation methods in main-plot and combinations of water quality with moisture conservation in sub-plot. The bitter gourd (variety: Batuk in 2022 and F1 HYBRID LHB-APEX in 2023) was sown on 29th January 2022 and on 20th January 2023. For saline water irrigation, during 2022, water from the Matla River (EC of 21.4 dS m^{-1}) was collected and diluted to get EC_{iw} of 5.82 dS m^{-1}. In 2023, for saline water irrigation, water from the Matla River (EC of 26.7 dS m^{-1}) was collected and diluted to get EC_{iw} of 4.60 dS m^{-1}. For the initial one month, BAW was used for the establishment of the crop. For saline water treatments, irrigation was applied from 26th February 2022 and 20th February 2023. The bitter gourd yield from each treatment and plot were recorded and converted to t ha^{-1} by multiplying with a suitable conversion factor. The data were analysed for significant variations among the treatments by using F-test and the means were compared by using the least significant difference (LSD) value at a 5% level of probability (Gomez and Gomez, 1984).

The third phase of this study was demonstration of the best treatment from Phase 2 in the farmers' fields. The pitcher irrigation methodology along with PSM practices was demonstrated in the farmers' fields at Bali, Chandipur and Gosaba islands in the Indian Sundarbans for growing vegetable crops such as cucumber, pumpkin, bitter gourd and pointed gourd.

RESULTS AND DISCUSSION

During the 2022 study, mean soil salinity for pitcher irrigation was 4.88 dS m^{-1}, whereas for check basin irrigation, the soil salinity increased to 5.71 dS m^{-1}. Irrigation with saline water (EC_{iw} 5.82 dS m^{-1}) increased the mean seasonal soil salinity ($EC_{1:2}$) to 6.43 dS m^{-1}, whereas soil salinity was less (4.16 dS m^{-1}) when non-saline (EC_{iw} 1.27 dS m^{-1}) water was used for irrigation. Mulching with paddy straw also reduced the mean soil salinity buildup during the *Rabi* season to 4.59 dS m^{-1} compared to no mulch treatment (6.00 dS m^{-1}).

The mean soil salinity during 2023 for pitcher irrigation was 4.58 dS m^{-1}, whereas for check basin irrigation, the soil salinity increased to 5.99 dS m^{-1}. Irrigation with saline water (EC_{iw} 4.60 dS m^{-1}) increased the mean seasonal soil salinity ($EC_{1:2}$) to 5.78 dS m^{-1}, whereas soil salinity was less (4.78 dS m^{-1}) when relatively less saline (EC_{iw} 1.80 dS m^{-1}) water was used for irrigation. Mulching with paddy straw also reduced the mean soil salinity build up during the *Rabi* season to 4.76 dS m^{-1} compared to no mulch treatment (5.80 dS m^{-1}).

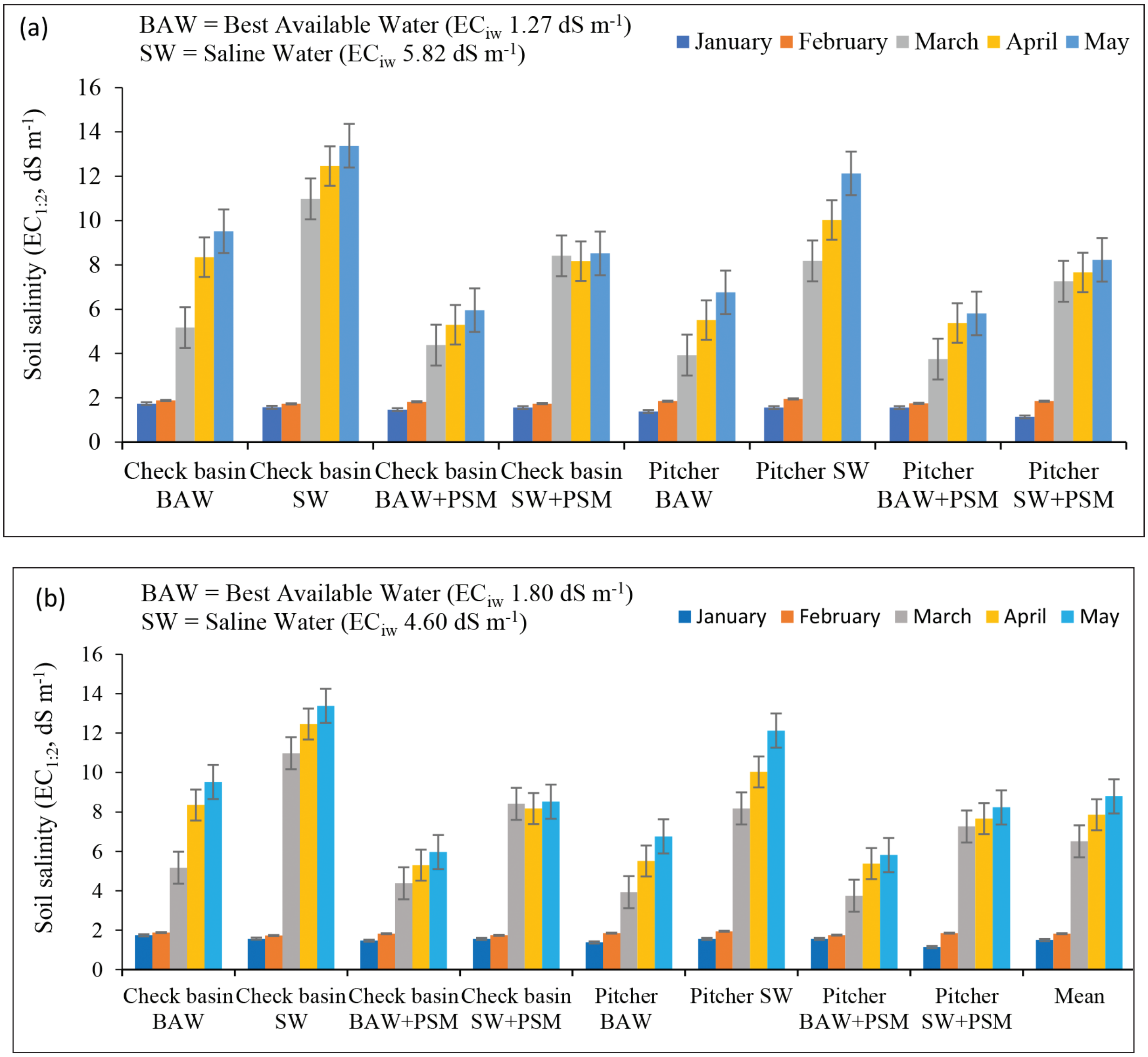


Fig. 3. *Effect of irrigation methods, water quality and mulching (PSM- paddy straw mulch) on soil salinity (0-15 cm depth) during(a) 2022 and (b) 2023 Rabi seasons (Test crop: Bitter gourd)*

Crop yield

During 2022, the bitter gourd yield was lowest (2.14 t ha^{-1}) when check basin irrigation was followed with saline water (EC_{iw} 5.82 dS m^{-1}) and highest (9.07 t ha^{-1}) by using best available water (EC_{iw} 1.27 dS m^{-1}) in pitcher with PSM (Table 2). The average bitter gourd yield was 2.83 t ha^{-1} under check basin irrigation which increased to 6.62 t ha^{-1} in pitcher irrigation. The mean bitter gourd yield reduced to 3.75 t ha^{-1} with saline water irrigation whereas it was higher (5.7 t ha^{-1}) when good quality irrigation water is used. Application of saline irrigation water (4 dS m^{-1}) exclusively after inflorescence appearance in broccoli caused a 22.2% decrease in the head dry biomass compared to non-saline water (2 dS m^{-1}) irrigation (Gioia *et al.,* 2018). Mulching had a significant effect on the yield of bitter gourd with a mean yield of 5.4 t ha^{-1} with mulching and 4.05 t ha^{-1} without mulching. Paddy straw mulching reduces soil salinity and conserves soil moisture (Sarangi *et al.,* 2021).

In 2023, the lowest bitter gourd yield (3.55 t ha^{-1}) was recorded when check basin irrigation was followed

Table 2. *Yield and economics of bitter gourd cultivation under different irrigation practices*

Treatments	Yield (t ha^{-1})	Cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	Benefit cost ratio
2022					
Pitcher irrigation with SW	3.85	106,250	115,500	9,250	1.09
Pitcher irrigation with SW + PSM	6.61	110,300	198,240	87,940	1.80
Pitcher irrigation with BAW	6.95	108,500	208,590	100,090	1.92
Pitcher irrigation with BAW + PSM	9.07	112,100	272,010	159,910	2.43
Check basin irrigation with SW	2.14	85,300	64,200	-21,100	0.75
Check basin irrigation with SW + PSM	2.40	81,250	72,000	-9,250	0.89
Check basin irrigation with BAW	3.26	87,100	97,800	10,700	1.12
Check basin irrigation with BAW + PSM	3.52	83,500	105,480	21,980	1.26
2023					
Pitcher irrigation with SW	4.17	81,350	125,125	43,775	1.54
Pitcher irrigation with SW + PSM	5.31	85,400	159,250	73,850	1.86
Pitcher irrigation with BAW	4.78	83,600	143,500	59,900	1.72
Pitcher irrigation with BAW + PSM	6.27	87,200	188,125	100,925	2.16
Check basin irrigation with SW	3.55	86,400	106,500	20,100	1.23
Check basin irrigation with SW + PSM	4.48	83,350	134,500	51,150	1.61
Check basin irrigation with BAW	5.22	88,200	156,625	68,425	1.78
Check basin irrigation with BAW + PSM	6.39	84,600	191,750	107,150	2.27
LSD (P = 0.05)	1.34	-	-	-	-

In 2022 BAW = Best available water (EC_{iw} 1.27 dS m^{-1}); SW = Saline water (EC_{iw} 5.82 dS m^{-1}); PSM = Paddy straw mulching. In 2023, BAW = (EC_{iw} 1.80 dS m^{-1}); SW = (EC_{iw} 4.60 dS m^{-1})

with saline water (EC_{iw} 4.60 dS m^{-1}) and the yield was > 6 t ha^{-1} when using BAW (EC_{iw} 1.80 dS m^{-1}) either in pitcher or check basin irrigation combined with PSM (Table 2). The average bitter gourd yield was 4.91 t ha^{-1} under check basin irrigation which increased to 5.13 t ha^{-1} in pitcher irrigation. The mean bitter gourd yield reduced to 4.38 t ha^{-1} with saline water irrigation whereas it was higher (5.67 t ha^{-1}) when BAW was used. Mulching had a significant effect on the yield of bitter gourd with a mean yield of 5.61 t ha^{-1} compared to 4.43 t ha^{-1} without mulching.

Economics

The highest net return (₹ 159,910 ha^{-1}) and benefit cost ratio of 2.43 was observed under pitcher irrigation with BAW combined with PSM in 2022. It is not economical to grow bitter gourd crop under check basin irrigation with the use of saline water of EC_{iw} 5.82 dS m^{-1} with or without PSM (Table 2). The use of saline water as irrigation in vegetable crops adversely affects the crop yield due to osmotic effects, nutrient imbalances and water deficit (Kim *et al.,* 2016). During 2023, the net return was highest (> ₹ 100,000 ha^{-1}) when BAW was used along with PSM. However, when saline water is to be used for irrigation in the case of non-availability of good quality water it is better to adopt pitcher irrigation with PSM for getting higher yield and net return (Table 2).

Demonstration

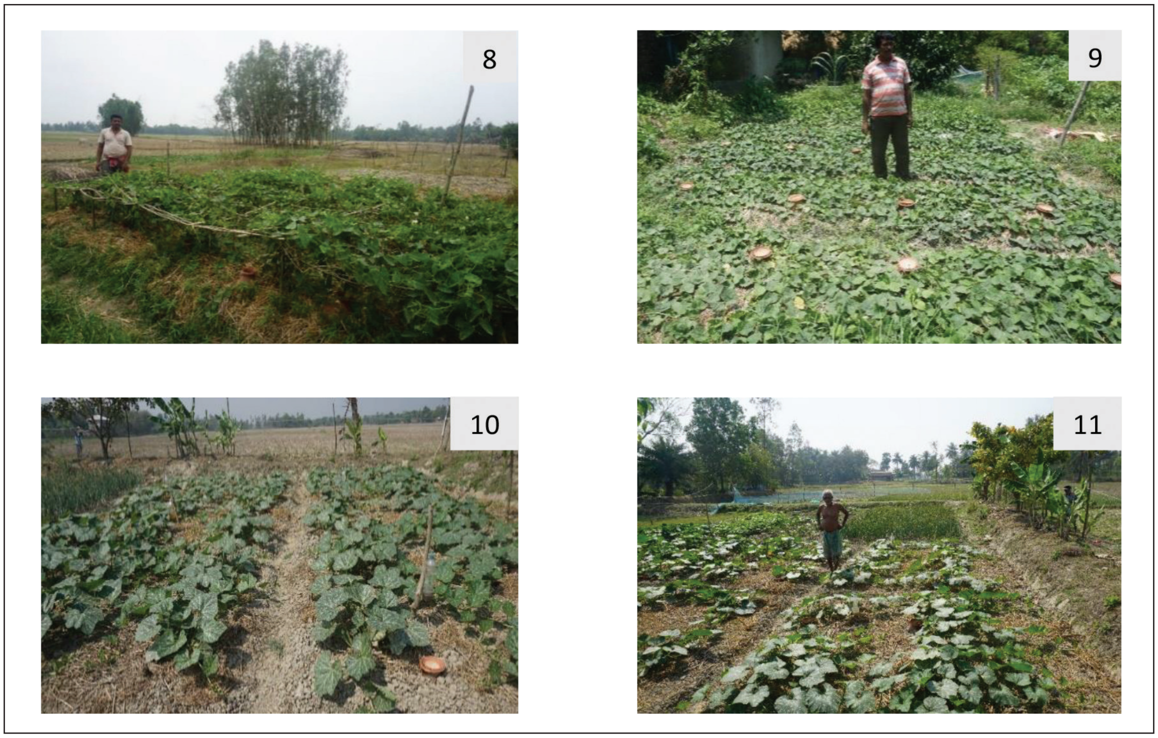
Pumpkin, pointed gourd, cucumber and bitter gourd crops were grown in the Bijoynagar area of Bali island (Plate 4), pumpkin was grown in the Gosaba (Plates 5 and 6) and bitter gourd and cucumber were grown in Chandipur islands. Mixed vegetables were grown under pitcher irrigation at Bali island (Plate 7). The yield and economics of vegetable crops grown under pitcher irrigation were promising (Table 3). Out of the four vegetable crops evaluated under pitcher irrigation during the summer season in the farmers' field, pumpkin and pointed gourd were more remunerative crops than cucumber and bitter gourd.

Plates. ***4*** *Demonstration of pitcher irrigation for growing pointed gourd,* ***5 & 6*** *pitcher irrigation for growing pumpkin and 7 pitcher irrigation for growing mixed vegetables in the homestead farming system during the Rabi season in farmers' fields (Sundarbans, West Bengal, India)*

Table 3. *Performance of vegetable crops under pitcher irrigation in the farmers' fields in 2021-22*

Location	Crop	Plot area (m^2)	Yield (kg $plot^{-1}$)	Yield (t ha^{-1})	Cultivation cost (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	Benefit cost ratio
Gosaba island								
F_1	Pumpkin	34.2	170	49.7	1,97,368	8,77,193	6,79,825	4.4
F_2	Pumpkin	22.5	112	49.8	2,22,222	9,95,555	7,73,333	4.5
F_3	Pumpkin	45.0	220	48.9	2,18,889	9,77,778	7,58,889	4.5
Bali island								
F_4	Pumpkin	56.1	180	32.1	1,78,253	6,41,711	4,63,458	3.6
F_5	Pointed gourd	35.0	70	20.0	1,42,857	6,00,000	4,57,143	4.2
F_6	Cucumber	74.3	68	9.2	1,00,942	2,28,802	1,27,860	2.3
F_7	Bitter gourd	61.4	32	5.2	95,277	1,56,352	61,075	1.6
Chandipur island								
F_8	Bitter gourd	56.7	27	4.8	97,002	1,42,857	45,855	1.5
F_9	Bitter gourd	62.4	33	5.3	97,756	1,58,654	60,898	1.6
F_{10}	Bitter gourd	55.2	29	5.3	97,826	1,57,609	59,783	1.6
F_{11}	Bitter gourd	48.6	25	5.1	98,765	1,54,321	55,556	1.6
F_{12}	Cucumber	60.5	40	6.6	1,00,826	1,65,289	64,463	1.6
F_{13}	Cucumber	57.7	45	7.8	1,00,870	1,94,974	94,104	1.9

During 2022-23, the pitcher irrigation technology was demonstrated in 11 farmers' fields at Bali, Chandipur and Gosaba islands for growing vegetable crops such as, pumpkin, ridge gourd, pointed gourd, cucumber, and bitter gourd. Pumpkin, pointed gourd, and cucumber crops were grown in the Bijoynagar area of the Bali island (Plates 8-9), pumpkin and ridge gourd were grown in the Gosaba island and bitter gourd, ridge



Plates. *Demonstration of pitcher irrigation for growing* ***8 & 9*** *Demonstration of pitcher irrigation for growing pointed gourd, and* ***10 & 11*** *for growing pumpkin during the Rabi season in farmers' fields (Sundarbans, West Bengal, India)*

Table 4. *Performance of vegetable crops under pitcher irrigation in the farmers' fields during 2022-23*

Location	Crop	Plot area (m^2)	Yield (kg plot^{-1})	Yield (t ha^{-1})	Cultivation cost (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	Benefit cost ratio
Gosaba island								
F_1	Pumpkin	100	110	11.00	1,35,000	3,30,000	1,95,000	2.44
F_2	Ridge gourd	67	60	8.96	1,11,940	3,13,433	2,01,493	2.80
F_3	Pumpkin	135	190	14.07	1,85,185	4,22,222	2,37,037	2.28
Bali island								
F_4	Pumpkin	100	120	12.00	1,40,000	3,96,000	2,56,000	2.83
F_5	Pointed gourd	67	95	14.18	2,01,493	6,38,060	4,36,567	3.17
F_6	Cucumber	100	170	17.00	1,65,000	6,80,000	5,15,000	4.12
F_7	Pointed gourd	67	120	17.91	2,23,881	8,05,970	5,82,090	3.60
Chandipur island								
F_8	Bitter gourd	67	35	5.22	1,26,866	2,08,955	82,090	1.65
F_9	Pumpkin	67	80	11.94	1,04,478	3,94,030	2,89,552	3.77
F_{10}	Ridge gourd	100	70	7.00	1,55,000	2,45,000	90,000	1.58
F_{11}	Cucumber	67	130	19.40	1,71,642	7,37,313	5,65,672	4.30

gourd and pumpkin were grown in Chandipur island (Plates 10-11). The yield and economics of vegetables crops grown under pitcher irrigation were promising (Table 4). Out of the five vegetable crops evaluated under pitcher irrigation during the 2022-23 season in the farmers' field, pumpkin, pointed gourd and cucumber were particularly remunerative crops, the net return of ₹ 400,000 - 500,000 ha^{-1} can be achieved from pointed gourd and cucumber cultivation. However, crop diversification is essential to reduce the risk of failure of any crop as well as for family consumption/nutrition from a variety of vegetables. Further, the year to year or season to season price fluctuation of vegetables can be addressed by diversification. This is one of the key principles for sustainable intensification in the coastal region (Emran *et al.,* 2022).

CONCLUSION

Under the situation of scarce irrigation water availability and limited resources available to farmers, low-cost pitcher irrigation is an alternative, eco-friendly and easily available option. In saline soils, this irrigation method should be combined with straw mulching to further conserve the water and suppress the weeds. This method of irrigation is suitable for creeping types of vegetables such as pumpkin, pointed gourd and cucumber, which cover the soil surface with foliage. However, irrigation water with moderate salinity may also be used if there is insufficient high-quality water.

The pitcher irrigation method can be a suitable option for the homestead gardens which are mostly managed by women farmers. The irrigation water consumption in this method is significantly less compared to the flood irrigation method, as a result the frequency of irrigation is less, thereby saving the time of women farmers. Since, the pitcher irrigation method only covers the root zone of the crop, the weed growth in the interrow spaces is very less, there by reducing the labour requirement for weeding. With the use of a small pump, the pitchers can be filled with irrigation water to reduce the drudgery and covered with an earthen lid, which reduces the evaporation loss. Therefore, this method of environment and gender-friendly irrigation technology for vegetable crops needs wider adoption through upscaling to large areas, where irrigation water is a scare resource for agriculture.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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