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Quantification of water productivity and economics of irrigation in summer clusterbean (*Cyamopsis tetragonoloba*) in hot arid region of India

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ABSTRACT

Clusterbean [*Cyamopsis tetragonoloba* (L.) Taub, *cv.* RGC 936] is generally grown in arid parts of India and requires about 650 mm water during its crop growth period. Keeping in mind the water scarcity in future, performance of this crop has been assessed under different irrigation levels at the experimental farm of ICAR−Central Arid Zone Research Institute (ICAR−CAZRI), Jodhpur during summer season of 2015, 2016 and 2017. For this purpose, a specially developed mini−lysimeter was used with a dimension of 0.50 m × 0.50 m × 0.55 m. The measurement resolution of the mini−lysimeter was 0.2 mm equivalent soil moisture depth. Four levels of irrigations were applied in the experiment: 100%, 80%, 60% and 40% of cumulative pan evaporation (CPE) of 50 mm. It was observed that deficit irrigation levels resulted in decrease of crop evapotranspiration (ET_c) by 19%, 34% and 50% under irrigation levels of 80%, 60% and 40% of CPW, respectively over control (irrigation = 100% CPE). However, the corresponding reductions in yield were 10%, 48% and 67%, respectively. Water productivity was found highest, 0.35 kg m^{-3}, at the irrigation level of 80% CPE. Further the economics of irrigation water application was computed to show the benefits of deficit irrigation apart from improving water productivity. It was found that for 1 ha−mm irrigation in the experimental field, it costs about ₹ 28.6. From this study, it may be inferred that by adopting 20% deficit irrigation level in summer clusterbean both physical water productivity and economic water productivity can be improved.

1. INTRODUCTION

For countries in the semi−arid and arid tropics, sustainability of agricultural production is mostly dependent on irrigation water security (Grey and Sadoff, 2007; Shah and Kumar, 2008). Agriculture is the largest user of water in many parts of the world (Wallace, 2000). Many such regions are primarily dependent on groundwater for irrigation (Schiffler, 1998). Particularly in the Indian context, electricity used for agriculture is heavily subsidized under both pro−rata and flat−rate tariff regimes (Kumar *et al*., 2011; Scott and Sharma, 2009). It is commonly perceived in most of these areas that energy subsidies are essential to allow small and marginal farmers to sustain irrigated crop production, which is becoming less profitable due to the rising cost of inputs, including irrigation. Further the competition for scarce water resources may lead to further increase in prices for irrigation water.

Indian agriculture is trapped in a complex situation of groundwater depletion and energy subsidies. This nexus is the product of past public policy choices that initially offered opportunities to India's small and marginal farmer to irrigate crops from the deep ground water table in most cases (Mohanty *et al*., 2020). This resulted into economic, social, and environmental distortions (Shah *et al*., 2012). Real energy cost of groundwater irrigation relative to agricultural productivity estimates reported by Shah *et al*. (2012) showed that average electricity used per ha of irrigation is about 1112 kWh in a year. Agricultural producers can adapt to increasing water price by adjusting irrigation management strategies. When water prices are high, deficit irrigation, the purposeful reduction of irrigation to reduce crop water requirement while accepting reduced yield, may increase net income (Trout and Manning, 2019; Kumar *et al*., 2020). Deficit irrigation can reduce water costs and may reduce the impact of high prices of water on net income (English *et al*., 2002).

Clusterbean is an important legume cash crop, grown in semi–arid and arid regions of Rajasthan, Haryana and Gujarat during rainy (*kharif*) season. Owing to its demand in the international market, it has been introduced in the non–traditional growing areas like Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra and Chhattisgarh. Further, its cultivation is also being taken up under irrigated conditions during summer (Bhatt *et al*., 2017; Manjunatha *et al*., 2018). This crop is a source to replenish nutrient, especially nitrogen of the low fertility soils and can withstand moisture stress. It is a photosensitive and indeterminate crop (Singh, 2014) and can be raised in summer season with irrigation facility. Therefore, the aim of the present study was focused on assessing the economics of irrigation water application and water productivity under different levels of deficit irrigation in clusterbean.

2. MATERIALS AND METHODS

Weather During Experimental Observations

The field experiment was conducted at research farm of ICAR–Central Arid Zone Research Institute, Jodhpur (26.3°N and 73.02°E; 224 m above mean sea level) during the summer seasons of 2015, 2016 and 2017. Soil of the experimental plots was taxonomically defined as coarse loamy mixed hyperthermic of camborthids. Soil organic carbon (SOC) content was very low (1.6 g kg^{-1}). The climate of the region is arid characterized by high diurnal and seasonal fluctuations in temperature and irregularity of annual and inter–annual rainfall with long dry seasons associated with strong winds. During the crop growing season in summer (March–May), four rainy days were recorded in 2015 with total rainfall of 38.7 mm while no rainfall was recorded in 2016, and five rainy days were recorded in 2017 with total rainfall of 86.5 mm (Fig. 1). Minimum temperature during the crop growth period varied from 15 to 31.7°C, 15.2 to 33.2°C and 10.5 to 30.9°C in 2015, 2016 and 2017, respectively whereas maximum temperature varied from 27 to 44.7°C, 30.2 to 49.4°C and 27.7 to 44.5°C in 2015, 2016 and 2017, respectively (Fig. 1).

Experiment Details

Clusterbean *cv.* RGC 936 was sown after pre–sowing irrigation of 60 mm on 11th March in 2015, 2nd March in 2016 and 4th March in 2017 using seed rate of 10–12 kg ha^{-1}. Distance between two rows was 50 cm whereas spacing between plants in a row was 10 cm. Basal dose of fertilizer through Diammonium phosphate (DAP) was applied at the rate of 20 kg N and 40 kg P_2O_5 ha^{-1}. Other cultural practices were followed as per standard package of practices in the region and were kept uniform across the treatments. The crop was harvested on 1st June, 25th May and 25th May in 2015, 2016 and 2017, respectively. Treatments were consisted of 4 irrigation levels, *viz.* irrigation at 100% ($I_{100\%}$), 80% ($I_{80\%}$), 60% ($I_{60\%}$) and 40% ($I_{40\%}$) of cumulative pan evaporation (CPE). The irrigation was applied, when CPE reached to 50±10 mm. Daily actual ET_c was measured by min–lysimeter of 50 cm × 50 cm × 55 cm in each irrigation treatment level. For this purpose, water balance components *e.g.* irrigation amount, rainfall, deep drainage, runoff etc were measured in the mini–lysimeter on daily basis. Soils of the mini–lysimeter were maintained like the experimental plots. The details of the mini–lysimeter may be found in Meena *et al*. (2015) and a schematic diagram of the lysimeter is given in Fig. 2. The sensor of the mini–lysimeter was a load balance sensor and measures the weight of total lysimeter. Change in weight of the lysimeter was converted to equivalent amount of water with a conversion factor of 1 kg = 4 mm following the design parameters of the lysimeter. The least count or resolution of the load cell used in the mini–lysimeter was 0.05 kg and thus the least count of measurement on water balance components using the mini–lysimeter was 0.2 mm. The change in weight of lysimeter was recorded on daily basis at 8:30 AM. Positive change in weight of the mini–lysimeter was due to rainfall or irrigation. Rainfall was measured separately using rain gauge at the nearby meteorological observatory. Drainage of water from the bottom of the mini–lysimeter was measured on daily basis by manually opening the drain out valve from the storage tank (~5 cm × 50 cm × 50 cm) available at the bottom

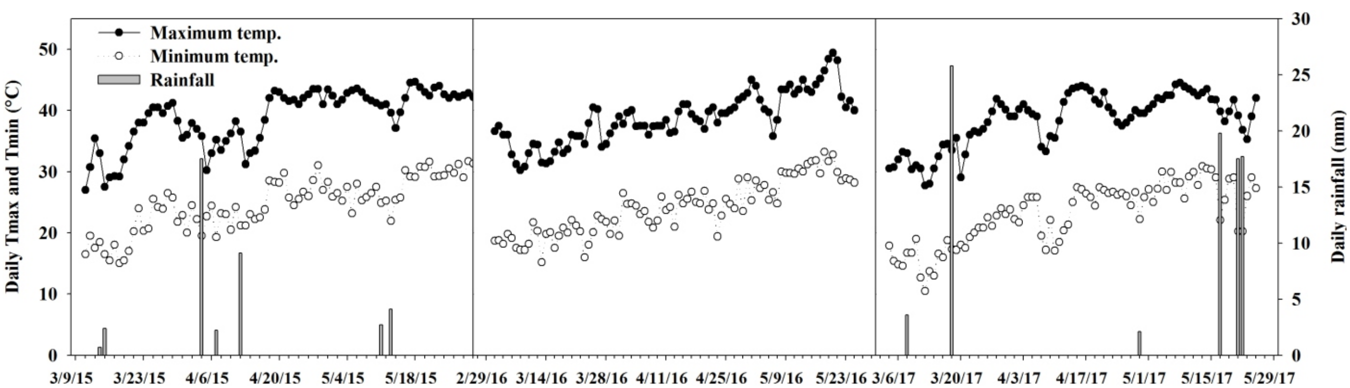

Fig. 1. Weather occurrence during crop growing season

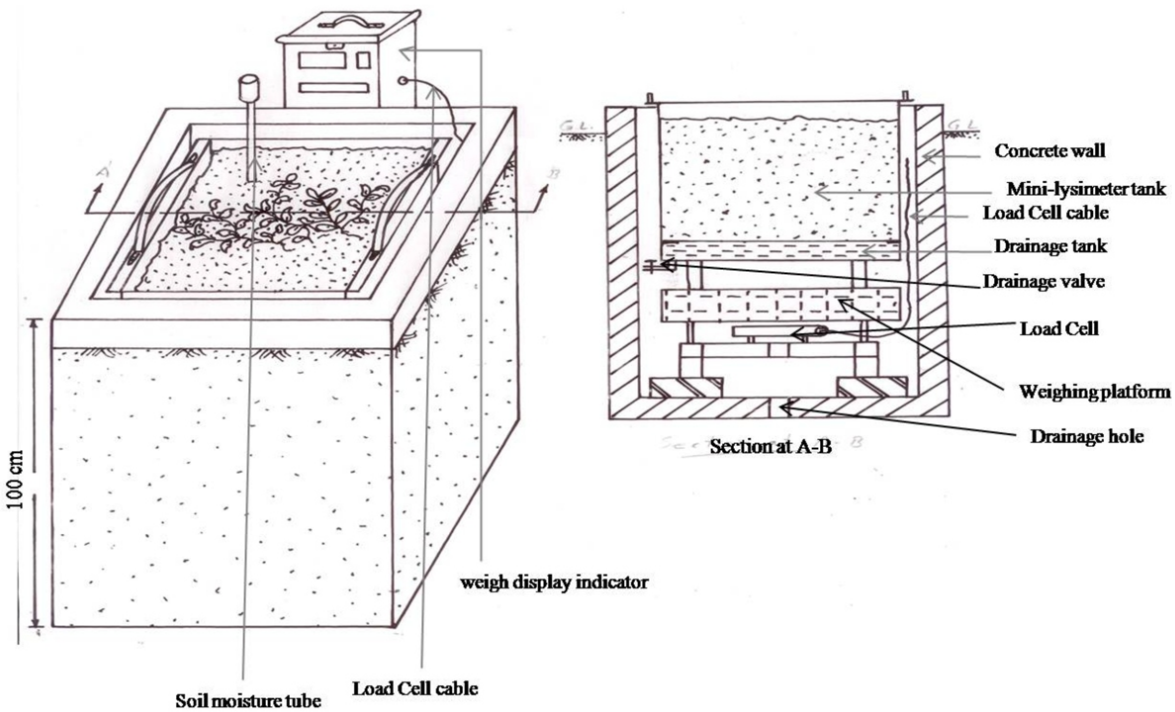

Fig. 2. Schematic diagram of mini−lysimeter

of the mini−lysimeter and the resultant negative change in weight of mini−lysimeter was considered as drainage component. Evapotranspiration was measured as the net negative change in weight of mini−lysimeter. In case of daily measured rainfall using rain gauge exceeding the positive change in mini−lysimeter on that particular day, the excess rainfall amount was considered as runoff.

Irrigation Network of the Experiment

Mini sprinkler irrigation network was installed in the experimental field, which was operated by 1 HP surface pump. The irrigation network consisted of main pipe (HDPE pipe of 63 mm diameter and 2.5 kg cm^{-2} pressure), screen filter (capacity: 25 $m^3 h^{-1}$), linear low−density polyethylene (LLDPE) plain lateral (32 mm; 2.5 kg cm^{-2}), risers, sprinkler head and pressure gauge. Single nozzle mini−sprinklers of model monsoon S−10 with nozzle size 2.5 × 1.5 mm were used in the field to irrigate the area. The mini−sprinklers were used in a part circle. The sprinkler fixed at the middle of the individual plot was fixed at 180°, while sprinklers at the corner of the plot were fixed at 90°. For each irrigation level six sprinklers were used, out of which, 2 sprinklers were fixed at 180° and four at 90°. The net area under one irrigation level was kept as 21 m × 11 m. The spacing of sprinklers along the lateral was kept as 10.5 m and spacing of laterals along the main line was kept at 10 m. One meter gap was left between the rows of two irrigation levels plots. The experiment was conducted at operating pressures of 1.0−1.5 kg cm^{-2} at the nozzle. Discharge of a single nozzle was found to be 480 lph. Precipitation rate of the sprinkler system was calculated to be 4.6 mm h^{-1}.

Calculation of Water Productivity

Based on the flow discharge of sprinkler nozzle, the flow rate of 6 sprinklers for the individual plot was calculated as 2880 lph and it was 11520 lph for the entire experimental area consisting of 24 mini−sprinklers. Time of operation of sprinkler system for irrigation levels of I_{100}, I_{80}, I_{60} and I_{40}% was calculated as 3.6, 2.9, 2.2 and 1.5 hrs, respectively. Assessment of water productivity was done as defined by Araya *et al.* (2011) and Payero *et al.* (2009).

$$WP = \frac{Y_a}{AET} \qquad ...(1)$$

Where, Y_a is the actual yield achieved (kg ha^{-1}) and AET is actual evapotranspiration (mm).

Economics of Irrigation

In the study, the total energy consumption to apply irrigation water in the field was calculated in two steps (Fig. 3). In the first step (part A), economics for lifting of ground water to a surface tank was calculated whereas in the second step (part B), economics for distribution of the stored water through pressurized irrigation system was calculated. The major principle of economic calculation was converting the energy requirement for lifting / distributing groundwater to monetary value using energy tariff rate. Following stepwise procedures were followed to calculate the energy requirement for lifting / distribution of irrigation water in field.

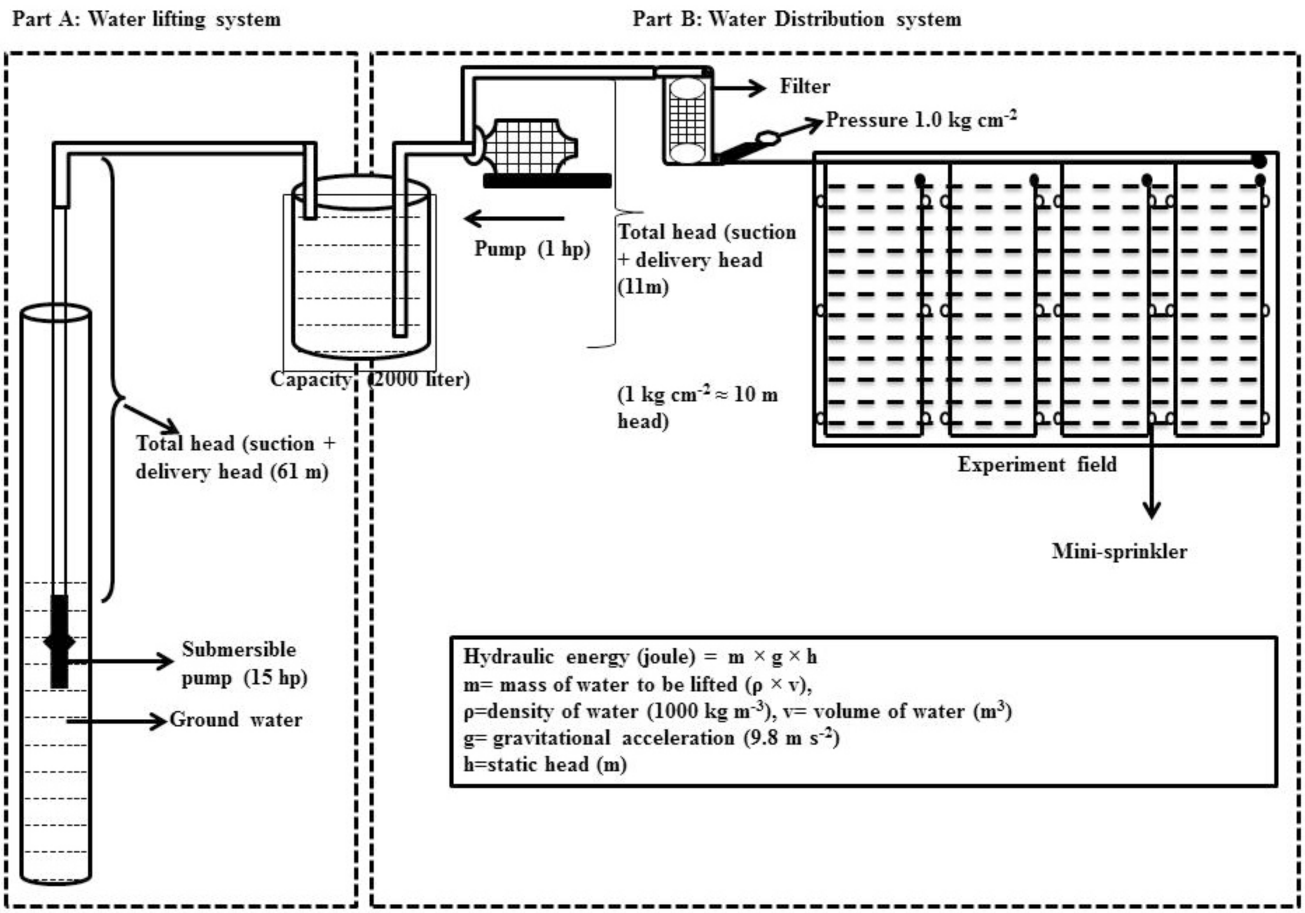

Fig. 3. Schematic diagram for calculating economic of irrigation water application

$$\text{Electric energy consumed by pump} = \frac{\text{Hydraulic energy}}{\text{Efficiency of pump}} \quad ...(2)$$

$$\text{Hydraulic energy (Joule m}^{-3}) = m\text{ (kg)} \times g\text{ (m s}^{-2}) \times h\text{ (m)} \quad ...(3)$$

$$\text{Hydraulic energy (kWh m}^{-3}) = \text{Hydraulic energy (Joule m}^{-3}) \times 3600 \quad ...(4)$$

$$\text{Cost of irrigation (₹ m}^{-3}) = \text{Hydraulic energy (kWh m}^{-3}) \times \text{Energy tariff (₹ kWh}^{-1}) \quad ...(5)$$

$$\text{Cost of irrigation (₹ ha-mm}^{-1}) = \text{Cost of irrigation (₹ m}^{-3}) \times 10 \quad ...(6)$$

Whereas, m is the mass of water to be lifted ($\rho \times v$), ρ is density of water (1000 kg m^{-3}), v is the volume of water (m^3), g is gravitational acceleration (9.8 m s^{-2}), h is total pumping head (m). Rated discharge of the pumps was considered to calculate the volume of water to be irrigated. Pump efficiency in the above calculation was considered 50%. In case of lifting the groundwater, the suction head was 61 m without any delivery head and thus the total pumping head was similar with suction head. In case of calculating the energy consumption for distribution of irrigation water through pressurized irrigation system operated at 1 kg cm^{-2} pressure (~10 m head) and suction head of 1 m, the total head of pumping was considered 11 m. Energy tariff rate for calculation of cost for pumping of irrigation water was considered ₹ 7.10 kWh^{-1} as per latest applicable energy tariff rate for agriculture (metered) connection for round the clock supply of electricity issued by Government of Rajasthan (www.energy.rajasthan.gov.in/content/raj/energy–department/en/departments/jvvnl/Tariff_orders.html).

3. RESULTS AND DISCUSSION

Evapotranspiration and Crop Water Productivity of Summer Clusterbean

Actual ET_c and crop water productivity of clusterbean is presented in Table 1, which are the average values across three seasons of 2015, 2016 and 2017. During crop growth seasons, observed ET_c was found highest in $I_{100\%}$ irrigation levels followed by $I_{80\%}$, $I_{60\%}$ and $I_{40\%}$ irrigation levels and these are 686, 554, 454 and 340 mm, respectively. Simultaneously, crop yield was recorded as 2.1, 1.9, 1.1 and 0.7 t ha^{-1} under $I_{100\%}$, $I_{80\%}$, $I_{60\%}$, and $I_{100\%}$ irrigation levels, respectively. It was observed that deficit irrigation levels resulted in decrease of ET_c by 19%, 34% and 50% in $I_{80\%}$, $I_{60\%}$ and $I_{40\%}$ irrigation levels, respectively over control ($I_{100\%}$) whereas corresponding yield reductions were 10%, 48% and 67%, respectively.

Table: 1
Water productivity of summer clusterbean

Treatment*	Actual crop ET (mm) (mean of three seasons)	Yield (kg ha^{-1})	Decrement yield (%)	Water productivity (kg m^{-3})
T_1 (I_{100}%)	686	2149	–	0.31
T_2 (I_{80}%)	554	1924	10	0.35
T_3 (I_{60}%)	454	1119	48	0.25
T_4 (I_{40}%)	340	708	67	0.21

**$I_{100\%}$ = Irrigation level with 100% of CPE; $I_{80\%}$ = Irrigation level with 80% of CPE; $I_{60\%}$ = Irrigation level with 60% of CPE; $I_{40\%}$ = Irrigation level with 40% of CPE*

Water productivity was found higher, 0.35 kg m^{-3}, at $I_{80\%}$ irrigation level, which was a deficit by 20% over control, for which water productivity was 0.30 kg m^{-3}. Applied water consumed by crop as ET_c was highest (686 mm) under $I_{100\%}$ irrigation level while lowest (340 mm) under $I_{40\%}$ irrigation levels (Table 1). Crop yield was decreased with reduction in amount of irrigation water or increase in deficit level. During the growing seasons, average crop water productivity was observed to vary from 0.21 ($I_{40\%}$) to 0.35 kg m^{-3} ($I_{80\%}$). Previous research literature by Kumar *et al*. (2016) also reported the almost similar water productivity of *kharif* clusterbean (0.38 kg m^{-3}) in hot arid region of India. Since hot arid region of India is a water scarcity zone, therefore, the main thrust for sustaining agriculture should be to increase water productivity. In this experiment providing irrigation depth of about 40 mm during each event and total irrigation depth of 558 mm offers opportunity for water savings. In other words, applying the water depth of 40 mm offers savings of water by 19.24% as compared to the fully irrigated treatment with only 10.46% yield reductions.

Economical Parameters of Irrigation

Economical parameters of irrigation in the experiment are presented in Table 2. Here, we presented the economics of irrigation system, which is a combination of lifting the groundwater in the first step followed by distributing it by another pumping system through pressurized irrigation system in the second step. For any other irrigation system, the economics of the applied irrigation water may be calculated according to the groundwater situation and pumping conditions. In our experiment, we found that the cost for applying 1 ha–mm irrigation in the field was about ₹ 28.6. Again, the major part of this cost was borne by the cost for lifting the deep groundwater table, which was found ₹ 24 in this study. It implies that dependency on deep groundwater sources for irrigation purpose will lead to increase in cost of cultivation and thus the agricultural production system may not be profitable. In this context, if the deficit irrigation level is found suitable for a particular crop it will not only increase the water productivity but also improves the economic water productivity.

Economics of Deficit Irrigation in Summer Clusterbean

Economics of deficit irrigation system in summer clusterbean is presented in Table 3. Total cost of irrigation water was calculated as ₹ 19,620 ha^{-1} under $I_{100\%}$ irrigation level. Irrigation water applied with $I_{80\%}$ level resulted in saving of 132 mm of irrigation water, which in monetary terms was ₹ 3,775. It is to be noted here that the cost for irrigation in the arid zone of India, where groundwater is very deep, constitutes a major part of the total cost of cultivation. Therefore, a small amount of saving in irrigation water will significantly reduce the total cost of cultivation. Therefore, irrigation with 80% of total water requirement of the crop or with 20% deficit level, not only saves the precious water resource, but also provides the opportunity to increase the net income. It is also possible to exploit the saved amount of water to nearby field and thus expansion in area under irrigated cultivation in the hot arid region of India may also be possible.

4. CONCLUSIONS

The cost of irrigation water in deep groundwater situation is expected to be quite high, but often is neglected

Table: 2
Parameters involved in water economics calculation

S.No.	Parameter	Water lifting (part A)	Water distribution (part B)
1.	Pump capacity (HP)	15	1
2.	Head (suction + delivery) (m)	61	11
3.	Rated discharge (lph)	33,874	11,520
4.	Time required for discharge of 1 mm irrigation in 1 ha (h)	0.30	0.87
5.	Energy consumption (kWh)	3.375	0.653
6.	Cost for 1 ha–mm irrigation (₹)	24.00/-	4.63/-
7.	Total cost for 1 ha–mm irrigation (₹)	28.63/-	

Table: 3
Economics of deficit irrigation levels for summer clusterbean crop grown in hot arid region of India

Treatment*	Actual crop ET (mm)	Water saving (mm ha^{-1})	Cost of irrigation (₹ ha−mm^{-1})	Monetary savings of irrigation water (₹ ha^{-1})
T_1 (I_{100}%)	686	0	28.63	0
T_2 (I_{80}%)	554	132	28.63	3775
T_3 (I_{60}%)	454	232	28.63	6635
T_4 (I_{40}%)	340	346	28.63	9896

**$I_{100\%}$ = Irrigation level with 100% of cumulative pan evaporation (CPE); $I_{80\%}$ = Irrigation level with 80% of CPE; $I_{60\%}$ = Irrigation level with 60% of CPE; $I_{40\%}$ = Irrigation level with 40% of CPE*

since farmers are paying the subsidized tariff rate for energy consumption to pump the groundwater. In arid zone of Rajasthan, groundwater is deep to very deep, and therefore pumping of water pumping for irrigation purposes require high amount of energy which requires attention for sustainable use of water resources in agricultural production system. We generally focus on increasing crop water productivity in water management experiments and tend to ignore the cost of water. In this study, economics of irrigation water application alongwith water productivity for summer clusterbean has been worked out. The study revealed that reduction of irrigation amount by about 20% of full irrigation in summer clusterbean resulted in reduction of yield by only 10.46%. Further, total cost of irrigation water was computed ₹ 19,620 ha^{-1} under full irrigation (100% of CPE) while it was ₹ 15,844 ha^{-1} at 80% irrigation level, providing an opportunity to save ₹ 3,775 ha^{-1} in total cost of cultivation. Crop water productivity (0.35 kg m^{-3}) was also found highest with 80% irrigation level. When the level of deficit irrigation was increased beyond 20% (equivalent to 80% irrigation) the corresponding yield reduction was proportionately high, therefore, irrigating the summer clusterbean at 80% level is recommended for hot arid condition.

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