Indian Journal of Agricultural Sciences **93** (11): 1202–1207, November 2023/Article
https://doi.org/10.56093/ijas.v93i11.141395

Crop yield, water use efficiency and economic assessment of purple broccoli (*Brassica oleracea*) across varied water and nitrogen management practices

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Received: 24 August 2023; Accepted: 15 September 2023

ABSTRACT

Inefficient management of irrigation and fertilizers emerges as the primary hurdle constraining the crop performance, profitability of broccoli (*Brassica oleracea* L. var. *italica*) production, resource wastage and environmental harm. To address this issue, a field experiment was conducted during winter (*rabi*) seasons of 2020–21 and 2021–22 at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi. The research focused on investigating the effect of irrigation techniques and nitrogen management on broccoli yield, water use efficiency (WUE) and economic feasibility. The two main irrigation methods of drip irrigation and furrow irrigation as main factor, 2 irrigation regimes of full irrigation (100% ET_C) and limited irrigation (75% ET_C) as sub-factor, 3 nitrogen doses (N) of 125, 100 and 75% recommended dose of N as sub-sub factor were given and replicated thrice. The study aimed to analyse the yield, water use efficiency and assessment of economics under diverse irrigation water and N-management approaches. Under drip irrigation the mean yield and water-use efficiency shown substantial increase by 12 and 52% in comparison with furrow irrigated purple broccoli grown under the same condition. The highest benefit to cost (B:C) ratio of 3.81 and 4.79 was obtained in the treatment DRI_1N_1 during 2020–21 and 2021–22, respectively. Undoubtedly, the significance of adequate irrigation regime (100% ET_C) and optimal N dose (125% RDN) became apparent, as they played significant roles in enhancing crop performance and ensuring the attainment of maximum broccoli yield, WUE and economics in Trans-Gangetic Plains region.

Keywords: Drip fertigation, Purple broccoli, Profitability, Water use efficiency, Yield

Enhancement in the productivity is essential to efficiently nourish an ever-growing population amidst dwindling resources. Attaining augmented yield and prime quality of produce hinges on the precise application of the optimal blend of water and nutrients. A skillfully planned drip fertigation setup dispenses water and nutrients with exact measurements, schedules and intervals. This approach enhances crop hydration and nutrient assimilation while curtailing the loss of nutrients and chemicals through leaching from the root zone of the farming area (Fanish *et al.* 2011). Moreover, implementing well-structured irrigation schedules for broccoli holds the potential to enhance water use efficiency (WUE) (Patra *et al.* 2022). This represents an environmentally sustainable irrigation technique that conserves over 60% of water and boosts crop yield by 30–40% compared to traditional approaches (Kapoor *et al.* 2014). Fertigation enables the precise delivery of essential plant nutrients uniformly to the wetted root zone, where the majority of active roots are concentrated and this enhances the nutrient use efficiency (Jat *et al.* 2011). Fertigation stands out as the cost-effective and highly efficient approach for applying fertilizers alongside irrigation, surpassing traditional methods (Brahma *et al.* 2010).

Broccoli (*Brassica oleracea* L. var. *italica*) is a *rabi* season crop. Renowned as the Crown of Jewel Nutrition, broccoli is a nutrient powerhouse abundant in vital minerals, antioxidants, and health-boosting glucosinolates (Saha *et al.* 2023). Among its diverse cultivars are the green and purple varieties, each distinguished by their growth characteristics, cultivation methods, utility, treatments, nutritional composition and even taste profiles. Anthocyanins in purple broccoli are reason for purple colour and possess higher antioxidant activity (Moreno *et al.* 2010). Anthocyanins enhance heart health by improving circulation and preventing blood clots, while isotonic and glucosinolates jointly activate enzymes that inhibit and suppress cancer growth. Purple broccoli is health beneficial and fetches higher market price.

Delhi Purple broccoli-DPB 1 is the first anthocyanin-rich, short duration and purple heading variant of the

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broccoli. Being a newly introduced crop with high economic potential and lesser available information on water and nitrogen requirement of purple broccoli demands appropriate understanding. On that account, an experiment was undertaken to assess yield, water use efficiency and economics for trans-gangetic plain conditions.

MATERIALS AND METHODS

The study was carried out during winter (*rabi*) seasons of 2020–21 and 2021–22 at the Precision Farming Development Centre (PFDC), Water Technology Centre, ICAR-Indian Agricultural Research Institute (28° 38' N and 77° 10' E, altitude of 230 meters AMSL), New Delhi. In the experiment, a split-split plot design was used with 12 treatments in total and each treatment was replicated thrice. These treatments included 2 drip irrigation methods (drip irrigation and furrow irrigation) as main treatments, 2 irrigation regimes (100% and 75% ET_C) as sub-plot treatments and 3 N levels (125%, 100% and 75% recommended dose of nitrogen) as sub-sub plot treatments (Table 1). The experimental soil had a typical Yamuna alluvial profile with a sandy loam texture, composed of 68.6% sand, 12.8% silt, and 18.6% clay. This soil maintained a *p*H level of 7.5, an electrical conductivity measuring 0.28 dS/m and an organic carbon content of 0.6%. Notably, it contained available nutrients, NPK at 128, 32 and 188 kg/ha, respectively. Soil moisture content was 24.3% at field capacity, 7.3% at permanent wilting point, with a hydraulic conductivity of 1.46 cm/h. New Delhi's location falls in the Trans-Gangetic plains agroclimatic zone, characterized by a semi-arid, sub-tropical climate with dry, hot summers and cold winters. The total rainfall recorded during the first year (October 2020–January 2021) and the second year (October 2021–January 2022) of the crop growth seasons amounted to 13.6 and 79.2 mm, respectively. The cumulative USWB Class A open pan evaporation during the cropping season was 216 mm in the first year and 187 mm in the second year.

The experimental plots had dimensions of 4 m × 2.5 m with a lateral and emitter spacing of 45 cm and crop spacing at 45 cm × 45 cm. The field was divided into two main plots with 2 m apart and further subdivided into sub-plots and sub-sub-plots, maintaining a 1 m spacing between adjacent plots. The plots featured with flat beds for drip irrigation method, each accommodating 5 rows of broccoli, while the furrows were raised to a depth of approximately 5 cm. Healthy and disease free 30-day old seedlings were transplanted to the field on 14th and 20th October of 2020 and 16th and 21st October of 2021 for drip and furrow irrigation system, respectively and it was subsequently harvested in the first week of January. The drip discharge rate was maintained at 2 litre/h. The field underwent proper ploughing initially with a disc harrow and subsequently with a cultivator.

The irrigation schedules were established through CROPWAT 8.0 software which relies on the Penman–Monteith methodology developed by the Land and Water Division of FAO (2009). The amount of irrigation was calculated in terms of gross irrigation requirements and pumping time per application, whereas irrigation time is dependent on crop evapotranspiration (ET_c) on daily basis. Irrigation water was applied through drip at 3-days interval as broccoli is a winter crop and evaporation rate is low. In furrow irrigation system, the furrows were irrigated with the concept of soil moisture deficit. Irrigation treatment was imposed after 7-days of transplantation to all the plots.

Urea, di-ammonium phosphate and muriate of potash (MoP) were utilised to apply the recommended dose of fertilizer (76:46:83 kg NPK/h). P and K were given as basal dose while urea was given in equal multiple splits, starting 7 days after transplanting and continued at 20-day intervals in 4 splits coinciding with critical growth stages of the crop as per the treatments. In the conventional fertilization treatment, the band placement approach was utilized to apply 50% of the N as well as 100% of P and K fertilizers. The remaining 50% of the N was divided into two separate applications, the first application after a 30-day interval from transplanting, while the second was implemented during the head formation stage.

Water use efficiency and irrigation water use efficiency were derived by the ratio of total marketable broccoli yield to the both ET and the applied amount of irrigation water, respectively (Erdem *et al.* 2010).

$$\text{WUE} = \frac{\text{Y}}{\text{ETc (IRw + R)}} \quad (1)$$

$$\text{IWUE} = \frac{\text{Y}}{\text{IRw}} \quad (2)$$

where R, Rainfall (mm); Y, total crop yield (kg/ha); IRw, Irrigation water applied (mm); ETc, Total water consumed for crop production (mm); WUE, water use efficiency (kg/ha/mm); IWUE, Irrigation water use efficiency (kg/ha/mm).

Total cost of cultivation included both fixed and variable cost. The fixed cost included the cost of the drip system. The formula used to calculate the annual fixed cost for the irrigation system was as following:

$$\text{CRF} = \frac{\text{ir}\,(1 + \text{ir})^{\text{y}}}{(1 + \text{ir})^{\text{y}} - 1} \quad (3)$$

where CR_F, capital recovery factor; ir, interest rate (fraction); y, useful life of component (years).

Table 1 Treatment combinations

Treatment	125% N-N_1	100% N-N_2	75% N-N_3
100% ET_C - I_1(DR)	DRI_1N_1 (T_1)	DRI_1N_2 (T_2)	DRI_1N_3 (T_3)
75% ET_C - I_2 (DR)	DRI_2N_1 (T_4)	DRI_2N_2 (T_5)	DRI_2N_3 (T_6)
100% ET_C - I_1 (FU)	FUI_1N_1 (T_7)	FUI_1N_2 (T_8)	FUI_1N_3 (T_9)
75% ET_C - I_2 (FU)	FUI_2N_1 (T_{10})	FUI_2N_2 (T_{11})	FUI_2N_3 (T_{12})

DR, Drip irrigation; FU, Furrow irrigation; T_1-T_{12}, Treatment combinations.

Multiplying the capital recovery factor (CR_F) at a predetermined interest rate (ir) of 12% (3 cropping cycle) by the present amount (taking into account farm gate value) and the useful life (10 years) (y) calculates the annual fixed cost (AFC). The variable costs included the operational and maintenance expenses for the drip system, as well as the cultivation expenses covering land preparation, seed costs, sowing and transplanting, nursery management, planting, plant protection measures, intercultural operations, fertilizer and its application, irrigation water and the harvesting for purple broccoli. The GRR was derived by considering the existing mean market value of the commodity during the experiment. To calculate the NER, the TCOC was subtracted from the GRR. The benefit cost ratio (BCR) for each treatment was calculated by evaluating the net return in relation to the cultivation cost, with all values expressed in rupees per hectare (₹/ha).

The data from the two-year study were subjected to analysis using a three-factor analysis of variance (ANOVA) test utilizing a split-split plot design as suggested by Gomez and Gomez (1984). Using standard statistical procedures, the critical difference (CD) for treatment contrasts was computed. The least significant difference (P=0.05) was calculated to indicate variations among the treatments.

RESULTS AND DISCUSSION

Crop yields: The mean marketable head yield under different treatment conditions of drip irrigation, surface irrigation and fertigation doses obtained during 2020–21 and 2021–22 is given in Fig 1. The purple broccoli attained the maximum yield at DRI_1N_1 (31.25 and 31.93 tonnes/ha) treatment combination whereas it yielded lowest under furrow FUI_2N_3 (19.17 and 19.07 tonnes/ha) treatment combination during 2020–21 and 2021–22, respectively. The drip irrigation method recorded 12% higher yield and conserved 52% more water in comparison to the furrow irrigation approach. Thus the study reveals that the yield of the crop is dependent on irrigation methods and regimes and fertigation levels. The results were in harmony with Tagar *et al.* (2012) and Qureshi *et al.* (2015).

Drip irrigation led to an increased head yield compared to surface irrigation due to its ability to distribute water more effectively in the active root zone (Ranjitha *et al.* 2018). By maintaining soil water near field capacity with low suction, this method improved nutrient availability and uptake throughout the plant's growth period, while also providing an optimal soil water-air balance. As a result, the rhizosphere benefited from an abundance of oxygen concentration, promoting healthier and more productive growth of broccoli (Patra *et al.* 2022). These contributing elements are believed to have triggered elevated physiological mechanisms, cellular mitosis, and photosynthetic processes within the plants (Brahma *et al.* 2010). However, a significant decrease in head yield was observed under FUI_2N_3 treatment, primarily attributed to severe soil water stress. This stress caused reverse osmosis in the plants, hindering their ability to meet the crop water requirements adequately (Kumari *et al.* 2018). This accounts for the incongruity between crop yield and its water necessities, reflecting the crop's responsiveness to various irrigation methods.

In contrast, the reduced yields under furrow irrigation system may also be due to stress during the critical growth period, less availability of nutrients for crop growth with high weed infestation between the crops (Paul *et al.* 2013). Surface irrigation led to a widespread wetting area over a substantial area due to high hydraulic gradient have less application efficiency (Lamichhane *et al.* 2022). Consequently, several problems emerged such as increased

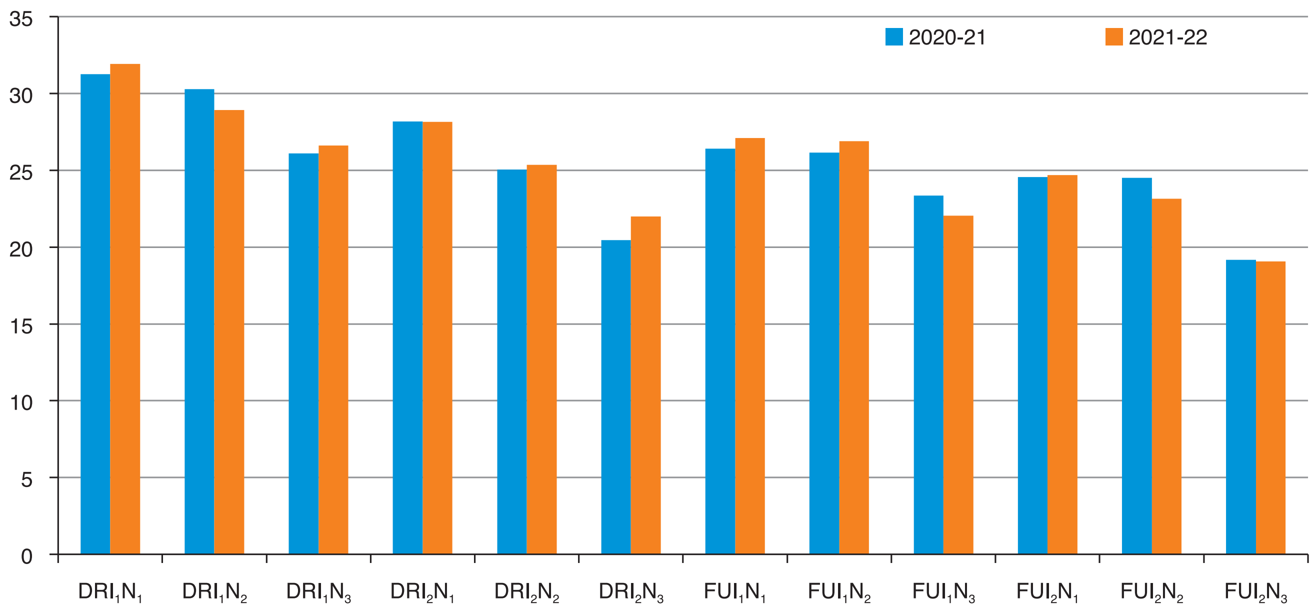

Fig 1 Influence of irrigation methods, irrigation regimes and N application on yield (tonnes/ha) of purple broccoli (2020–21 and 2021–22).

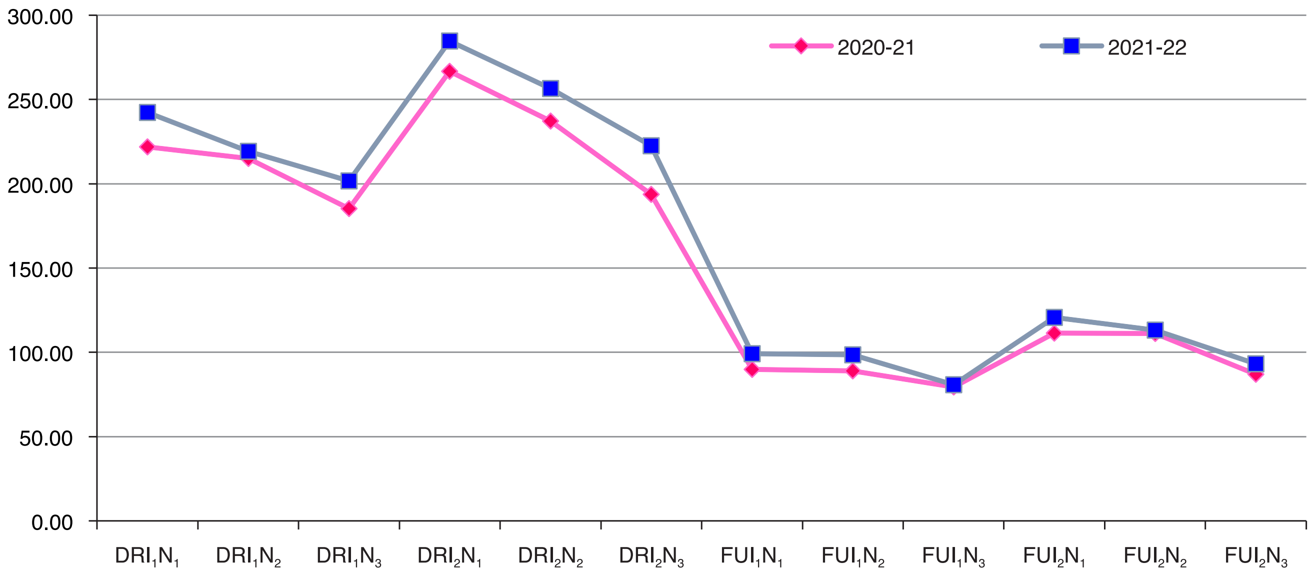

Fig 2 Effect of irrigation methods, irrigation regimes and N application on WUE of purple broccoli (2020–21 and 2021–22).

soil evaporation, abundant water and nutrient losses through deep percolation, diminished soil aeration immediately post-irrigation, intensified soil water stress between consecutive irrigations. Furthermore, the heavy irrigation load led to reduced nutrient availability, ultimately proving detrimental to the overall crop growth and resulting in a drastic reduction in yield. The disparity between the crop water requirement and its actual yield reflects the crop responsiveness to varying irrigation methods. These outcomes are in align with Singh *et al.* (2009), Tagar *et al.* (2012), Kapoor *et al.* (2014).

Water use efficiency (WUE): Irrigation was planned based on effective rainfall occurrences throughout the crop growth periods. Fig 2 and 3 represents the data concerning WUE and IWUE for all treatments in the years 2020–21 and 2021–22. The observed IWUE values exceeded the WUE values, a difference that can be attributed to the additional water contributed by rainfall (Erdem *et al.* 2010).

The total water requirement for purple broccoli was calculated at different growth stages with 3-day intervals for drip irrigation and weekly intervals for surface irrigation. The mean seasonal water requirement for purple broccoli under drip irrigation was ascertained to be 140.8 and 131.8 mm at 100% ETc and 105.6 and 98.8 mm at 75% ETc for the years 2020–21 and 2021–22, respectively.

For surface irrigation (FU), the observed total mean seasonal water requirement was 294.0 mm and 272.8 mm at 100% ETc, and 220.5 mm and 204.6 mm at 75% ETc for the same years. It is noted that the FU treatments consumed more water than the drip irrigation method in all the years.

The study reveals that DRI_2N_1 treatment recorded highest WUE (266.81 mm) and IWUE (284.78 mm) while FUI_1N_3 treatment recorded the lowest WUE (79.47 mm) and IWUE (80.83 mm) for both the years. According to the study findings, drip fertigation showed 52% higher WUE than furrow irrigation, comparitively. The study's outcomes shown that drip fertigation showed 52% higher WUE recorded as opposed to furrow irrigation. These results were in agreement with Tanaskovik *et al.* (2011) and Bazai *et al.* (2015).

Drip irrigation stands out as the most water-efficient method, delivering water directly to the root zone and minimizing losses through surface evaporation and deep percolation (Ambomsa 2020). Drip irrigation restricts water provision to plants' needs, upholding minimal soil moisture in the root zone to enhance water savings. A notable trait of drip irrigation is its adaptability to saline water, facilitated by frequent irrigation cycles that ensure the plant base remains consistently wet, preventing salt accumulation beyond critical levels (Reddy 2010). Conversely, furrow irrigation demonstrates diminished water usage efficiency, necessitating a substantial volume of irrigation to fulfill the crop water requirement (Kumar and khanna 2019). Non-uniform water distribution throughout the field results in irregular water absorption by plants, detrimentally affecting crop development and yield. Furrow irrigation exacerbates this issue as post-irrigation, soil moisture shifts from saturation to field capacity to dryness, subjecting plants to moisture stress prior to the subsequent irrigation cycle. This methodology significantly hampers plant growth (Aziz *et al.* 2021). The occurrence of percolation losses in furrow irrigation can be attributed to dispensation of a large volume of water use across entire field simultaneously, without taking into account the specific growth stage of the crop. This inefficiency makes furrow irrigation less practical and economically viable, especially for vegetable crops. The attained outcomes are in align with Tagar *et al.* (2012) and Job *et al.* (2018).

Economic analysis: The findings illustrate a significant increase in total production costs, net income and benefit-cost ratio (BCR) as irrigation regimes and fertilizer quantities rise (Table 2). This escalation is primarily driven by increased pumping costs resulting from variations in seasonal water application and the greater use of fertilizers.

In terms of economics, the DRI_1N_1 treatment emerged

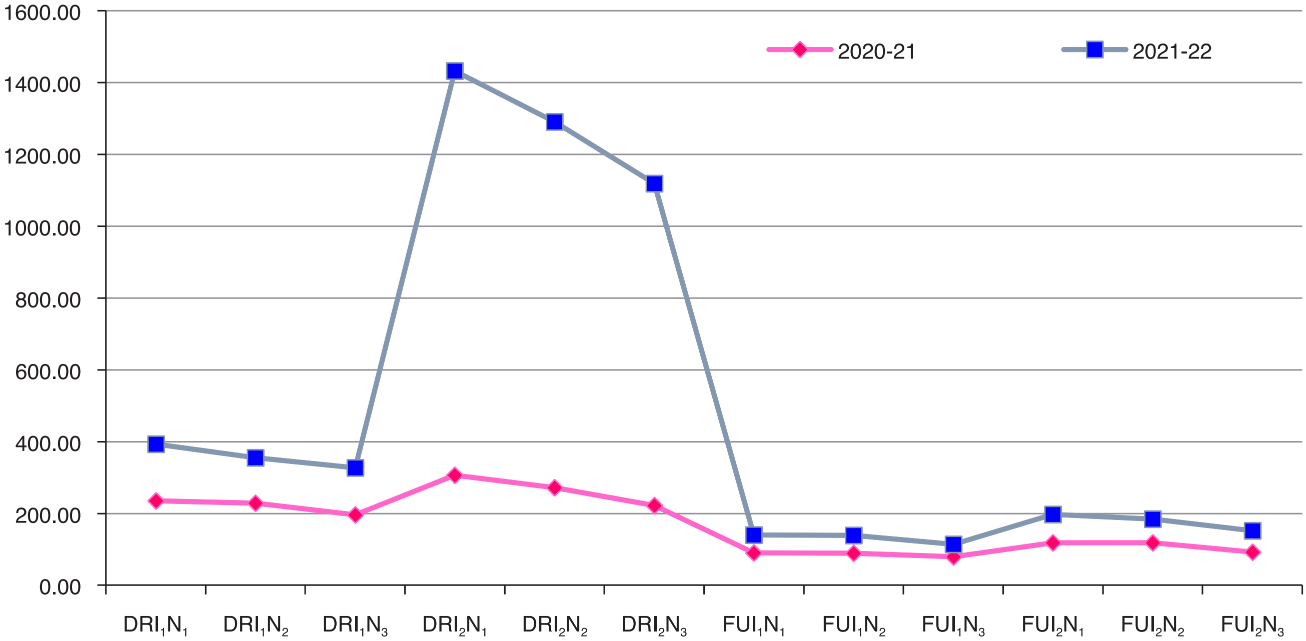

Fig 3 Effect of irrigation methods, irrigation regimes and N application on IWUE of purple broccoli (2020–21 and 2021–22).

as the most favourable, displaying the highest net returns (460957.83 and 631762.21) and B:C ratio (3.81 and 4.79) and lowest net return (214521.84 and 320329.27) and B:C ratio (2.27 and 3.05) was observed with the treatment FUI_2N_3 in both the years. Although the surface irrigation method has a lower initial cost, it consistently underperformed and resulted in lower net returns compared to the drip irrigation system due to its dimnished gross returns. The drip irrigation system incurred elevated initial costs, resulting in higher gross expenditures. Nonetheless, the drip irrigation system yielded elevated gross income due to the superior produce quality and increased yield it facilitated. The B:C ratio improved with higher irrigation regimes (100% ETc) and fertigation levels (125% RDN). Hence, the DRI_1N_1 treatment combination established itself as the most economically advantageous approach, promising benefits for the farming community. Conversely, the remaining treatments exhibited economic shortcomings, primarily due to decreased gross returns attributable to reduced crop yields. Himanshu *et al*. (2013) and Vasu and Reddy (2013) reported the similar findings in their studies on economics of broccoli and cabbage.

The study establishes that drip irrigation is the superior and water-efficient method for cultivating broccoli, resulting in higher crop yield, water use efficiency and B:C ratio. In contrast, furrow irrigation proved inadequate with its inefficiency in water usage and detrimental effects on broccoli growth. Therefore present

Table 2 Economic assessment of purple broccoli with varied irrigation methods, regimes and N doses (2020–21 and 2021–22)

Treatment	TCOC (₹)		GRR (₹/ha)		NER (₹/ha)		B:C ratio	
	2020–21	2021–22	2020–21	2021–22	2020–21	2021–22	2020–21	2021–22
DRI_1N_1	164007	166607	624964.83	798369.21	460957.83	631762.21	3.81	4.79
DRI_1N_2	161976	159376	605644.37	722734.12	443668.37	563358.12	3.74	4.53
DRI_1N_3	160079	156579	522069.69	664923.15	361990.69	508344.15	3.26	4.25
DRI_2N_1	156007	159107	563492.88	703766.65	407485.88	544659.65	3.61	4.42
DRI_2N_2	153976	159076	501030.77	633930.02	347054.77	474854.02	3.25	3.99
DRI_2N_3	152079	157079	409182.90	549821.85	257103.90	392742.85	2.69	3.50
FUI_1N_1	172861	172407	528010.67	677336.74	355149.67	504929.74	3.05	3.93
FUI_1N_2	170836	170376	522765.26	672161.01	351929.26	501785.01	3.06	3.95
FUI_1N_3	168925	152879	467299.75	551251.04	298374.75	398372.04	2.77	3.61
FUI_2N_1	172281	160407	491472.83	617055.30	319191.83	456648.30	2.85	3.85
FUI_2N_2	171036	153376	490302.63	578579.31	319266.63	425203.31	2.87	3.77
FUI_2N_3	168925	156379	383446.84	476708.27	214521.84	320329.27	2.27	3.05

TCOC, Total cost of cultivation (fixed and variable cost); GRR, Gross returns; NER, Net returns.

study recommends drip irrigation with optimal irrigation and fertigation levels over conventional methods for purple broccoli cultivation. Drip irrigation offers significant water-saving potential, increased yield and economic practicability, making it a more sustainable and productive choice for farmers.

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