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Aashu Rajput
Department of Soil Science, College of Agriculture, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

KP Raverkar
Department of Soil Science, College of Agriculture, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Gurvinder Singh
Department of Soil Science, College of Agriculture, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Pardeep Kumar
Department of Soil Science, College of Agriculture, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Jitendra Yadav
Research Scholar, Department of Agronomy, Shri Durga Ji Post Graduate College, Chandeshwar, Azamgarh, Uttar Pradesh, India

Vipin Kumar Yadav
Research Scholar, Department of Agronomy, Shri Durga Ji Post Graduate College, Chandeshwar, Azamgarh, Uttar Pradesh, India

Drishty Katiyar
Department of Soil Science, College of Agriculture, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Corresponding Author:
Aashu Rajput
Department of Soil Science, College of Agriculture, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

Irrigation methods and integrated nutrient management enhanced water use parameters and economics of vegetable pea (*Pisum sativum* L.)

Aashu Rajput, KP Raverkar, Gurvinder Singh, Pardeep Kumar, Jitendra Yadav, Vipin Kumar Yadav and Drishty Katiyar

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Abstract
In the northern-western Himalayan region of India, the winter vegetable crop, vegetable pea, is pivotal for regional food security and ecological equilibrium. To ensure its sustainable management, it is imperative to discover irrigation methods harmonizing with organic farming practices. Drip irrigation, recognized for precise water delivery and minimal loss, emerges as a promising solution. A field experiment in the Rabi season of 2020 at the Norman E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, scrutinized two irrigation approaches (drip and flood) and assessed six nutrient management combinations in a split-plot design. Compared to flood irrigation, drip irrigation exhibited substantial advantages in irrigation water use efficiency, water productivity, gross return, net returns, and B:C ratio. Particularly, an integrated nutrient management practice (RDF + FYM @2.5 t/ha + vermicompost @ 1t/ha) under drip irrigation resulted in a 29.4% increase in irrigation water use efficiency and a 28.3% rise in water productivity. The highest B:C ratio (3.5) was achieved with RDF + FYM 2.5t/ha + Vermicompost 1t/ha under drip irrigation. This strategy not only enhances water use efficiency and economic returns but also augments soil health, bolstering the long-term sustainability of regional agriculture.

Keywords: Vegetable pea, drip irrigation, sustainable agriculture, nutrient management

Introduction
India's diverse agro-climatic zones offer favourable conditions for cultivating a wide range of fruits and vegetables, including the cool-season legume crop, pea (*Pisum sativum* L.). Pea cultivation is prevalent in several Indian states, such as Karnataka, Madhya Pradesh, Rajasthan, Himachal Pradesh, Uttarakhand, Punjab, Haryana, and Bihar. Its early maturation allows it to fit seamlessly into crop rotations, such as Rice-Spring Maize, Rice-late sown wheat, and Rice-sugarcane, rendering it profitable with significant potential in both domestic and export markets. Pea cultivation also contributes to soil fertility through nitrogen fixation by Rhizobium leguminosarum (Pandey *et al*., 2017; Singh *et al*., 2019) [19, 24]. In India, vegetable pea (*Pisum sativum* L.) occupies 552,000 hectares of land, yielding 5.56 million tonnes with a productivity rate of 10.1 metric tonnes per hectare during the 2018-19 periods (India Agristat, 2018-2019). In Uttarakhand, pea cultivation covers 6,810 hectares, producing 0.050 million tonnes (State Horticulture Mission Government of Uttarakhand, 2018-2019).
To optimize crop production, chemical fertilizers have traditionally been the primary source of nutrients. These concentrated fertilizers offer readily available nutrients to plants and are cost-effective compared to organic alternatives. However, their imbalanced use can harm soil health, leading to issues like water contamination, nutrient loss, soil degradation, increased pest sensitivity, and reduced beneficial microbial communities, such as Rhizobium (Chen, 2006) [3].
Valuable nutrient sources like organic manures and crop residues are readily available on farms, including farmyard manure, vermicompost, and compost. Vermicompost, rich in plant nutrients like nitrate, phosphate, sulphate, and potassium, also contains various bacteria, fungi, and enzymes that enhance plant growth and productivity (Piya *et al*., 2018) [20].

Enzymatic activities increase significantly with the addition of mineral fertilizers to organic manures, stimulating soil biological activity (Samuel *et al*., 2018) [22]. Organic manures offer several benefits, including increased soil nutrient availability, balanced nutrient supply, and improved biogeochemical cycles (Ahmad *et al*., 2016) [1]. They boost crop productivity, nitrogen utilization efficiency, and soil health compared to chemical fertilizers (Murmu *et al*., 2013) [18]. Furthermore, organic materials contribute to soil organic carbon content, which helps mitigate climate change (Moraditochaee *et al*., 2014) [17] and enhances the legume-Rhizobium symbiosis while promoting root growth and overall plant development (Purbajanti *et al*., 2019) [21]. However, a reduction in soil organic matter can negatively impact soil properties (Gupta *et al*., 2019) [7].

Water management is crucial for enhancing crop production and preserving the environment. In India, irrigated farming plays a vital role in food production, with projections indicating the need for an increase in irrigated areas. However, water availability for agriculture is declining, making it imperative to improve water productivity through agronomic and technological interventions. Conventional pea cultivation employs flood irrigation, which has low water use efficiency due to water conveyance losses and the risk of soil damage and groundwater contamination (Irmak and Rathje, 2008) [9]. Water stress during critical growth periods can reduce crop yields and quality (Mal and Kaur, 2019) [15]. Water-saving agriculture, such as drip irrigation, offers a solution to these challenges, minimizing water losses and groundwater exploitation (Saroch *et al*., 2015) [23]. Drip irrigation not only increases crop yields but also reduces water consumption by up to 30% compared to conventional methods.

Materials and Methods

The soil of the experimental site was sandy-loam in texture having pH 7.42, organic carbon 0.91%, 109.0kg N/ha, 24.7 kg P/ha and 189 kg K/ha. The treatments consisted of two irrigation methods i.e., drip and flood, and six nutrient management practices i.e. T_1: Recommended dose of fertilizer (RDF) @ 30:60:30:: N: P_2O_5:K_2O/ha, T_2: RDF + FYM @ 5t/ha, T_3: RDF + FYM @ 2.5t/ha + vermicompost @ 1t/ha, T_4: Vermicompost @ 4.5 t/ha, T_5: FYM @ 10t/ha and T_6: Vermicompost @ 2.5t/ha + FYM @ 5t/ha. The experiment was laid out in split plot design and replicated thrice. Irrigation treatments were assigned to main plot and nutrient management practices to sub plots. Vegetable pea variety "Azad pea-3" was sown in the first fortnight of the November during the study. Seeds were manually drilled in rows spaced 20 cm apart using seed rate @80 kg/ha. In all, there were 36 experimental plots, each measuring 2.4 m x 4.5 m. A buffer space of 1m was maintained between two adjacent plots to avoid interference of one treatment with another plot. In each plot, a total 12 rows were accommodated at a spacing of 20 cm. Drip laterals were installed in the field immediately after sowing of vegetable pea. Laterals were spaced at 40 cm row spacing between two pea rows. Spacing of online drippers was 30 cm having the discharge rate of 2.2 liters per hour (LPH). Control valves were fixed in all the plots to facilitate controlling the water flow as per the treatments.

CPE value of previous three days was multiplied with Pan Coefficient value of 0.7 to apply irrigation on PET basis. Rainfall was subtracted from the CPE. In flood-method pre-sowing irrigation depth of 6 cm was maintained while later on it was 5 cm. and total four irrigations were given using Parshall flume.

Epan = Pan evaporation x K pan (in general taken as 0.7).

Entire dose of recommended P, K and 25% of N dose, as per treatment, were applied as basal through fertilizer NPK (12:32:16) + urea + MOP. The requisite quantity of organic manures in full on dry weight basis, as per treatments, was applied as basal. The water use parameters and economics were recorded as per standard procedures.

Water use parameters

Soil moisture content

Soil moisture content was measured employing gravimetric method (Jackson, 1973) [10]. Soil samples from each plot at 0-15cm soil depth were drawn using auger and fresh weight was recorded. Soil samples were kept in an oven at 105 °C for drying till the constant weight attained. Dry weight of soil samples was recorded and moisture content was calculated using formula as below.

$$\text{Soil moisture content (\%)} = \frac{\text{Fresh weight of soil} - \text{Oven dry weight of soil (g)}}{\text{Oven dry weight of soil (g)}} \times 100$$

Volumetric moisture content (%) = Gravimetric content * bulk density

Total irrigation depth and water saving

Total irrigation depth was calculated by summing total amount of irrigation water applied in each treatment. Water saving under each treatment was determined against conventional method and expressed as percent.

$$\text{Water saving (\%)} = \frac{\text{Water applied in flood irrigation} - \text{Water applied in drip irrigation}}{\text{Water applied in flood irrigation}} \times 100$$

Irrigation water use efficiency (IWUE)

Irrigation water use efficiency under varying treatments was calculated by dividing the pod yield with total irrigation depth applied inn respective treatments. IWUE was expressed as kg/ha-cm.

$$\text{IWUE (kg/ha - cm)} = \frac{\text{Pod yield (kg/ha)}}{\text{Total irrigation depth applied (cm)}}$$

Water productivity

The water productivity (W_P) of vegetable pea was computed using the following formula.

$$\text{Water productivity (kg/m}^3\text{)} = \frac{\text{Pod yield (kg/ha)}}{\text{Total water applied (m3/ha)}}$$

Economic water productivity

Economic water productivity was calculated in terms of Rs. /m^3 as below.

$$\text{Economic water productivity (Rs. /m}^3\text{)} = \frac{\text{Net return (Rs.)}}{\text{Irrigation water applied (m3)}}$$

Economics

Cost of cultivation

The cost of cultivation was calculated using the local charges of different operations and market price of various inputs and reported as Rs/ha.

Gross return

Gross return was calculated by multiplying the green pod yield with average market price and reported as Rs/ha.

Net return
Net return was calculated by subtracting the cost of cultivation from gross return of particular treatment.

Benefit: Cost ratio
Benefit: Cost ratio was obtained by dividing net return from a particular treatment with respective cost of cultivation.

$$\text{B:C Ratio} = \frac{\text{Net Return}}{\text{Cost of Cultivation}}$$

Statistical Analysis
The data collected from the experiment at different growth stages was subjected to statistical analysis, appropriate to Split Plot Design as per procedures of Gomez and Gomez (1984). Whenever treatments exhibited significance at five percent level of probability, the critical differences were calculated as below.

CD = SEm ± × t (0.05) at error degree of freedom

$$\text{SEm} \pm = \sqrt{\frac{Error\ mean\ sum\ of\ square}{Number\ of\ replications}}$$

Results and Discussion
The data related to influence of organic manures, inorganic fertilizers, alone or in combination, under different irrigation methods on irrigation depth, water saving, irrigation water use efficiency, water productivity and economic water productivity are presented in Table 1. During the entire growing period only 21.1 mm rainfall was received. Irrigation water use efficiency and water productivity (0.087 and 0.075 t/ha-mm, respectively) were found higher under drip irrigation as compared to flood irrigation (0.047 and 0.039 t/ha-mm, respectively) owing to higher pod yield, less irrigation depth and consumptive use in drip method. Drip irrigation recorded 41.1% water saving as compared to flood irrigation. Total water applied was lower under drip irrigation (153.4 mm) in respect to the flood method (231.1 mm). Under drip irrigation, economic water productivity was significantly higher (Rs. 1235/mm) as compared to flood irrigation (Rs. 698/mm) owing to higher net returns and lower irrigation depth under drip irrigation.

Table 1: Water use parameters of vegetable pea as influenced by different treatments

Treatment	Pod yield (t/ha)	Total Irrigation depth (mm)	Irrigation water savin (%)	IWUE (t/ha-mm)	EWP (Rs. /mm)	Total water applied (mm)	Water productivity (t/ha-mm)
Irrigation method							
Drip	11.48	132.3	41.1	0.087	1235	153.4	0.075
Flood	9.81	210.0	-	0.047	698	231.1	0.039
SEm±	0.42	-	-	-	0.70	-	-
CD aT5%	0.07	-	-	-	4.59	-	-
Nutrient management							
T_1	8.89	171.2	-	0.051	835	192.3	0.046
T_2	11.13	171.2	-	0.065	1022	192.3	0.058
T_3	11.34	171.2	-	0.066	1075	192.3	0.059
T_4	10.76	171.2	-	0.063	952	192.3	0.056
T_5	10.89	171.2	-	0.064	952	192.3	0.057
T_6	10.85	171.2	-	0.063	962	192.3	0.056
SEm±	0.282	-	-	-	2.72	-	-
CD at 5%	0.095	-	-	-	8.08	-	-

The treatment combination RDF + FYM @2.5t/ha + Vermicompost @1t/ha recorded 29.4 and 28.3% higher irrigation water use efficiency and water productivity, respectively than control (RDF) owing to higher pod yield. Significantly highest economic water productivity was recorded with RDF + FYM @2.5t/ha + Vermicompost @1t/ha nutrient combination (Rs. 1075/mm) as compared to control (Rs. 835/mm). Interaction effects of different nutrient management practices and irrigation methods on economic water productivity of vegetable pea were significant. Across the respective nutrient management practices drip irrigation mostly supported higher economic water productivity compared to flood irrigation (Table 2 and Fig. 1). An application of RDF + FYM @2.5t/ha + Vermicompost @1t/ha, under drip irrigation, produced significantly highest economic water productivity (Rs. 1397/mm), while lowest (Rs.1057/mm) was under control. Under flood irrigation, RDF + FYM 5t/ha registered highest economic water productivity (Rs.755/mm) which was statistically at par with RDF + FYM @2.5t/ha + Vermicompost @1t/ha, while lowest (Rs. 613/mm) in control (RDF).

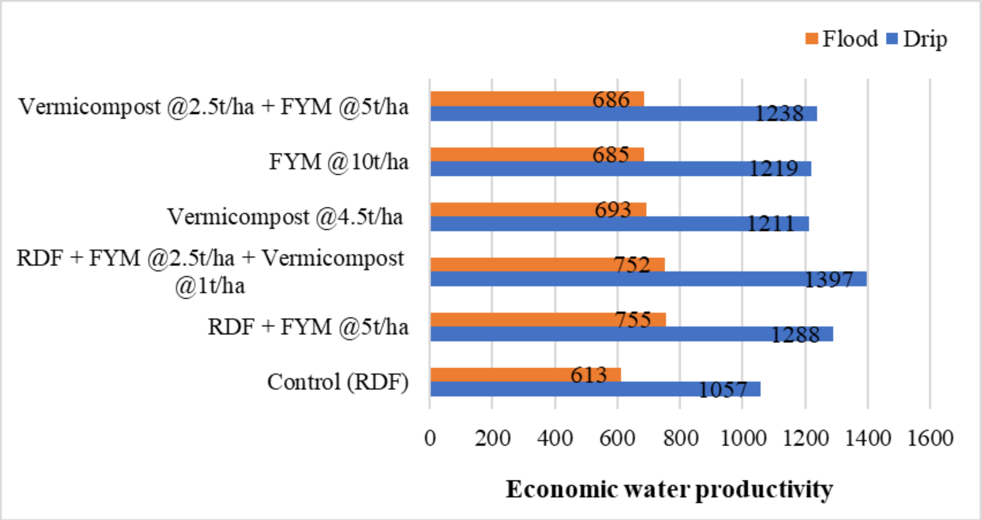

Fig 1: Effect of different irrigation and nutrient management practices on economic water productivity (Rs. /mm)

Higher water productivity, irrigation water use efficiency, economic water productivity and irrigation water saving was observed under drip (Table 1). The results are in conformity with that of Kumar *et al.* (2016) [14] and Jha *et al.* (2017) [11]. Improved irrigation water use efficiency under drip irrigation could be attributed to the optimized moisture and aeration in the rhizosphere facilitating proper growth of roots as well as shoots, which enhanced the nourishment of the crop leading towards a greater number of pods that ultimately led to high pod yield. Higher net returns because of drip irrigation in vegetable pea increased the economic water productivity under drip as compared to flood irrigation. The lower value of total irrigation depth and total water applied under drip irrigation helped in saving the irrigation water. Kumar and Katre (2018) reported improved irrigation water saving percent by use of drip irrigation method. Similarly, nutrient management practices comprising organic manures and inorganic fertilizers enhanced various water parameters in vegetable pea. Improved aeration, aggregation of soil particles due to organic manures helps in storing higher moisture (Bhattacharyya *et al.*, 2008; Zhang *et al.* 2020) [2, 27], this may lead to healthy growth of plant.

The data on cost of cultivation, gross and net returns and B:C ratio are presented in Table 2. The cost of cultivation was higher in drip irrigation (Rs. 52097/ha) as compared to flood irrigation (Rs. 49764/ha) owing to additional cost required in installation of drip line system.

Table 2: Economic parameters of vegetable pea as influenced by different organic manures, inorganic fertilizers and irrigation methods

Treatment	Cost of cultivation (Rs. /ha)	Gross returns (Rs. /ha)	Net returns (Rs. /ha)	B:C ratio
Irrigation method				
Drip	52097	215500	163403	3.18
Flood	49764	196244	146481	2.99
SEm±	-	659	656	0.015
CD aT5%	-	4315	4296	0.096
Nutrient management				
T_1	38345	172600	134256	3.50
T_2	49682	214200	164518	3.31
T_3	48548	219967	171418	3.53
T_4	54824	207767	152943	2.79
T_5	57092	209666	152575	2.67
T_6	57092	211033	153942	2.69
SEm±	-	478	479	0.009
CD at 5%	-	1421	1423	0.027

*RDF-30kg N+50kg P_2O_5 +30 kg K_2O/ha

The gross and net returns were significantly higher under drip irrigation (Rs. 215500 and Rs. 163403/ha, respectively) as compared to flood irrigation (Rs. 196244 and Rs. 146481/ha, respectively) owing to significantly higher pod and stover yield under drip irrigation. As a result, the B:C ratio was also higher under drip irrigation (3.18) than flood irrigation (2.99). This shows that the yield advantage in terms of net return was more than the cost incurred on installation of driplines.

The cost of cultivation was higher in nutrient management combinations, FYM @10t/ha (Rs. 57092/ha) and vermicompost @2.5t/ha + FYM @5t/ha (Rs. 57092/ha) as compared to control (Rs. 38345/ha) owing to high cost and amount of organic manures used. Significantly highest gross and net returns was recorded in treatment with RDF + FYM @2.5t/ha + Vermicompost @1t/ha (Rs. 219967 and Rs. 171418 /ha, respectively) and lowest in control receiving RDF (Rs. 172600 and Rs. 134256/ha, respectively). The B:C ratio was higher in RDF + FYM @2.5t/ha + Vermicompost @1t/ha (3.53) as compared to FYM@10t/ha (2.67).

Interaction effects of different nutrient management practices and irrigation methods on B:C ratio of vegetable pea were significant. Across the respective nutrient management practices, drip irrigation supported higher B:C ratio compared to flood irrigation (Fig. 2). The nutrient management combination RDF + FYM @2.5t/ha + Vermicompost @1t/ha, under drip irrigation, recorded significantly higher B:C ratio (3.72) as compared to FYM @10t/ha (2.77). B: C ratio under flood irrigation with RDF in control (3.46) was higher while lower in FYM @10t/ha (2.57).

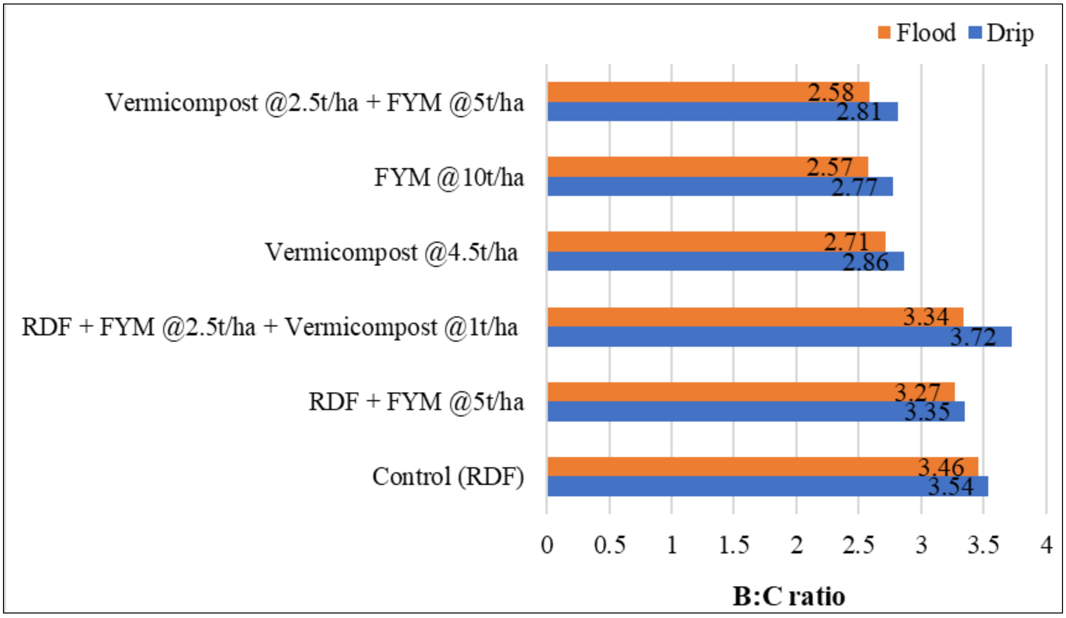

Fig 2: Influence of different irrigation and nutrient management practices on B:C ratio

Enhanced economic parameters under drip irrigation can be answered with the ability to supply nutrients as well as water uniformly with proper distribution patterns resulting in favorable conditions for optimized plant growth and ultimately for yield of crop (Gal and Dudley, 2003) [5]. The higher gross and net returns and B:C ratio in integrated practices may be because of higher growth attributes as well as yield attributes and crop yield gained. High cost of production under organic manures was because of high cost and amount used but overall, benefit was recorded. These findings are in concurrence with the reports of Kumar *et al.* (2017) [12] and Meti *et al.* (2019) [16].

Conclusion

The study's results unequivocally endorse the adoption of drip irrigation in conjunction with an integrated nutrient management approach, specifically the combination of RDF + FYM @2.5 t/ha + Vermicompost @1 t/ha, in Himalayan pea farming. This synergy not only augments pea yields but also ensures the preservation of optimal soil and water conditions. The increased yield translates into enhanced income for vegetable pea farmers, underpinning the economic viability of this approach. Furthermore, this sustainable agricultural practice has the potential to mitigate environmental impacts associated with traditional farming methods while fortifying the ecological equilibrium in the region.

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