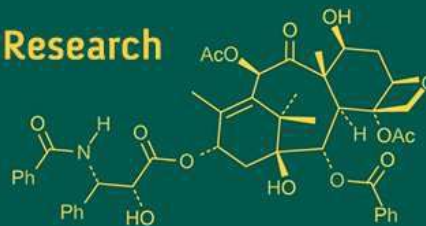


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Formulate empirical models to optimize mustard irrigation level by using energy balance residual and benefit-cost analysis

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Abstract

A two-year research study (2020-2022) titled "Formulating Empirical Models to Optimize Mustard Irrigation Levels Using Energy Balance Residual and Benefit-Cost Analysis" was conducted at the IRS Farm of Sam Higginbottom University of Agriculture, Technology and Science, Prayagraj, Uttar Pradesh, India. The study focused on irrigation scheduling based on the Energy Balance Residual for the mustard crop, specifically the Varuna (T-59) variety. The experiment followed a randomized block design (RBD) with five irrigation treatments: I₁: $\lambda ET = 1.75$, total irrigation depth = 180 mm, I₂: $\lambda ET = 1.5$, total irrigation depth = 240 mm, I₃: $\lambda ET = 1.0$, total irrigation depth = 300 mm, I₄: $\lambda ET = 0.755$, total irrigation depth = 360 mm, I₅: $\lambda ET = 0.5$, total irrigation depth = 420 mm. Among these treatments, the highest yield (2.23 t/ha), 1000-seed weight (5.4 g), and harvest index (24.3%) were observed when irrigation was scheduled at $\lambda ET = 1.5$ with a total water depth of 240 mm (Treatment I₂). Additionally, the maximum benefit-cost ratio (BCR) of 3.43 was recorded under this treatment. Furthermore, the residual method of energy balance demonstrated a satisfactory correlation between the benefit-cost ratio and irrigation depth, with a coefficient of determination ($R^2 = 0.6808$).

Keywords: Latent heat of vaporization (λET), irrigation depth, irrigation scheduling, benefit-cost ratio, total available water (TAW)

1. Introduction

The Indian economy is based primarily on agriculture, and one of the best strategies to save water and energy is to time irrigation plays a crucial role in global agriculture, significantly enhancing crop productivity and ensuring food security. Approximately 80% of the water supply is currently used for irrigation. It is anticipated that this will decrease by up to 73%. Droughts have occurred in India recently. Drought-stricken areas were identified for the 2015-16 school year in Andhra Pradesh, Telangana, Karnataka, Maharashtra, Madhya Pradesh, Chhattisgarh, Odisha, Jharkhand, and Uttar Pradesh. Droughts must be prevented in all of these states through effective water resource management. In essence, irrigation scheduling is deciding how much and when to apply water to a field or crop. The primary objective of irrigation scheduling is to maintain an optimal level of soil moisture by applying an adequate depth of water while maximizing irrigation efficiency without compromising crop yield. Several methods are available for determining the appropriate timing of irrigation, including the climatic approaches, soil water depletion method (deficit irrigation), plant-based indices, climatic approaches, and the critical growth stage method. Evapotranspiration (ET) estimation and irrigation scheduling are two applications of the residual method of energy balance. Its foundation is the idea that sensible heat flux (H), latent heat flux (λET), or ground heat flux (G) all use the energy that is available at the surface. India has the lowest productivity among the major mustard-growing countries. While China, the highest producer, achieved a productivity of 4.10 tonnes per hectare, India's average yield was only 1.4 tonnes per hectare during 2019-20. The highest productivity among Indian states was recorded in Haryana (2,058 kg/ha), followed by Gujarat (1,745 kg/ha), Rajasthan (1,720 kg/ha), Punjab (1,523 kg/ha), Uttar Pradesh (1,483 kg/ha), and Madhya Pradesh (1,422 kg/ha), with an overall national average of 1,499 kg/ha. In Uttar Pradesh, the average demand for mustard is 40 lakh metric tons. However, in the previous year, mustard was cultivated on 7.01 lakh hectares in the state, yielding a total production of only 10.08 lakh

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metric tons. This reveals a significant gap between demand and production in Uttar Pradesh.

To bridge this gap, increasing mustard productivity through effective irrigation management is crucial. With this objective, research was conducted to develop empirical models for irrigation levels and the benefit-cost ratio of mustard cultivation under energy balance residual.

2. Study Area Description: Field studies were conducted at

research farm of Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj (Allahabad), Uttar Pradesh, India for two consecutive seasons; November 2020 to April 2021 and November 2021 to April 2022. Prayagraj is situated in the South-eastern part of the State Uttar Pradesh. It lies between the parallels of 24°77' and 25°47' north latitudes and 81°21' and 82°21' east longitudes.

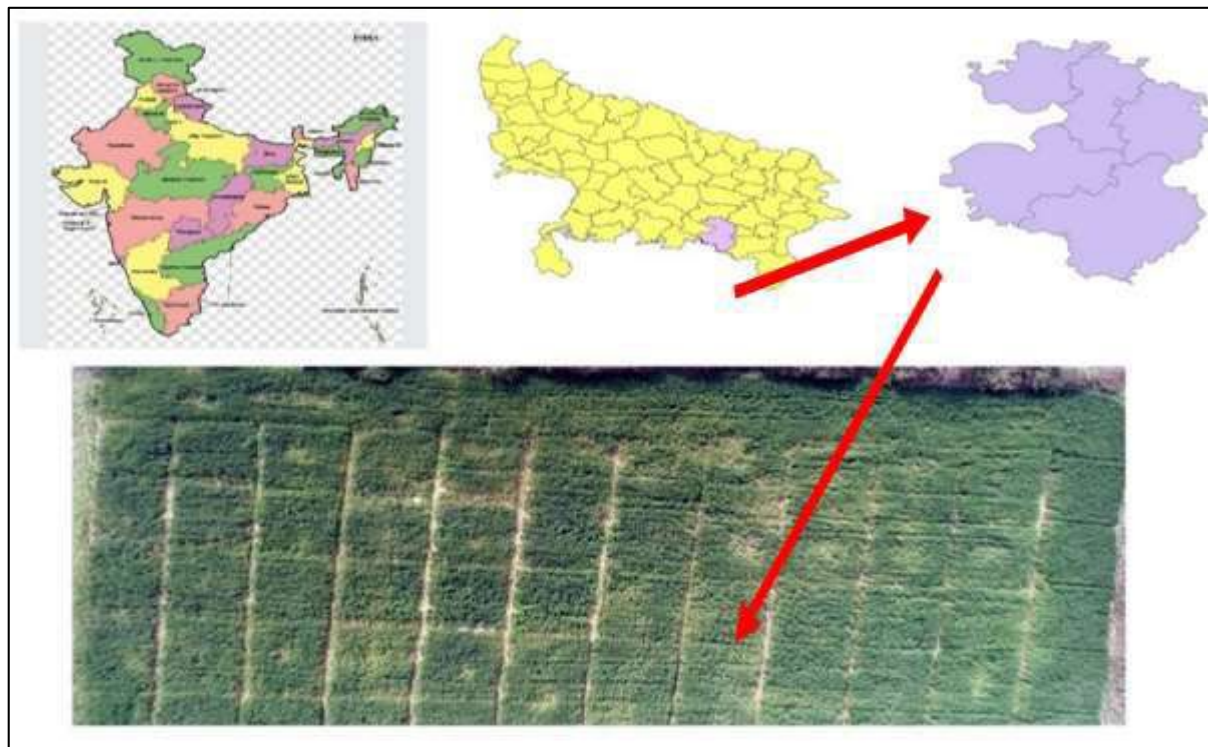


Fig 1: Location of Field Experiment at Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj (Allahabad).

Table 1: Experiment details

Particulars	Specifications
1. Location	Research farm of SHUATS
2. Test Crop	Indian mustard
3. Variety	Varuna T-59
4. Season	Rabi 2020-2021 and 2021-2022
5. Experimental design	Randomized Block Design
6. Number of replications	4.0
7. Number of Treatments	5
8. Number of plots	15
9. Seed rate	5Kg/ha
10. Recommended fertilizer dose	80:40:40(NPK)
11. Gross plot size	4.5X4.5
11. Net plot size	4x4
12. Soil	Sandy Loam

2.1 Calculation of soil moisture content: on the basis of oven-dry method (a soil sample is retrieved from the field, weighed, and then placed in an oven set at 105 °C for 24 hours) moisture of soil is calculated:-

$$\text{Moisture content (\%)} = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \dots \dots (1.0)$$

2.2 Total available water (TAW): By deducting the quantity of soil water at the permanent wilting point from the amount at field capacity, the total amount of water for plant growth that is accessible between those two points is known as the capillary water.

$$\text{TAW} = 1000 [(\theta_{FC} - \theta_{PWP})] \times Z_r \dots \dots \dots (1.0, \text{FAO-56})$$

TAW = Total available water, (mm), θ_{FC} = Moisture content at field capacity, (%), θ_{PWP} = Moisture content at Permanent wilting point, (%), Z_r = Effective root zone depth, (m). Using soil moisture constants, firstly total available water is determined for the experimental soil. For the purpose depth of effective root zone is taken 1m for mustard crop.

2.3 Readily available water (RAW): The portion of the total accessible water (TAW) that easily obtainable by plants from the soil is known as readily available water. Crop rooting depth, soil type, and irrigation systems all play a major role in radial available water.

$$\text{RAW} = p \text{ TAW} \quad (2)$$

IW-depth of irrigation to be applied in one irrigation (mm).

2.4 The depth of irrigation: The available water holding capacity of root zone

$$\text{TAW} = 1000(\theta_{fc} - \theta_{wp}) \times Z_r \quad \text{TAW} = 1000(0.28 - 0.16) \times 1$$

TAW = 120 mm, Water depletion from soil (p) for mustard crop = 0.5 from FAO-56 .Net depth of irrigation water in the root zone = water holding capacity of the root zone x Water

depletion from soil (p). Net depth of irrigation = $120 \times 0.5 = 60$ mm.

2.5 Treatment details of residual method of energy balance

With three replications and five treatments, the field experiment is set up using a randomized block design. A 60 mm net irrigation depth is used. In terms of energy received per unit area, water depths can also be described. The term "energy" refers to the heat or energy needed for free water to vaporize. The latent heat of vaporization, a term used to describe this energy, depends on the temperature of the water. At 20 °C, λ is equal to 2.45 MJ kg⁻¹. To put it another way, 1.45 MJ are required to vaporize 0.001 m³ of water, or 1 kg. As a result, vaporizing 0.001 m³ or 1 mm of water requires 2.45 MJ per m², hence 1 mm of water is comparable to 2.45 MJ per m². Rate of evapotranspiration expressed in MJm⁻²day⁻¹.

$$\lambda ET = Rn - G - H \dots \dots (3.0).$$

λET = latent heat of vaporization (MJ /m² day). The value of the latent heat varies slightly over normal temperature ranges. T= mean air temperature (°C). At 20°C, $\lambda = 2.45$ MJ/kg (FAO 56) where, at 20°C, $\lambda = 2.45$ MJ/kg. Various values of λET are 1.75, 1.5, 1, 0.75, 0.50. The irrigation details are as follow: I₁: $\lambda ET = 1.75$, total irrigation depth = 180 mm, I₂: $\lambda ET = 1.5$, total irrigation depth = 240 mm, I₃: $\lambda ET = 1.0$, total irrigation depth = 300 mm, I₄: $\lambda ET = 0.755$, total irrigation depth = 360 mm, I₅: $\lambda ET = 0.5$, total irrigation depth = 420 mm.

3. Results and Discussion

Irrigation production efficiency for various irrigation schedule based on the residual method of energy balance showed in table 2. Divide the yield by the amount of water used for irrigation to get the field's water usage efficiency. Water consumption efficiency (Kg/m³) is affected by various irrigation scheduling strategies. From the aforementioned Table, it can be seen that treatment I₂ (irrigation at $\lambda ET = 5$ with 240 mm depth of water) recorded the highest water usage efficiency of mustard at 1.0 Kg/m³, while treatment I₁ (irrigation at $\lambda ET = 1.75$ with 180 mm depth of water) recorded the lowest at 0.80 Kg/m³. Water consumption efficiency was 0.58 and 0.43 Kg/m³ respectively for treatments I₃ (irrigation at $\lambda ET = 1.0$ with 300 mm of water) and I₄ (irrigation at $\lambda ET = 0.75$ with 360 mm of water). During the first-year experiment, treatment I₅ (irrigation at $\lambda ET = 0.5$ and a water depth of 420 mm) had the lowest water use efficiency, with a reading of 0.230 Kg/m³. While during the second trial in 2021-2022, treatment I₁ (irrigation at $\lambda ET = 1.75$ with 180 mm of water depth) had the highest water use efficiency of 0.44 Kg/m³ of mustard crop and treatment I₅ (irrigation at $\lambda ET = 0.5$ with 420 mm of water depth) had the lowest water use efficiency of 0.03 Kg/m³. In pooled data, highest mustard water use efficiency was 0.71 Kg/m³ under treatment I₂ (irrigation at $\lambda ET = 1.5$ with 240 mm of water depth), while the lowest mustard water use efficiency was 0.042 Kg/m³ under treatment I₅ (irrigation at $\lambda ET = 0.5$ with 420 mm of water depth). The results showed that irrigation with 240 mm depth of water at irrigation level $\lambda ET = 1.5$ is preferable for

Table 2: Irrigation production Efficiency for Mustard under residual method of energy balance.

Treatment	yield (Kg/ha)	Seasonal water applied	Irrigation production Efficiency	Yield (Kg/ha)	Seasonal water applied	Irrigation Production efficiency	Pooled Irrigation production Efficiency (IPE)
	(2020-2021)	(m ³ /ha)	(Kg/m ³)	(2021-2022)	(m ³)	(Kg/m ³)	(Kg/m ³)
I1 (180 mm)	1438.79	1800	0.80	799.33	1800	0.44	0.62
I2 (240 mm)	2411.73	2400	1.00	1004.89	2400	0.42	0.71
I3 (300 mm)	1738.54	3000	0.58	579.51	3000	0.19	0.39
I4 (360 mm)	1555.45	3600	0.43	432.07	3600	0.12	0.28
I5 (420 mm)	968.81	4200	0.230	179.41	4200	0.042	0.136
SE (m)			0.016			0.012	0.014
CD			0.053			0.04	0.046

3.1 Economics return

Production costs, gross returns, net returns and benefit-cost ratios for two years of study (2020-2021 and 2021-2022) as affected by the residual technique of energy balancing are shown in Table 3. (a) and Table 3 (b), while pooled data are expressed in Table 3 (c). The effect of different treatments on the cost per hectare of farming. Different irrigation scheduling based on residual strategies of energy balancing resulted in total production costs between t/ha 30282.80 and t/ha 36711.42 in the first experiment (2020-21) and between t/ha 37033.11 and 43585.73 t/ha in the second experiment (2020-21). The total cost of production varying with water depths due to differences in the price of water development, water pumping, packaging, and transport. The total cost of production varied between the two trials as a result of slight variations in operating expenses. Gross return at different levels of irrigation influenced the gross income. Maximum gross return ₹122998.40 calculated under treatment I₂ (irrigation at $\lambda ET = 5$ with 240 mm depth of water) in contrast of minimum gross return ₹/ha 49409.48 was

estimated under treatment I₅ (irrigation at $\lambda ET = 0.5$ with 540 mm of depth of water) during first experiment 2020-2021 from table 3 (a). During second year experiment 2021-2022, Maximum (Rs.116056) and minimum (₹.43781) gross return per hectare observed under treatment I₂ and I₅ respectively. In pooled analysis from Table 3. (c) maximum (₹119527.40) and minimum (₹.46595.48) gross return per hectare observed under treatment I₂ and I₅ respectively. The difference in net return due to different irrigation scheduling based on residual method of energy balance presented in Table 3 (a) and Table 3 (b) respectively. Maximum net return ₹. 55230.37 and 77385.15 per hectare was calculated under treatment I₂ during first year experiment and second year experiment respectively. While minimum net return ₹.12698.06 and ₹.195.75 per hectare was calculated under treatment I₅ during first year experiment and second year experiment respectively. In pooled analysis from Table. 3. (c). Maximum (₹.84293.30) and minimum (₹.6446.91) net return per hectare observed under treatment I₂ and I₅ respectively.

Benefit-cost ratio affected due variation in gross return and net return. The difference in benefit-cost ratio due to different irrigation scheduling based on residual method of energy balance presented in table 3. (a) and Table 3 (b). Maximum Benefit-Cost ratio 3.87 and 3.0 was calculated under treatment I₂ during first-and second-year experiment (from Table. 3. (a) and Table. 3 (b) respectively. While minimum Benefit-Cost 1.35 and 1.0 was calculated under treatment I₅ during first-and second-year experiment respectively. In pooled analysis from Table 3. (c) maximum 3.43 and minimum 1.0 Benefit-Cost ratio observed under treatment I₂ and I₅ respectively.

Table 3 (a): Effect of residual method of energy balance on total cost of production, gross return, Net return and benefit cost ratio on mustard crop during experiment year 2020-2021.

First year experiment 2020-2021				
Treatments	Total cost of production (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B/C Ratio
I ₁ (180 mm)	30282.8	73378.12	43095.32	2.42
I ₂ (240 mm)	31796.95	122998.4	91201.45	3.87
I ₃ (300 mm)	33435.11	88665.48	55230.37	2.65
I ₄ (360 mm)	35073.26	79327.95	44254.69	2.26
I ₅ (420 mm)	36711.42	49409.48	12698.06	1.35

Table 3 (b): Total cost of production, gross return, Net return and benefit cost ratio on mustard crop influenced by residual method of energy balance during experiment year 2021-2022.

Second year experiment 2021-2022				
Treatments	Total cost of production (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B/C Ratio
I ₁ (180 mm)	37033.11	78553.76	41520.65	2.12
I ₂ (240 mm)	38671.26	116056.41	77385.15	3
I ₃ (300 mm)	40309.42	91776.85	51467.43	2.28
I ₄ (360 mm)	41947.57	73561.67	31614.1	1.75
I ₅ (420 mm)	43585.73	43781.48	195.75	1

Table 3 (c): Effect of residual method of energy balance on mean cost of production, gross return, Net return and benefit cost ratio on mustard crop.

Pooled data				
Treatments	Total cost of production (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B/C ratio
I ₁ (180 mm)	33657.95	75965.94	42307.99	2.27
I ₂ (240 mm)	35234.11	119527.4	84293.3	3.43
I ₃ (300 mm)	36872.26	90221.16	53348.9	2.46
I ₄ (360 mm)	38510.42	76444.81	37934.39	2.01
I ₅ (420 mm)	40148.57	46595.48	6446.91	1.18

3.2 Water production function of mustard crop.

Fig.2. shows the link between maximum yield and irrigation level for first-and second-year experiment. With changes in

water level, irrigation production efficiency either rises or falls. During the first trial (2020-2021) and second experiment (2021-22), depth of seasonal water applied ranged between 180 mm and 420 mm and the average yield fluctuates between 0.92 and 2.35 t/ha. According to Fig.2.0, there was a strong correlation between the maximum yield and irrigation level ($R^2 = 0.722$). Mustard crop is very diplomatic regarding irrigation level and moisture stress. Despite adequate irrigation depth in treatments I₄ and I₅, yield is quite poor in these two treatments. The yield is much lower under treatments I₄ and I₅ due to abiotic stress, since mustard is extremely sensitive to water depth or moisture stress. Cross ponding to irrigation levels attributes of mustard crop also affected due to abiotic stresses and moisture stresses.

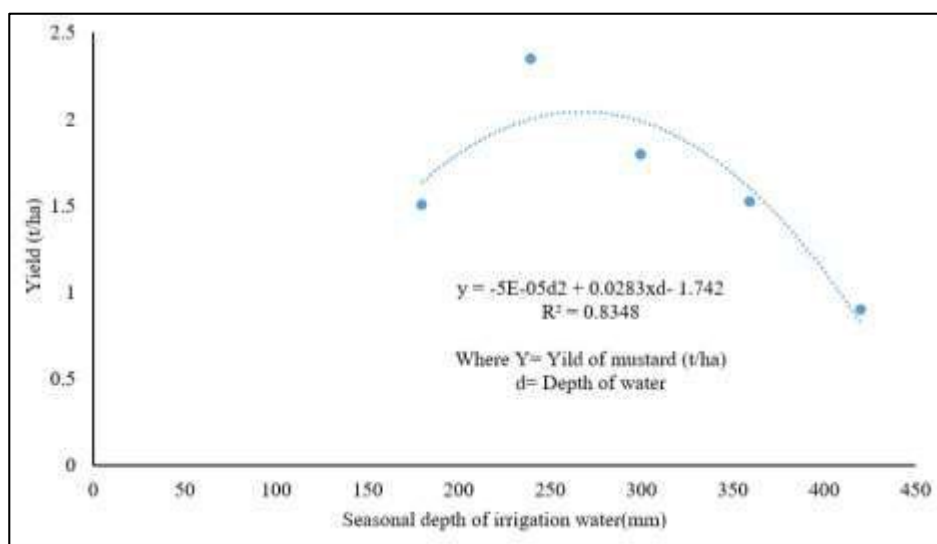


Fig 2: The relationship between yield and depth of water (mm) influenced by residual method of energy balance.

3.3 Empirical model between irrigation levels and economic returns

Figure 3. shows the relationship between benefit-cost ratio and water depth; the results showed that benefit-cost ratio decreased as water depth increased and vice versa. The

depth of the water and the benefit-cost ratio are inversely related to each other. It is clear from the aforementioned Figure that, there is a strong relation between benefit-cost ratio and seasonal water depth ($R^2 = 0.68$).

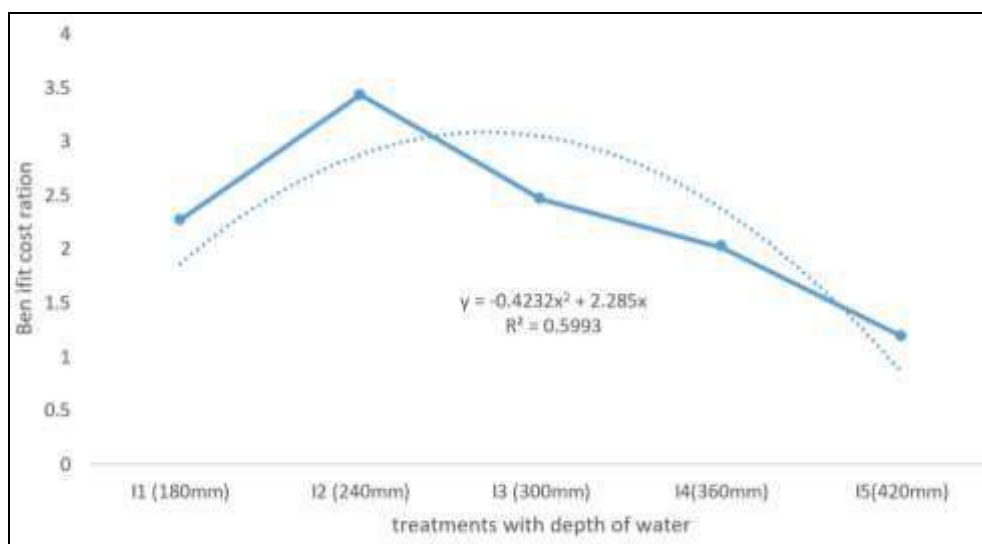


Fig 3: Shows the relationship between benefit-cost ratio and water depth.

4. Conclusion

In case of residual method of energy balance 240 mm depth of water seems to be desirable for highest yield of mustard crop (Varuna T-59) in sandy loam soil trans Yamuna area of Prayagraj under humid subtropical arid zone. The highest benefit-cost ratio (BCR) of 3.43 was observed with this treatment. Moreover, the residual energy balance method showed a strong correlation between the benefit-cost ratio and irrigation depth, with a coefficient of determination ($R^2 = 0.6808$).

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