Energy Assessment in *Rabi* Sunflower under Varying Drip Irrigation Regimes and Fertigation levels

Abstract

Efficient Irrigation and Nutrient Management Strategies are Important for Sustainability of Agriculture. In order to elucidate the above hypothesis, an on-farmexperiment was carried out at Water Technology Centre, PJTSAU, Hyderabad to study the effect of different combinations of drip irrigation regimes and fertigation levels on energy dynamics under Rabi sunflower. The experimental design was split-plot design and contained three replications for DRSH^{-1} sunflower variety. Three treatments of drip irrigation were compared as main plots (0.8 Epan, 1.0 Epan and 1.2 Epan base values of the Epan pan) and four levels of fertigation at the sub-plots (60%, 80%, 100% and 120% of the recommended dose). 75:90:30 kg NPK ha^{-1} was set for the fertilizer recommendation. Energy parameters: energy output, energy efficiency, net energy gain, energy profit, and energy intensity were assessed across treatment combinations.The findings indicated that peak energy consumption transpired under settings integrating 1.2 Epan irrigation with a 120% recommended dosage of N and K□O fertigation. The optimal irrigation level was 1.0 Epan, which produced enhanced outcomes in energy output (102.6 GJ ha^{-1}), use efficiency (5.02), and nett energy gains (90.1 GJ ha^{-1}) relative to lower irrigation levels. The application of the full prescribed dose in fertigation treatments proved to be excellent, exhibiting exceptional performance across all energy metrics: output (105.6 GJ ha^{-1}), usage efficiency (8.1), nett energy (92.5 GJ ha^{-1}), profitability (0.223), and intensiveness (0.0022). Statistical study revealed no significant interaction between irrigation and fertigation treatments, indicating that these parameters independently affect energy efficiency indicators.

Key words: Energy, Sunflower, Energy use efficiency, fertigation, drip irrigation

Introduction:

In India's agricultural sector, sunflower (Helianthus annuus L.) is a vital oilseed crop, esteemed for its exceptional oil quality and its extraordinary adaptability to many growing situations. The Rabi growing season poses specific challenges, especially with water accessibility and resource efficiency. With the growing prevalence of water scarcity, the implementation of effective irrigation systems is essential for sustained agricultural production (Chaitanya et al., 2022). Contemporary drip irrigation technology signifies a substantial improvement over traditional flooding techniques, especially in water-scarce regions (Sidhu et al., 2021). This precision method supplies water directly to plant roots, reducing waste and preserving ideal soil moisture levels. This focused water delivery improves nutrient absorption and promotes superior crop development, rendering it especially beneficial for Rabi sunflower agriculture, where resource optimisation is essential (Alharbi et al., 2024).

The utilisation of energy in agriculture has become a vital factor in modern farming methods. Given escalating energy expenses and increasing environmental consciousness, comprehending and enhancing energy efficiency in agricultural production systems has become imperative. The correlation between energy inputs and agricultural outputs is a crucial measure of production sustainability and economic feasibility (Pervanchon et al., 2002; Pretty, 2008). Fertigation technology, which integrates irrigation with accurate fertiliser application, presents promising possibilities for enhancing resource utilisation. This approach allows farmers to align nutrient delivery with crop needs, potentially improving resource efficiency and energy conservation (Paramesh et al., 2020; Shah & Wu, 2019).

Notwithstanding these evident benefits, studies investigating the synergistic energy effects of precision irrigation and diverse nutrient treatment rates in Rabi sunflower farming are scarce. A comprehensive study was devised to assess energy dynamics across various management situations, thereby addressing this information gap. The research framework integrated several irrigation levels according to pan evaporation rates (0.8 Epan, 1.0 Epan, and 1.2 Epan) alongside various fertigation intensities (from 60% to 120% recommended dose of N and K2O). This study seeks to measure essential energy indicators such as output levels, efficiency measures, nett energy gains, profitability variables, and intensity measurements. This investigation aims to determine the most effective combinations of irrigation and fertiliser management strategies that enhance energy efficiency and crop output in Rabi sunflower cultivation. These findings will provide essential insights for formulating sustainable agriculture techniques that harmonise resource conservation with productive yield.

Materials and methods:

The experimental study was conducted at the Water Technology Centre, Professor Jayashankar Telangana State Agricultural University (PJTSAU), Rajendranagar, Hyderabad (17°19'N latitude, 78°23'E longitude, 542.3 m above mean sea level) during the Rabi season of 2019-20. The experimental site featured sandy clay loam soil with an alkaline pH and non-saline characteristics. Pre-experimental soil analysis indicated low available nitrogen levels, high accessible phosphorus and potassium levels, and medium organic carbon content. The soil moisture retention capacity was measured at 60.91 mm within a 45 cm depth profile. The analysis of irrigation water revealed a neutral pH of 7.22 and a C3 classification, signifying its appropriateness for crop cultivation with appropriate management measures.

The experiment utilised a split-plot design with three replications to assess the synergistic effects of irrigation and fertigation treatments. The primary plot treatments consisted of three drip irrigation regimes determined by cumulative pan evaporation (Epan): irrigation at 0.8 Epan (I1), 1.0 Epan (I2), and 1.2 Epan (I3). The sub-plot treatments comprised four fertigation levels based on the recommended dose (RD) of 75:90:30 kg NPK ha^{-1} as the baseline: 60% RD of N and K_2O (F1), 80% RD of N and K_2O (F2), 100% RD of N and K_2O (F3), and 120% RD of N and K_2O (F4). Nutrient management was executed using a combination of basal application and fertigation. The complete phosphorus (P_2O_5) need was delivered as a basal dose before planting, while nitrogen and potassium were supplied via the drip irrigation system using urea and sulphate of potash (SoP), respectively. The fertigation regimen was organised into 18 applications at four-day intervals, commencing 10 days after sowing (DAS). The application rates were meticulously calibrated based on crop growth phases and nutritional needs, guaranteeing maximum nutrient availability during the growing season.

The total energy input per hectare was calculated by summing the energy contributions from many sources, including human labour, fossil fuels (diesel and petrol), machinery operations, irrigation systems, chemical fertilisers, drip irrigation components, and agrochemicals. Energy values were computed utilising conventional energy equivalents (Table 1) and articulated in gigajoules per hectare (GJ ha^{-1}). The output energy was calculated based on the energy content of both economic yield (seeds) and agricultural residues (biomass) utilising their respective energy equivalents.

The following energy indicators were calculated according to the methodology outlined by(Ekinci et al., 2020):

$$\text{Net Energy } (GJ\ ha^{-1}) = \text{Out put energy } (GJ\ ha^{-1}) - \text{Input energy } (GJ\ ha^{-1}) \qquad (1)$$

$$\text{Energy use efficiency} = \frac{\text{Energy output } (GJ\ ha^{-1})}{\text{Energy input Energy input } (GJ\ ha^{-1})} \qquad (2)$$

$$\text{Energy productivity} = \frac{\text{Crop or system yield (Mg ha}^{-1})}{\text{Input Energy (GJ ha}^{-1})} \qquad (3)$$

$$\text{Energy Efficiency Ratio} = \frac{\text{Total Output Energy in Main Product (GJ ha}^{-1})}{\text{Total Input Energy (GJ ha}^{-1})} \qquad (4)$$

$$\text{Specific energy } (MJ\ ha^{-1}) = \frac{\text{Total Input Energy (GJ ha}^{-1})}{\text{Total Main Product Yield (Mg ha}^{-1})} \qquad (5)$$

$$\text{Energy intensiveness } = \frac{\text{Input Energy } (GJ\ ha^{-1})}{Cost\ of\ cultivation\ Rs/ha} \qquad (6)$$

$$\text{Energy profitability} = \frac{\text{Net energy returns}}{\text{Input energy } (GJ\ ha^{-1})} \qquad (7)$$

Table: Energy equivalents of different inputs and agronomic practices.

Energy sources	Units	Energy equivalent (MJ)	Reference
Inputs			
Human labour	Hrs	1.96	Panesar & Bhatnagar(1994)
Machinery			(Khan & Hanjra, 2009)
A) Tractor	Hrs	64.80	
B) Farm machinery	Hrs	62.70	
Diesel (Including lubricants)	L	56.31	(Khan & Hanjra, 2009)
Petrol (Including lubricants)	L	48.23	(Khan & Hanjra, 2009)
Fertilizers			(Khan & Hanjra, 2009)
A) N	Kg	60.6	
B) P_2O_5	Kg	11.1	
C) K_2O	Kg	6.7	
Insecticides	Kg	120	Khan & Hanjra (2009)
Fungicides	Kg	120	Khan & Hanjra (2009)
Oil seeds	Kg	120	Khan & Hanjra (2009)
Irrigation water	m^3	0.63	Yaldiz et al. (1993)
Drip plastic	kg	120	
Output energy			
Sunflower seed	kg	25	Akdemir et al., (2017)
Sunflower stalk	kg	12.5	Akdemir et al., (2017)

Results and discussions:

Energy input (GJ ha^{-1})

The investigation demonstrated discrepancies in energy usage among various irrigation and fertilisation regimens (Fig.1). The energy required for irrigation levels varied from 11.9 to 13.1 GJ/ha. The fertigation treatments exhibited a broader range, necessitating between 10.8 and 14.2 GJ/ha. An incremental rise in energy input was noted as irrigation levels escalated from 0.8 to 1.2 Epan, and as fertigation rates advanced from 60% to 120% of N & K_2O

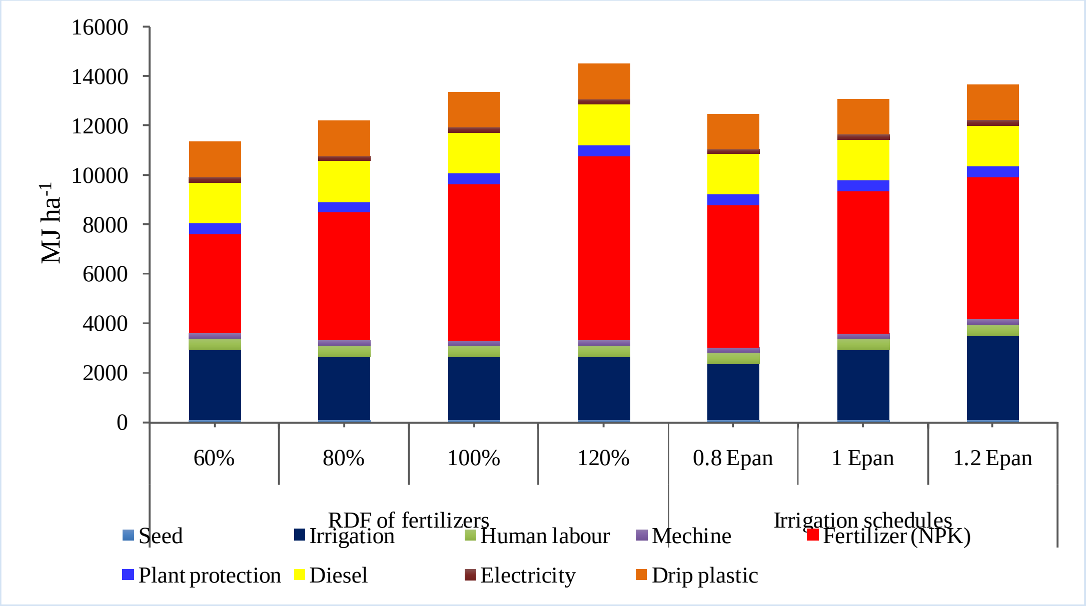

Fig.1 Energy distribution in different irrigation regimes and fertigation levels (MJ ha^{-1})

Energy Output(GJ ha^{-1})

The analysis of energy output across several drip irrigation treatments demonstrated notable discrepancies. The maximum energy output (102.6 GJ ha^{-1}) was attained with drip irrigation scheduled at 1.2 Epan, which was statistically superior to the output from irrigation at 0.8 Epan (87.7 GJ ha^{-1}). No substantial difference was detected between the irrigation schedules of 1.2 Epan and 1.0 Epan, with both providing 102.6 GJ ha^{-1}. Fertigation treatments exhibited varied patterns of energy output regarding nutrient management. The application of the full recommended dose (100% RD) of nitrogen and potassium oxide yielded a significantly greater energy output of 105.6 GJ ha^{-1}, in contrast to the 80% RD, which produced 96.1 GJ ha^{-1}, and the 60% RD, which resulted in 87.6 GJ ha^{-1}. Significantly, elevating the fertigation level to 120% RD (106.7 GJ ha^{-1}) did not produce statistically significant enhancements compared to the 100% RD treatment, indicating that the ideal nutrient application rate is likely within this range.

Energy Indicators

Energy Use Efficiency

The energy use efficiency (EUE) exhibited considerable variance across various irrigation and fertigation regimens. The highest EUE (8.2) was seen under drip irrigation set at 1.0 Epan, which was statistically superior to 0.8 Epan (7.4). The improved efficiency at 1.0 Epan is due to the ideal equilibrium between energy production and input. No notable variation was detected between the irrigation schedules of 1.0 Epan and 1.2 Epan, with both attaining an EUE of 8.2. The analysis of fertigation treatments indicated that the 100% recommended dose (RD) of nitrogen and potassium oxide resulted in a substantially greater economic utilisation efficiency (EUE) of 8.1, in contrast to the 120% RD, which yielded an EUE of 7.5. The EUE values for 80% RD (8.0) and 60% RD (8.1) were statistically comparable to the 100% RD therapy. The data indicate that augmenting fertigation levels beyond 100% RD may not yield corresponding improvements in energy efficiency.

Net Energy(GJ ha^{-1})

Nett energy evaluations across treatments revealed significant differences in response to varying irrigation and fertigation amounts. The highest nett energy (93.6 GJ ha^{-1}) was seen with drip irrigation scheduled at 1.2 Epan, which was statistically superior than irrigation at 0.8 Epan (75.8 GJ ha^{-1}). The nett energy acquired at 1.2 Epan was statistically comparable to that at 1.0 Epan (90.1 GJ ha^{-1}), indicating analogous energy efficiency at these irrigation levels. In nutrient management, fertigation using 100% of the recommended dose (RD) of nitrogen and potassium oxide produced a much greater nett energy production of 92.5 GJ ha^{-1}, in contrast to the 80% RD yield of 84.2 GJ ha^{-1} and the 60% RD yield of 76.8 GJ ha^{-1}. Notably, elevating the fertigation level to 120% RD (92.4 GJ ha^{-1}) did not yield statistically significant enhancements compared to the 100% RD treatment, suggesting that the ideal nutrient application threshold is approximately at the 100% RD level.

Specific energy, Energy Efficiency ratio and energy productivity

Statistical examination of energy characteristics indicated non-significant differences in specific energy, energy efficiency ratio, and energy productivity among various watering schedules and fertigation treatments ($p > 0.05$). The interaction effects between irrigation levels (0.8^{-1}.2 Epan) and fertigation doses (60^{-1}20% RD N & K□O) demonstrated no significant impact on these energy parameters, suggesting uniform system performance irrespective of input combinations.

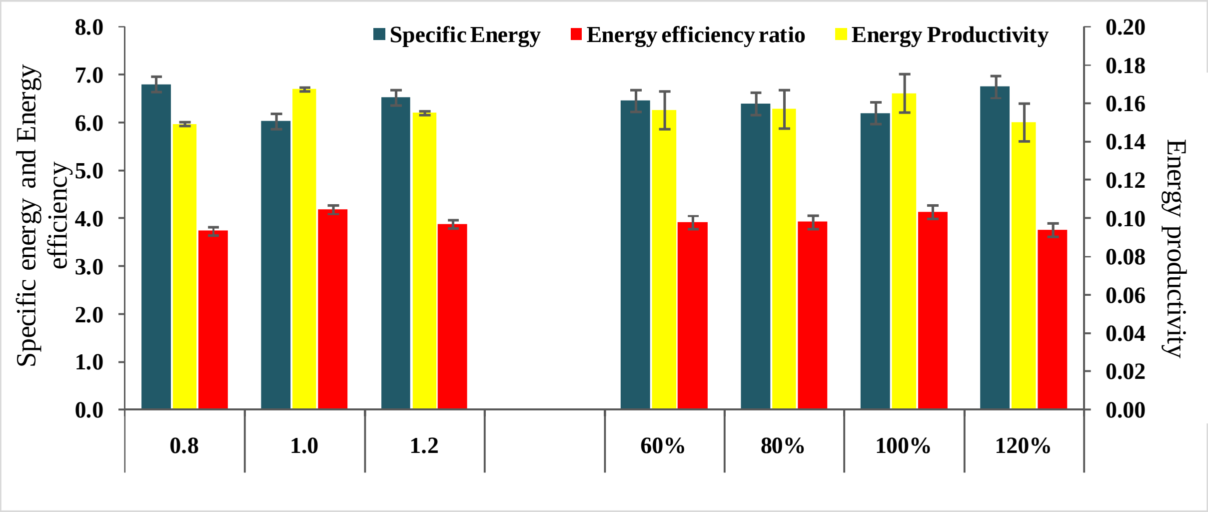

Fig.2 Specific energy, Energy efficiency ratio, Energy productivity as influenced by different levels of drip irrigation regimes and fertigation

Energy profitability and energy intensiveness

The assessment of energy economic indicators revealed clear variations in response to irrigation schedule and fertigation interventions. The energy profitability and energy intensity showed no significant variations across different irrigation schedules (0.8^{-1}.2 Epan), showing stable energy-economic linkages regardless of irrigation levels. Fertigation treatments exhibited notable differences in these parameters, with 120% RD N & K□O attaining significantly greater energy profitability (0.223) and energy intensiveness (0.0022) in comparison to reduced fertigation levels of 80% RD (0.201 and 0.0021, respectively) and 60% RD (0.183 and 0.0019, respectively). The energy economic characteristics at 120% RD were statistically similar to those at 100% RD N & K□O, measuring 0.221 and 0.0022, respectively.

Discussion

This study emphasises the significance of optimum drip irrigation and fertigation levels in enhancing energy efficiency for Rabi sunflower cultivation. Among the assessed irrigation regimes, drip irrigation at 1.0 Epan was identified as the most energy-efficient. The maximum energy output (102.6 GJ ha^{-} ^{1}), energy consumption efficiency (5.02), and nett energy gains (90.1 GJ ha^{-} ^{1}) were attained relative to both the lower (0.8 Epan) and higher (1.2 Epan) irrigation levels. This result indicates that moderate irrigation optimally balances water and energy inputs, aligning with studies highlighting the diminishing returns associated with both under- and over-irrigation. Excessive irrigation, shown in the 1.2 Epan treatment, certainly increased energy inputs without significantly improving yields, underscoring the need for careful water management to optimise resource use in energy terms. This outcome is also consistent with the findings of Soltani et al. (2013) and Unakıtan& Aydın (2018).

The fertigation treatments highlight the significance of aligning nitrogen supply with crop needs. The optimal recommended dose (RD) of nitrogen and potassium (75:90:30 kg NPK ha^{-1}) exhibited superior performance, attaining the highest energy metrics, including energy output (105.6 GJ ha^{-1}), energy use efficiency (8.1), nett energy (92.5 GJ ha^{-1}), energy profitability (0.223), and energy intensity (0.0022). The results demonstrate that excessive fertilisation, evidenced by the 120% RD treatment, results in increased energy consumption without corresponding enhancements in yield or energy efficiency. This aligns with supplementary research demonstrating that balanced nutrient management enhances economic returns and energy efficiency by preventing nutrient waste and mitigating the environmental impact of fertilisers. The lack of significant interaction between irrigation and fertigation treatments suggests that these two variables operate independently in influencing energy efficiency. In situations of water constraint, reduced irrigation may be compensated by improved fertigation to maintain energy efficiency. Conversely, in situations when nutrient inputs are limited or costly, emphasising precise irrigation timing may enhance the yield from available nutrient resources. This flexibility in management strategies is particularly advantageous in regions facing water scarcity and rising input costs, as it facilitates site-specific adjustments to promote sustainable sunflower growth. Improved energy indicators in various watering schedules were also noted by Li et al. (2020) and Sinha et al. (2017).

Table.2Energy output, Energy use efficiency (EUE), Energy productivity and Energy balance as influenced by different levels of drip irrigation regimes and fertigation

Treatments	Energy input (GJ ha^{-1})	Energy output (GJ ha^{-1})	Net energy	EUE	Energy Intensiveness	Energy Profitability
Main plot – (Irrigation regimes):						
I_1: Drip irrigation at 0.8 Epan	11.9	87.7	75.8	7.4	0.0019	0.183
I_2: Drip irrigation at 1.0 Epan	12.5	102.6	90.1	8.2	0.0022	0.214
I_3: Drip irrigation at 1.2 Epan	13.1	106.7	93.6	8.2	0.0022	0.223
SEm ±	-	1.1	1.0	0.08	0.00002	0.18
C.D (P=0.05)	-	4.3	4.3	0.32	NS	NS
Sub plot – (Fertigation levels) :						
F_1 – 60 % RD N & K_2O	10.8	87.6	76.8	8.1	0.0019	0.183
F_2 – 80 % RD N & K_2O	11.9	96.1	84.2	8.0	0.0022	0.201

F_3 – 100 % RD N & K_2O	13.1	105.6	92.5	8.1	0.0022	0.221
F_4 – 120 % RD N & K_2O	14.2	106.7	92.4	7.5	0.0019	0.223
SEm ±	-	1.9	1.9	0.14	0.00004	0.001
C.D (P=0.05)	-	5.5	5.5	0.42	0.00012	0.001
Interaction:						
Fertigation levels at same level of irrigation regimes:						
SEm ±	-	3.2	3.2	0.25	0.00007	0.01
C.D (P=0.05)	-	NS	NS	NS	NS	NS
Irrigation regimes at same or different levels of fertigation:						
SEm ±	-	3.0	3.0	0.23	0.00006	0.18
C.D (P=0.05)	-	NS	NS	NS	NS	NS

Conclusion:

The results indicate that optimising drip irrigation and fertigation parameters substantially enhances energy efficiency in Rabi sunflower cultivation. Drip irrigation at 1.0 Epan and fertigation with 100% recommended doses of nitrogen and potassium oxide were the most effective, maximising energy output, utilisation efficiency, and nett energy gains. The lack of significant interaction between irrigation and fertigation indicates that both factors enhance energy metrics independently, allowing for management flexibility. These findings provide a basis for more resource-efficient and sustainable sunflower agriculture, particularly in regions with limited water supplies.

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