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Thermal Indices and Energetics of linseed as influenced by different irrigation scheduling and nitrogen levels in Chhattisgarh, India

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ABSTRACT
A field experiment was conducted during Rabi season of 2015-16 at the Instructional cum Research Farm, IGKV, Raipur (21°4′N, 81°35′E and 290.20 masl) to study the thermal indices and energetics of linseed crop under different irrigation scheduling and nitrogen levels. The experiment was laid out in split plot design keeping four irrigation scheduling viz., come-up (I_1), one (I_2), two (I_3) and three irrigation (I_4) in main plots and four levels of nitrogen viz., control (N_0), 30 kg (N_1), 60 kg (N_2) and 90 kg N ha^{-1} (N_3) in sub plots with three replications. Results revealed that the number of days to 50% flowering, 50% pod formation and physiological maturity; energy input, accumulated GDD, HTU and HYTU increases with increasing the number of irrigations and rate of nitrogen levels. However, maximum seed and oil yield along with energy output and efficiencies i.e. dry matter efficiency, production efficiency, heat use efficiency, helio-thermal use efficiency and hydro-thermal use efficiency were recorded highest with the application of two irrigations (I_3) and 90 kg N ha^{-1} (N_3). In case of net energy, energy profitability, energy use efficiency and energy productivity were recorded higher value with the application of two irrigations (I_3) and 60 kg N ha^{-1} (N_2). Similarly, the lower value of specific energy and energy intensiveness were recorded with the application of two irrigations (I_3) and three irrigations (I_4), respectively, but in case of nitrogen levels, the lower value of specific energy and energy intensiveness were recorded without nitrogen treatment (N_0).
Keywords: *Thermal indices, Energetics, Linseed, Oil content, Physiological characters*

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INTRODUCTION

Linseed is highly nutritious, unique (best herbal source of omega-3 fatty acids) and emerging among oilseeds for its technical grade vegetable oil and good quality fibre producing ability. The demand, supply and gap of edible oil in India are 18.94, 10.08 and 8.86 (47%) million tons respectively [1]. Chhattisgarh having third highest yield gap between improved technology and farmer's practice in irrigated condition [2]. Chhattisgarh is one of the important linseed growing state of India, where linseed is cultivated in about 0.026 million hectare area with a production of 0.011 million tones but its productivity is low in Chhattisgarh (423 kg ha^{-1}) and national (498 kg ha^{-1}) compared to global (877 kg ha^{-1}) productivity [3]. The major reason for low productivity of linseed may be due to adoption of primitive sowing method like *Utera* and perpetual scarcity of basic agro-inputs like irrigation, fertilizers etc. Chhattisgarh government is giving more emphasis to grow oilseed and pulse crops in place of summer paddy on account of heavy water requirement. The irrigation scheduling in linseed plays an important role in the growth and development of linseed crop; and to maximize yield and oil content, adequate soil moisture must be maintained during critical period. Besides other agronomic factors, nitrogen is major factor which determine the crop vigor and ultimately yield of linseed, especially when grown under irrigated condition. It was therefore felt that for bumper harvest of linseed crop by applying appropriate irrigation scheduling and levels of nitrogen to be standardized for the Chhattisgarh farmers.
Weather and climate greatly influence the agricultural productivity in any region. The adverse agro-meteorological events like extreme hot and cold temperatures, the lesser brighter sunny days and irregular and uneven distributions of rains are the major factors for the decreasing growth and yields of

any field crops. The oilseed production in India is mainly depending on the vagaries of monsoon [4]. Agricultural production and productivity of any region is being regulated by the prevailing climate of that area through temperature, humidity, rainfall, light intensity, radiation, sunshine duration etc. [5]. The key importance of temperature, light and humidity in enhancing plant nutrient availability and absorption, ultimately crop yield; and also the role they play in disease and pest infestation is well documented [6]. Heat plays significant role in physiological, chemical and biological processes of plants and plants require a specific amount of heat to complete their life cycle. The heat unit concept explains the linear relationship between growth and temperature/light/humidity. Agronomic application of temperature effect on plants is the heat unit concept which had been variously applied to correlate phonological development in crops to predict maturity dates [7] and may be useful to find out the proper recommendation for a specific area on the basis of their local weather condition. Therefore, it is important to find out heat unit requirement and their climatic variation during life span of linseed, so that maximum benefits of agro-management practices could be achieved under various agro-climatic conditions.

Energy consumption from sowing to fibre extraction in linseed is widely accepted parameter than cost of cultivation. Energy use in agriculture has been increasing in response to increasing population, limited supply of arable land and a desire for higher standards of living [8]. Energy output and net energy are crucial parameters when the availability of arable land is the limiting factor for crop production [9]. Efficient use of energy is one of the principle requirements for sustainable agricultural productions which helps to achieve increased production and productivity; and contributes to the economy, profitability and competitiveness of agriculture sustainability in rural areas [10]. Sufficient availability of the right energy and its effective and efficient use are pre-requisites for improving crop production and it has been reported that yield of different crops increased upto 30% by efficient management of energy [11]. In this paper thermal and energy indices has been carried out by using weather and energy variables, respectively.

MATERIALS AND METHODS

Experimental site

A field experiment was conducted during *Rabi* season of 2015-16 at the Instructional *cum* Research Farm, Indira Gandhi Krishi Vishwavidyalaya, Raipur (21°4′ N latitude, 81°35′ E longitude and altitude 290.20 meter above mean sea level) Chhattisgarh, under seventh Agro-climatic region of India *i.e.* Eastern plateau and hills which is classified as sub-humid with hot summer and cold winter. The main source of rainfall is south-western monsoon. The soil was clayey in texture (20.45% sand, 35.36% silt, 44.19% clay), neutral in pH (6.68), normal in EC (0.18) and had low in available N (226 kg ha^{-1}), medium in available P (12.64 kg ha^{-1}), high in available K (367 kg ha^{-1}) and low in organic carbon (0.48%) contents.

The daily weather data records during crop period were collected from the Meteorological Observatory of IGKV, Raipur are presented in Fig. 1. The crop received weekly mean maximum temperature varied from 25.9^{0}C in third week of January to 34.8^{0}C in second week of March, whereas, minimum temperature varies from 11.0^{0}C in fourth week of December to 22.0^{0}C in first week of March. Weekly mean relative humidity throughout the crop season varied between 71.9 to 90.7 percent at morning and 25.1 to 51.3 percent in evening hours, whereas, weekly average sunshine hours highly varied from 1.5 to 9.3 hours' day^{-1} during the crop period.

Treatment detail

The experiment was laid out in split-plot design with three replications. The treatment consisted of four irrigation scheduling *viz.* come-up irrigation (I_1), one irrigation at maximum branching (I_2), two irrigations at branching and flowering stage (I_3) and three irrigations at branching, before flowering and capsule formation stage (I_4) in main plots; and four levels of nitrogen *viz.*, no nitrogen, 30 kg (RDN-50%), 60 kg (RDN) and 90 kg N ha^{-1} (RDN+50%) denoted by N_0, N_1, N_2 and N_3 respectively, arranged in sub-plots. The come-up irrigation was given to the all treatments just after sowing to maintaining soil moisture for proper germination of linseed crop then irrigation was scheduled according to the treatments.

Crop management

Linseed (cv: *RLC-92*) was planted on 21st November, 2015 with the seed rate of 25 kg ha^{-1}. After that recommended dose of P_2O_5 and K_2O (30:30 kg ha^{-1}) were applied as basal dressing to all sub-plots treatments. The crop was harvested on 20th February to 08th March, 2016 at physiological maturity. All the recommended agronomic management practices were followed except for the treatments.

Physiological observations

Days to 50% flowering, 50% pod formation and physiological maturity were recorded through a visual observation in each plot when 50% plants were at flowering and pod formation stage; and 90% plants reached physiological maturity from the sowing date.

Computation of dry matter and production efficiency

Dry matter and production efficiency were calculated by using the following formulae [12].

Dry matter efficiency (mg plant^{-1} day^{-1}) **=** Dry matter accumulation (mg plant^{-1}) / Duration of the crop (days)

Production efficiency (kg ha^{-1} day^{-1}) **=** Seed yield (kg ha^{-1}) / Duration of the crop (days)

Oil extraction

Oil was extracted from the ground linseed seed with the help of soxhlet apparatus as described [13] using petroleum ether as solvent.

Computation of thermal indices

The various thermal or agro-meteorological indices were calculated by using the following formulae [14].

Growing degree days [GDD (^{0}C day)] = $\sum\{\frac{Tmax + Tmin}{2}\}$ - Tb

Where, Tmax = Daily maximum temperature (^{0}C), Tmin = Daily minimum temperature (^{0}C), Tb = Base temperature (4.44^{0}C)

Heat use efficiency [HUE (kg ha^{-1} ^{0}C day^{-1})] **=** Seed yield (kg ha^{-1}) / Accumulated GDD (^{0}C day)

Helio-thermal unit [HTU (^{0}C day hour)] = ∑ GDD × ∑ Actual Sunshine hours

Helio-thermal use efficiency [HTUE (g ha^{-1} ^{0}C day hour^{-1})] = Seed yield (g ha^{-1}) / HTU (^{0}C day hour)

Hydro-thermal unit [HYTU (^{0}C day)] = ∑ GDD × ∑ Average relative humidity (%)

Hydro-thermal use efficiency [HYTUE (g ha^{-1} ^{0}C day^{-1})] = Seed yield (g ha^{-1}) / HYTU (^{0}C day)

Computation of energy indices

Energy input and output was calculated from sowing to fibre extraction of all the treatments of linseed crop. It was estimated in Mega Joules (MJ) ha^{-1} with reference to the standard values (Table 1) [15 and 16]. The standard energy coefficient for seed and fibre of linseed was multiplied with their respective yields and summed up to obtain the total energy output. The energy input for linseed was calculated by adding the respective values under linseed crop. The various energy indices were calculated by using the following formulae [17].

Net energy return (MJ ha^{-1}) = Energy output (MJ ha^{-1}) – Energy input (MJ ha^{-1})

Energy profitability (MJ ha^{-1}) = Net energy return (MJ ha^{-1}) / Energy output (MJ ha^{-1})

Energy use efficiency (Energy ratio) = Energy output (MJ ha^{-1}) / Energy input (MJ ha^{-1})

Energy productivity (kg MJ^{-1}) = Seed yield (kg ha^{-1}) / Energy input (MJ ha^{-1})

Specific energy (MJ kg^{-1}) = Energy input (MJ ha^{-1}) / Seed yield (kg ha^{-1})

Energy Intensiveness (MJ ₹$^{-1}$) = Energy input (MJ ha^{-1}) / Cost of cultivation (₹ha^{-1})

Statistical analysis

Data collected were statistically analyzed by using the procedure suggested [18]. The differences among treatments were compared by applying 'F' test of significance at 5 per cent level of probability.

RESULTS AND DISCUSSION

Physiological characteristics

The physiological characteristics significantly differed due to all the treatments (Table 2). Results exhibited that the number of days to 50% flowering, 50% pod formation and physiological maturity (duration of crop) increases with increasing the number of irrigations and rate of nitrogen levels. The increments were might be due to increased vegetative growth and checked the reproductive growth of the linseed plant. Similar results were reported [19] that the more number of days taken to flower initiation and maturity in irrigated treatments from control; the maturity of linseed crop was delayed under cool and wet conditions [20]; and also opined that increasing the levels of nitrogen fertilization had potential to enhance number of days to 50% flowering, 50% boll formation and maturity of linseed plant [21].

Dry matter and production efficiency

Dry matter and production efficiency of any crop are an important pre-requisite for higher yield, as it signifies photosynthetic ability of the crop. Results showed that, the dry matter and production efficiency were significantly affected due to irrigation scheduling and levels of nitrogen (Table 2). The highest dry matter efficiency (33.25 mg plant^{-1} day^{-1}) and production efficiency (16.64 g plant^{-1} day^{-1}) were recorded under the application of two irrigations (I_3), which was found significant superior then other treatments, but dry matter efficiency was at par with three irrigations (I_4). The lowest dry matter efficiency (18.37 mg plant^{-1} day^{-1}) and production efficiency (8.94 g plant^{-1} day^{-1}) were recorded under the treatment of come-up irrigation (I_1). The data clearly reported that the treatment receiving three irrigations recorded nearly double efficiencies, compared to the treatment receiving come-up irrigation. As regards to levels of nitrogen, the application of nitrogen increases the dry matter and production efficiency were increased in similar trend. The highest dry matter efficiency (31.25 mg plant^{-1} day^{-1}) and production efficiency (15.78 g plant^{-1} day^{-1}) were obtained with the application of 90 kg N ha^{-1} (N_3), which was statistically at par with the application of 60 kg N ha^{-1} (N_2). The lowest dry matter efficiency (21.28 mg plant^{-1} day^{-1}) and production efficiency (10.53 g plant^{-1} day^{-1}) were recorded under no nitrogen (N_0) fertilized treatment. The higher value of dry matter efficiency and production efficiency were possibility due to higher dry matter accumulation and seed yield by the plant, respectively.

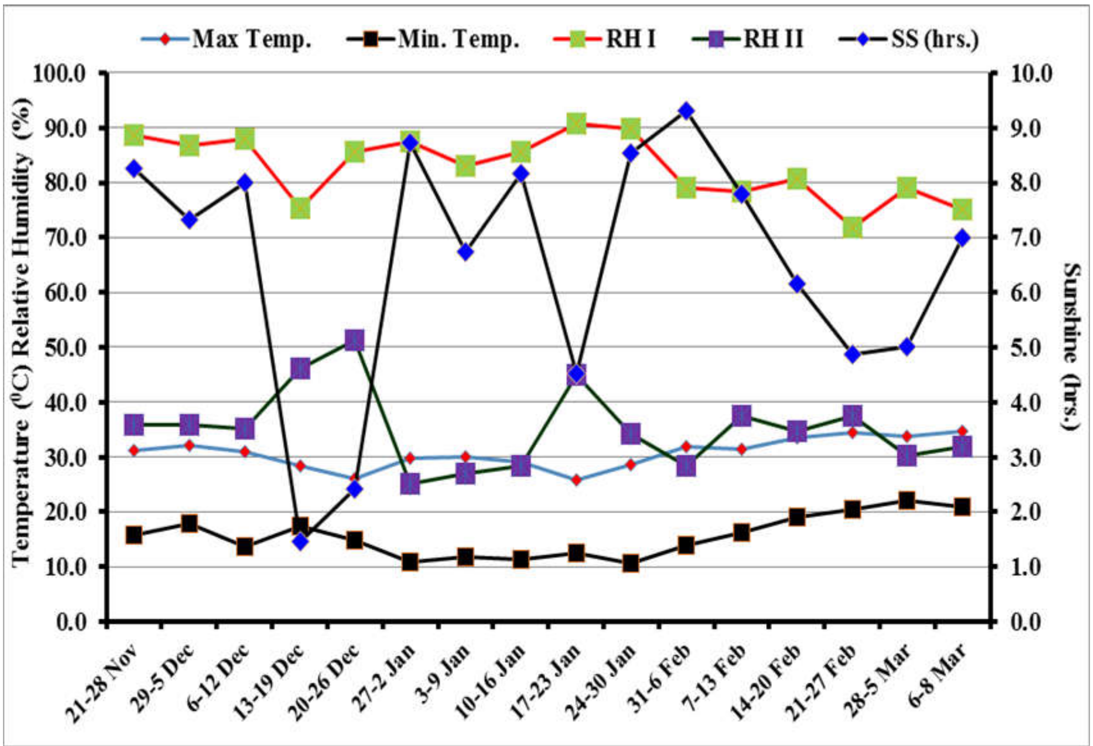

Fig. 1. Weekly meteorological observation during crop period (21 November 2015 to 08 March 2016)

Table 1: Standard values for calculation of energy relationship during the course of investigation

Input and output form	Units	Energy equivalent (MJ)
Input		
Adult man	hour	1.96
Diesel	litre	56.3
FYM	kg	0.3
N	kg	60.6
P_2O_5	kg	11.1
K_2O	kg	6.7
Inferior chemicals (Carbendazim, PSB, Azotobacter)	kg	10
Superior chemicals (Pesticides)	kg	120
Electric motor	kg	64.8
Irrigation	LW hr^{-1}	11.93
Output		
Seed	kg	14.7
Fibre	kg	11.8

[Source: [15 and 16] MJ: Mega joule

Table 2: Physiological characteristics, dry matter efficiency and production efficiency of linseed crop as influenced by irrigation scheduling and levels of nitrogen

Treatment	Days to 50% flowering	Days to 50% capsule formation	Days to physiological maturity	Dry matter efficiency (mg plant^{-1} day^{-1})	Production efficiency (kg ha^{-1} day^{-1})	Seed yield (kg ha^{-1})	Oil content (%)	Oil yield (kg ha^{-1})
Irrigation scheduling								
I_1 - Come-up irrigation	61.42	78.17	90.50	18.37^{d}	8.94^{d}	811^{d}	34.02^{d}	276^{d}
I_2 - One irrigation	63.17	80.42	97.58	25.86^{bc}	13.97^{bc}	1367^{c}	38.43^{c}	527^{c}
I_3 - Two irrigations	66.75	83.75	100.75	33.25^{a}	16.64^{a}	1683^{a}	40.28^{ab}	681^{a}
I_4 - Three irrigations	68.17	85.00	104.17	29.55^{ab}	15.06^{b}	1572^{ab}	41.80^{a}	659^{ab}
SEm±	0.15	0.16	0.31	1.82	0.38	37	0.45	17
CD (P=0.05)	0.52	0.55	1.06	6.29	1.31	129	1.57	59
Levels of nitrogen								
N_0 - Control	62.75	79.75	95.33	21.28^{d}	10.53^{d}	1013^{d}	37.59^{d}	386^{d}
N_1 - 30 kg ha^{-1}	64.58	81.67	97.67	24.15^{c}	12.87^{c}	1270^{c}	38.67^{bc}	500^{c}
N_2 - 60 kg ha^{-1}	65.58	82.50	99.25	30.35^{ab}	15.43^{ab}	1547^{ab}	39.52^{a}	624^{ab}
N_3 - 90 kg ha^{-1}	66.58	83.42	100.75	31.25^{a}	15.78^{a}	1604^{a}	38.75^{b}	633^{a}
SEm±	0.28	0.20	0.26	0.64	0.33	33	0.25	13.87
CD (P=0.05)	0.82	0.59	0.77	1.88	0.95	95	0.73	40.47

Values within a column followed by the same superscripts 'a-d' are not significantly different at 5% level of significance using DMR Test

Table 3: Thermal indices of linseed crop as influenced by irrigation scheduling and levels of nitrogen

Treatment	Growing degree days (^{0}C day)	Heat use efficiency (kg ha^{-1} ^{0}C day^{-1})	Helio-thermal unit (^{0}C day hour × 10^3)	Helio-thermal use efficiency (g ha^{-1} ^{0}C day hour^{-1})	Hydro-thermal unit (^{0}C day × 10^3)	Hydro-thermal use efficiency (g ha^{-1} ^{0}C day^{-1})
Irrigation scheduling						
I_1 - Come-up irrigation	1594^{d}	0.51^{d}	971^{d}	0.83^{d}	8696^{d}	0.093^{d}
I_2 - One irrigation	1754^{c}	0.78^{bc}	1138^{c}	1.20^{bc}	10235^{c}	0.133^{bc}
I_3 - Two irrigations	1826^{b}	0.92^{a}	1201^{b}	1.39^{a}	10994^{b}	0.152^{a}
I_4 - Three irrigations	1882^{a}	0.83^{b}	1267^{a}	1.24^{b}	11663^{a}	0.134^{b}
SEm±	5	0.02	6	0.03	58	0.004
CD (P=0.05)	19	0.08	21	0.12	202	0.013
Levels of nitrogen						
N_0 - Control	1704^{d}	0.59^{d}	1082^{d}	0.93^{d}	9772^{d}	0.103^{d}
N_1 - 30 kg ha^{-1}	1756^{c}	0.71^{c}	1133^{c}	1.10^{c}	10295^{c}	0.121^{c}
N_2 - 60 kg ha^{-1}	1788^{b}	0.86^{ab}	1169^{b}	1.30^{ab}	10635^{b}	0.143^{ab}
N_3 - 90 kg ha^{-1}	1808^{a}	0.88^{a}	1194^{a}	1.32^{a}	10885^{a}	0.145^{a}
SEm±	6	0.02	6	0.03	63	0.003
CD (P=0.05)	18	0.05	17	0.08	183	0.009

Oil content and yield

Data showed (Table 2) that the highest oil content (41.80%) was obtained with the application of three irrigations (I_4), however statistically on par with the application of two irrigations (I_3), while the lowest oil content (34.02%) was obtained from come-up irrigation (I_1). The greater oil content in seed of linseed in two and three irrigations might be due to no moisture stress especially at flowering and grain filling stage. Similar results were reported [22 and 23]. As regard to levels of nitrogen, the oil content in seed increased upto 60 kg N ha^{-1} but further increase in N level to 90 kg ha^{-1} slightly reduced oil content this might be due to synthesis of proteins and carbohydrates takes place at the expense of fatty acids. Similar results were reported [24].

Table 4: Energetics of linseed as influenced by irrigation scheduling and levels of nitrogen

Treatment	Energy input (MJ ha^{-1})	Energy output (MJ ha^{-1})	Net energy (MJ ha^{-1})	Energy profitability (MJ ha^{-1})	Energy use efficiency	Energy productivity (kg MJ^{-1})	Specific energy (MJ kg^{-1})	Energy Intensiveness (MJ ₹$^{-1}$)
Irrigation scheduling								
I_1 - Come-up irrigation	9286	14643^{d}	5357^{d}	0.61^{d}	1.61^{d}	0.089^{d}	11.32	0.320
I_2 - One irrigation	9397	25204^{c}	15807^{c}	1.70^{c}	2.70^{c}	0.147^{c}	6.84	0.316
I_3 - Two irrigations	9508	31188^{a}	21680^{a}	2.28^{a}	3.28^{a}	0.177^{a}	5.64	0.313
I_4 - Three irrigations	9619	29604^{b}	19984^{ab}	2.11^{ab}	3.11^{ab}	0.165^{ab}	6.09	0.309
SEm±	-	700	700	0.08	0.08	0.005	0.29	-
CD (P=0.05)	-	2421	2421	0.29	0.29	0.016	1.00	-
Levels of nitrogen								
N_0 - Control	6706	18448^{d}	11742^{d}	1.74^{abc}	2.74^{abc}	0.151^{a}	6.93	0.230
N_1 - 30 kg ha^{-1}	8540	23449^{c}	14909^{c}	1.74^{ab}	2.74^{ab}	0.148^{abc}	7.33	0.287
N_2 - 60 kg ha^{-1}	10374	28826^{ab}	18453^{a}	1.77^{a}	2.77^{a}	0.149^{ab}	7.33	0.343
N_3 - 90 kg ha^{-1}	12192	29916^{a}	17725^{ab}	1.45^{d}	2.45^{d}	0.131^{d}	8.30	0.398
SEm±	-	595	595	0.07	0.07	0.004	0.20	-
CD (P=0.05)	-	1736	1736	0.21	0.21	0.011	0.57	-

Table 5: Correlation coefficients of seed yield of linseed with respect to physiological characters, thermal and energy use

	SY	DF	DCF	DPM	DMA	GDD	HTU	HYTU
DF	0.859**							
DCF	0.879**	0.993**						
DPM	0.882**	0.951**	0.959**					
DMA	0.976**	0.844**	0.856**	0.840**				
GDD	0.891**	0.941**	0.961**	0.992**	0.848**			
HTU	0.884**	0.937**	0.951**	0.996**	0.838**	0.996**		
HYTU	0.891**	0.953**	0.967**	0.996**	0.853**	0.998**	0.996**	
EI	0.586*	0.507*	0.486^{NS}	0.421^{NS}	0.576*	0.388^{NS}	0.406^{NS}	0.402^{NS}

Where: SY= Seed yield; DF= Days to 50% flowering; DCF= Days to 50% capsule formation; DPM= Days to physiological maturity; DMA= Dry matter accumulation per plant; GDD= Growing degree days; HTU= Helio-thermal unit; HYTU= Hydro-thermal unit; EI= Energy input.

**, ** indicates significant at 5 % and 1 % probability level respectively*

The ultimate objective of oilseed crop production is the oil yield, which is the product of seed yield and seed oil content. Increased oil yield per area can be achieved by increasing both seed yield and seed oil content. The effect of irrigation scheduling showed that highest oil yield (681 kg ha^{-1}) was harvested from two irrigations (I_3) treatment, however statistically on par with the application of three irrigations (I_4), while the significantly lowest oil yield (276 kg ha^{-1}) was produced with the application of come-up irrigation (I_1). The greater oil yield of linseed with the application of two irrigations was mainly due to increased seed yield. Similar results were reported [22 and 23]. As regard to levels of nitrogen. the maximum oil yield (633 kg ha^{-1}) was obtained with the application of 90 kg N ha^{-1} (N_3), however statistically on par with the application of 60 kg N ha^{-1} (624 kg ha^{-1}), while the statistically lowest oil yield (386 kg ha^{-1}) was obtained with no nitrogen application (N_0). The increment in oil yield of linseed was mainly due to application of proper dose of nitrogen and resulted higher seed yield. Similar results were reported [25].

Thermal indices

The data shown (Table 3) witnessed that, the thermal indices were significantly affected due to irrigation scheduling and levels of nitrogen. Results showed that the accumulated GDD, HTU, HYTU increases with increasing the number of irrigations and rate of nitrogen levels. The effect of irrigation scheduling showed that significantly highest GDD (1882 ^{0}C day), HTU (1267 ^{0}C day hour × 10^3) and HYTU (11663 ^{0}C day × 10^3) were exhibited with the application of three irrigations (I_4), while the significantly lowest GDD (1594 ^{0}C day), HTU (971 ^{0}C day hour × 10^3) and HYTU (8696 ^{0}C day × 10^3) were exhibited from the application of come-up irrigation (I_1). The greater GDD and HTU computed were mainly due to higher days require for physiological maturity in three irrigated treatments. However, heat, halio-thermal and hydro-thermal use efficiency were significantly higher with the application of two irrigations (0.92 kg ha^{-1} ^{0}C day^{-1}, 1.39 g ha^{-1} ^{0}C day hour^{-1} and 0.152 g ha^{-1} ^{0}C day^{-1}, respectively). The higher values were might be due to higher seed yield, production efficiency and dry matter efficiency of the respected treatments.

Among the levels of nitrogen, the significantly highest GDD (1808 ^{0}C day), HTU (1194 ^{0}C day hour × 10^3), HYTU (10885 ^{0}C day × 10^3), HUE (0.88 kg ha^{-1} ^{0}C day^{-1}), HTUE (1.32 g ha^{-1} ^{0}C day hour^{-1}) and HYTUE (0.145 g ha^{-1} ^{0}C day^{-1}) were computed with the application of 90 kg N ha^{-1} (N_3), but these efficiencies were remained on par with the application of 60 kg N ha^{-1} (N_2). The higher values were might be due to higher seed yield, production efficiency and dry matter efficiency by the linseed plant. However, significantly lowest GDD (1704 ^{0}C day), HTU (1082 ^{0}C day hour × 10^3), HYTU (9772 ^{0}C day × 10^3), HUE (0.59 kg ha^{-1} ^{0}C day^{-1}), HTUE (0.93 g ha^{-1} ^{0}C day hour^{-1}) and HYTUE (0.103 g ha^{-1} ^{0}C day^{-1}) were computed from control (N_0). The results concur the findings those reported in groundnut [26] and potato crop [27].

Energetics

Data calculated on energetic parameter have been presented in Table 4. Data exhibited that the application of three irrigations (I_4) required maximum energy input towards linseed production (9619 MJ ha^{-1}) followed by two irrigations (9508 MJ ha^{-1}). It was due to higher energy input required towards irrigation and labour imposed on it. The lower energy input on production was recorded in come-up irrigation (9286 MJ ha^{-1}). The application of two irrigations (I_3) gave the highest energy output (31188 MJ ha^{-1}), net energy (21680 MJ ha^{-1}), energy profitability (2.28 MJ ha^{-1}), energy use efficiency (3.28) and energy productivity (0.177 kg MJ^{-1}), which were at par with the application of three irrigations (I_4). The minimum outputs of above measures (14643 MJ, 5357 MJ, 0.61, 1.61 and 0.089 kg MJ^{-1} respectively) were obtained from come-up irrigation (I_1). The lower output in come-up irrigation was ascribed to lowest seed and fibre yield in this treatment. Come-up irrigation (I_1) was utilized more specific energy (11.32 MJ) to produce 1 kg linseed grain yield compared to lower specific energy (5.64 MJ kg^{-1}) utilized by applying two irrigations (I_3). These results indicate that less energy was utilized for more energy production, double grain yield produced by utilizing similar energy with the application of two irrigations (I_3) compared to come-up irrigation (I_1). Similarly come-up irrigation (I_1) required more cost (0.320₹) to given of 1 MJ energy, whereas, relatively less cost (0.309 ₹MJ^{-1}) was obtained with the application of three irrigations (I_4).

As regard to levels of nitrogen, significantly higher energy input (12192 MJ) and output (29916 MJ) recorded under the application of 90 kg N ha^{-1} (N_3), but it was found at par with the application of 60 kg N ha^{-1} (N_2). However, maximum net energy (18453 MJ) was recorded under the use of 60 kg N ha^{-1} (N_2), but it was found comparable with the application of 90 kg N ha^{-1} (N_3). Similar value of energy profitability, energy use efficiency and energy productivity was recorded under the application of 60 kg (N_2) and 30 N ha^{-1} (N_1); and no nitrogen used (N_0). Significantly minimum energy profitability, energy use efficiency and energy productivity were noted under the application of 90 kg N ha^{-1} (N_3). The no nitrogen (N_0) and application of 30 kg (N_1) and 60 kg N ha^{-1} (N_2) were utilized less energy (9.93, 7.33 and 7.33 MJ respectively) to produce 1 kg linseed grain yield which was non-significant with each other, but being superior from the application of 90 kg N ha^{-1} (8.30 MJ). Similarly, no nitrogen (N_0) treatment required very less cost (0.230₹) to given of 1 MJ energy, whereas, relatively more cost (0.398 ₹MJ^{-1}) was obtained with the application of 90 kg N ha^{-1} (N_3).

Correlation analysis

Considering the possibility of high yield through proper thermal and energy use, as primary interest in crop production, therefore, requires understanding the amount of the magnitude of correlations among various physiological characters, thermal and energy inputs. The correlation coefficients of seed yield with days to 50% flowering, 50% capsule formation and physiological maturity; dry matter accumulation plant^{-1}, accumulated GDD, HTU and HYTU by linseed were positively correlated and highly significant at 1% level of significance but the energy inputs were significant at 5% level of significance (Table 5).

CONCLUSION

Based on the above findings it was concluded that higher seed and oil yield along with efficiencies *viz*. dry matter efficiency, production efficiency, heat use efficiency, helio-thermal use efficiency, hydro-thermal use efficiency, energy use efficiency and energy productivity were recorded maximum in linseed crop with the application of two irrigations (I_3) and 90 kg N ha^{-1} (N_3). On the other hand, it can be concluded that among the irrigation scheduling, two irrigations (I_3) is better than three (I_4), one (I_2) or no irrigation (I_1). With respect to levels of nitrogen the application of 90 kg N ha^{-1} (N_3) was superior from the application of 60 (N_2) and 30 kg N (N_1), and no nitrogen (N_0) used. Application of two irrigations (I_3) and 90 kg N ha^{-1} (N_3) more productive and energy efficient in Eastern plateau and hills agro-climatic region of India, specially Chhattisgarh plains. Energy and thermal indices may be quite useful in predicting growth and yield of linseed. There is need by linseed farmers to improve the efficiency of energy and thermal consumption in production and to employ renewable energy.

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