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Energy Use Patterns and Econometric Models of Capsicum (*Capsicum annuum* L.) as Influenced by Automated Sensor-Based Irrigation and Fertigation

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Abstract: The energy input, output and utilization studies provide evidence that the total input energy was reduced during *kharif* season crop when compared to *summer* season and ranged between 71810 to 81501 MJ ha^{-1} and 84396 MJ ha^{-1} to 93952 MJ ha^{-1}, respectively. Among the different energy inputs plastic, chemical and fertilizers had higher energy utilization with notable reduction in *kharif* season., energy from indirect sources played a major role with a consumption of 75.9 to 81.7%, renewable energy resources had more share with 29.6 % in *kharif* season when compared to *summer* season (23.7 %). Econometric model evaluation showed the positive impact of Direct and Renewable Energy on yield of capsicum. Return to scale values were more than 1 for both modules, thus, there prevailed an increasing return to scale of capsicum for estimated model. Automated scheduling irrigation at 75 % available soil moisture along with 125 % recommended dose of fertilizers application through fertigation exhibited higher returns, output energy (301874 MJ ha^{-1}), energy use efficiency (3.32) and energy productivity (0.64) during *summer* season and notable increase in *kharif* season (327557 MJ ha^{-1}, 4.18 and 0.79, respectively). Hence it is economically viable, environmentally sustainable and energy efficient for cultivation of capsicum.

Keywords: Automation, Energy balance, Econometric model, Renewable energy, Sensor

India is an agrarian country with 139.4 million ha of net cultivated land and 200.2 million hectares of gross cropped area with a cropping intensity of 143.6 per cent. The net area sown area accounts to 42.4 per cent of the total geographical area (Annual Report 2021.). The estimates report that global food production must increase by 70 % to meet the food demand of the population projected to around 9 billion by 2050 (CTA-CCAFS 2011). With the increasing population and changing land usage pattern, improved and modern agricultural technologies like protected cultivation is necessary to use cultivated land intensively to meet the growing demand. The protected cultivation under controlled environment aid in high quantity of fresh and quality vegetable and fruits, fetching higher returns to the farmers (Santosh Nagappa Ningoji et al 2023). Sensor based moisture detection and scheduling automated irrigation is a way in addressing the real time challenge of precise soil moisture-based irrigation schedule. Irrigation scheduling based on soil moisture on real time basis provide optimum micro-climate in utilizing the available resources efficiency. Further, application of water soluble fertilizers through drip provides an added advantage in precision nutrient supply as per crop demand (Biwalkar et al 2015).

The economic returns and resource use efficiency are synonymous to the farmers (Kuswardhani et al 2013). Presently, energy, environment and economic returns are interrelated and are key parameters to evaluate any agricultural production system. The inputs such as electricity, fuel, machinery, fertilizer, seed and plant protection chemicals take major share of the energy supplies in the modern agriculture production system. The efficient use of energy resources are required to enhance the production, productivity and profitability of agriculture as well sustainability of rural livelihood (Hatirli et al 2005). Preparing energy balance is the best approach to examine energy use efficiency and environmental impact of the agricultural production system. It also aids researchers to calculate net energy produced, energy use efficiency, energy productivity, specific energy required and energy use patterns in an agricultural production system. Moreover, the energy audit provides sufficient data to establish functional forms to investigate the relationship between input and output energy. Estimating these functional forms is very useful in terms of determining elasticities of inputs on yield and production (Oren and Ozturk 2006).

Considerable work has been carried out on the use of energy in protected cultivation with respect to efficient and economic use for sustainable production in different countries (Heidari and Omid 2011, Ozkan et al 2011 and Kuswardhani et al 2013). However, studies related to energy usage and relations in protected cultivation is meager in India. Hence, the present study was carried out to know the influence of automated sensor-based irrigation and fertigation on energy use patterns and econometric models of capsicum. In addition to these, the study had also aimed to calculate output-input ratio, energy productivity, and specific energy used in greenhouse capsicum production in India.

MATERIAL AND METHODS

Experimental site and treatment details: The greenhouse experiment was conducted for two seasons during 2020-21 at reduced runoff farming block, University of Agricultural Sciences, GKVK, Bengaluru, India situated in the Eastern Dry Zone of Karnataka at 12° 58' N latitude and 75° 35' E longitude at an altitude of 930 meter above mean sea level. The experiment was laid out in completely randomized block design with factorial concept (3×4) and replicated thrice during *summer* (February to June) and *kharif* (July to December) 2020-21. The experiment was carried out with two different factors *viz*., Automated Sensor based irrigation (I_1: 75 % available soil moisture (ASM), I_2: 50 % ASM, I_3: 25 % ASM) and Fertigation levels (F_1: 75 % recommended dose of fertilizers (RDF), F_2: 100 % RDF, F_3: 125 % RDF, F_4: 150 % RDF). Control was maintained with 100 % RDF (150: 112.5: 150 kg NPK ha^{-1} + 25 t FYM ha^{-1}) with surface irrigation in open field condition.

Cultural practices: Beds of 7m × 120cm × 15cm (L × W × H) with 45 cm inter bed space were prepared and basal fertilizer dose of 37.5:37.5:30 NPK and 25 t FYM ha^{-1} was applied uniformly. The beds were covered with silver coloured polythene mulch having 30-micron thickness and 1.20 m width. Seedlings of Hybrid Delisha were raised in portrays and transplanted to greenhouse after 30-35 days of sowing at recommended spacing (60 cm x 45 cm). The experiment was designed to harvest rain water from roof top. Six greenhouse having roof area of 200 m^2 each and storage tank having 3,00,000 liters capacity. During 2020, water harvested was 7,74,000 liters from a roof top of 1200 m^2 green house. The harvested water was used to irrigate capsicum that met 100 % water requirement of capsicum during both the seasons.

Scheduling of irrigation and fertigation: The double drip lateral line laid for each bed, and inline emitters with discharge rate of 2 l h^{-1} were spaced at 30 cm interval on the lateral drip. Irrigation was scheduled according to moisture regime of the treatment with automated sensor and fertigation system (Smart flow) based on volumetric soil moisture content. The VH400 moisture sensors were used during the study, which uses superior transmission line techniques (Time-Domain Reflectometry) as does to measure the moisture content of the soil. The threshold limit for each irrigation regimes were fixed and when the soil moisture content drops below the threshold limit, the sensors will transmit signal to control system to start irrigation until the soil moisture content reaches the desired limit (Field capacity at 27.5% volumetric basis and 18.5, 21.5 and 24.5 % threshold limit in 25, 50 and 75 % ASM, respectively). Water soluble fertilizers are given through fertigation with venturi-type applicators as per treatments (75, 100, 125 and 150 % of RDF) during the entire crop growth period, initiated from third week after transplanting. A total 16 fertigation schedules were given at weekly interval according to the calibrated schedule based on the crop demand.

Energy balance: The agricultural inputs *viz*., seeds, labour, fertilizers, organic manures, irrigation water, electricity, animals, machinery, *etc.* and every agricultural outputs like fruits, vegetables and stalk have their own equivalent energy (Mega Joules) values (Table 1). The energy balance sheet was calculated by talking input energy used in production and output energy produced. Further related parameters *viz.,* net energy, energy use efficiency, energy productivity and specific energy were calculated (Heidari and Omid 2011).

$$Net\ energy\ returns\ (MJ\ ha^{-1}) = Output\ energy - input\ energy$$

$$Energy\ use\ efficiency = \frac{Output\ energy\ (MJ\ ha^{-1})}{Input\ energy\ (MJ\ ha^{-1})}$$

$$Energy\ productivity\ (kg\ MJ^{-1}) = \frac{Grain\ yield\ (kg\ ha^{-1})}{Input\ energy(MJ\ ha^{-1})}$$

$$Specific\ energy\ (MJ\ kg^{-1}) = \frac{Input\ energy(MJ\ ha^{-1})}{Grain\ yield\ (kg\ ha^{-1})}$$

Production functions: Cobbe Douglass (CD) production function was used for assessing statistical significance and expected signs of parameters. The influence of direct, indirect, renewable and nonrenewable energies on production was modeled s (Mobtaker et al 2010).

$$Model\ I: lnY_i = \beta_1 lnDE + \beta_2 lnIDE + e_i$$

$$Model\ II: lnY_i = \gamma_1 lnRE + \gamma_2 lnNRE + e_i$$

where Yi is the ith treatment yield, βi and γi are coefficient of exogenous variables. DE and IDE are direct and indirect energies, respectively, RE is renewable energy and NRE is non-renewable energy.

The concept of returns to scale (RTS) provides the input and output relationship when one or other is changed. It refers to change in efficiency of production system based on extent of change in inputs or outputs (Manzoni and Islam 2009). If doubling of fertilizers (inputs) results in doubling of output, then it is called as constant RTS or CRS. If increase in inputs results in increase in outputs greater proportion than input use, then it is called as increasing RTS or IRS. The production function is called as decreasing RTS or DRS, when proportionate increase in all inputs results in less than proportionate increment in output. In this paper RTS values were calculated for Model I and II by adding the elasticities, derived in the form of regression coefficients in the CD production function. The sum of regression coefficients more than, equal to, or less than unity, imply IRS, CRS, or DRS, respectively.

Economics: The variable cost inclusive of fertilizers and other inputs in the prevailing local markets of Karnataka (India) were considered for cost of cultivation per hectare. Gross returns from the economic produce of the capsicum was calculated by multiplying existing price with fruit yield and expressed on hectare basis (Rs. ha^{-1}). Net return (on hectare basis) was calculated by subtracting the total cost of cultivation from the gross returns (Rs. ha^{-1}). Benefit: cost ratio (B: C ratio) was calculated as the ratio of gross return to the cost of cultivation (Rana et al 2014).

RESULTS AND DISCUSSION

Analysis of input output energy use: Total energy requirements in producing capsicum under automated sensor based irrigation at 75 % ASM with 125 % RDF through fertigation during *summer* and *kharif* were 90965.3 MJ h^{-1} and 78451.1 MJ h^{-1}, respectively (Table 2). Among different energy sources plastic used highest input energy *i.e.,* 44.1 per cent during *summer* (40140 MJ h^{-1}). The plastic includes plastic threads used for staking the capsicum plants at regular intervals and plastic mulch used to cover the beds in the greenhouse. Due to higher share of plastic among energy inputs during *summer*, the plastic threads are reused during *kharif* to reduce the input energy of plastic. The, energy share of plastic reduced 32.4 per cent (25380 MJ h^{-1}). Hence, using the reusable plastic mulch and threads or jute threads are highly recommended to cut down the energy consumption as well as cost. After plastic, chemical fertilizers (14179.7 MJ h^{-1}) and plant protection chemicals (9239.4 MJ h^{-1}) recorded higher chemical energy in total energy consumption. Since high and frequent usage of pesticide for plant protection, the

Table 1. Energy equivalents of inputs and output in cultivation of capsicum crop

Energy source	Energy equivalent (MJ)	Units	Reference
Human (Head)			
Man	1.96	MJ hr^{-1}	(Shahan et al 2008)
Woman	1.57	MJ hr^{-1}	(Shahan et al 2008)
Chemical fertilizer (Kg)			
Nitrogen	60.6	MJ. kg^{-1}	(Shahan et al 2008)
Phosphorus	11.1	MJ. kg^{-1}	(Shahan et al 2008)
Potassium	6.7	MJ. kg^{-1}	(Shahan et al 2008)
Chemicals			
Pesticide (Kg)	199	MJ. kg^{-1}	(De et al 2001)
Pesticide (l)	196	MJ. ltr^{-1}	(Ortiz and Hernanz 1999)
Fungicide (l)	168	MJ. ltr^{-1}	(Djevic and Dimitrijevic 2009, Ozkan et al 2007)
Fungicide (Kg)	92	MJ. kg^{-1}	(Djevic and Dimitrijevic 2009)
Herbicide (l)	238	MJ. ltr^{-1}	(Djevic and Dimitrijevic 2009)
Machines (h)			
Power tiller	2.74	MJ hr^{-1}	(Alam et al 2005)
Knapsack sprayer	1.4	MJ hr^{-1}	(Gezer 2003)
Electricity (kwh)	11.93	MJ kWh^{-1}	(Shahan et al 2008)
Manure (Kg)	0.3	MJ. kg^{-1}	(Yaldiz et al 1993)
Diesel (l)	56.31	MJ. ltr^{-1}	(Heidari and Omid 2011, Shahan et al 2008)
Water irrigation (m^3)	0.63	MJ m^{-3}	(Heidari and Omid 2011, Ozkan et al 2007)
Out put			
Capsicum fruit	0.80	MJ. kg^{-1}	(Canakci and Akinci 2006, Naderi et al 2019)
Capsicum stalk	7.5	MJ. kg^{-1}	(Yelmen 2019)

chemical energy of capsicum had higher values among input energy. Apart from plastic and chemical energy, energy consumption through human labour in the both season was more than $^{1}/_{10}{}^{th}$ of total energy consumption (10983.8 MJ h^{-1} and 12856.0 MJ h^{-1}, respectively), which implies labour force is essential for capsicum cultivation.

Energy sources: The energy can be classified as Direct and Indirect as well as Renewable and Non-renewable energy resources (Ozkan et al 2007). The inputs used in production of capsicum according to the direct, indirect, renewable and non-renewable sources of energy (Table 3 and 4).

Direct energy and Indirect energy: The direct energy includes diesel and electricity, human and animal efforts. the indirect energy source includes plant protection chemicals, manure, fertilizer and machinery. About 42 to 45% of total energy input was in the form of indirect energy for tomato under glasshouse and more than 50% energy used was in form of direct energy for lettuce in greenhouse production (Kuswardhani et al 2013). Cultivation of capsicum in green house consumed only 18.3 % as Direct and 81.7 % as indirect energy during *summer* season and 24.1 and 75.9 % in *kharif* season. In open field conditions (Control) was 21.1 % and 78.9 % during summer season and 29.6 and 70.4 % during *kharif* season, respectively (Table 3).

Renewable and non-renewable energy inputs: The total inputs used in both greenhouse as well as open field condition are mostly dependent on nonrenewable energy (NRE) resources. In green house, the share of renewable energy (RE) resources was only 23.7 % during *summer* and 29.6 % during *kharif* reuse of plastic threads from *summer* season has enhanced share of renewable resources by 5.9 %, like wise reuse of nonrenewable resources like plastic threads, mulching paper and use of solar energy will enhance the share of renewable resources in green house (Table 4). Kuswardhani et al (2013) reported dependency on the nonrenewable form of energy up to 54 to 66% under greenhouse and 59 to 64% in open field vegetable production. Heidari and Omid (2011) observed that non-renewable energy is mostly constituted energy for tomato and cucumber, (94 and 90%, respectively) in greenhouse vegetable production. In open field cultivation has consumed comparatively less nonrenewable energy resources in both the seasons (67.8 and 59.0 %, respectively) might be attributed due to reduced usage of plastic threads and not using plastic mulch to cover the beds.

Econometric model estimation of cultivation of capsicum: The relationship between DE, IDE, RE and NRE and capsicum yield were estimated using CD production

Table 2. Energy use patterns for cultivation of capsicum with automated sensor based irrigation with fertigation and control

Input (Unit)	Summer season				*Kharif* season			
	Automated sensor-based irrigation and fertigation (I_1F_3)		Control		Automated sensor-based irrigation and fertigation (I_1F_3)		Control	
	(MJ h^{-1})	%	(MJ h^{-1})	%	(MJ h^{-1})	%	(MJ h^{-1})	%
Human labour	10983.8	12.1	8654.0	12.6	12856.0	16.4	10611.0	18.5
Diesel	4617.4	5.1	5011.6	7.3	4955.3	6.3	5574.7	9.7
Electricity	1034. 3	1.1	813.6	1.2	1075.1	1.4	851.8	1.5
Machinery	153.4	0.2	169.9	0.2	676.6	0.9	707.0	1.2
Seedling	720.0	0.8	720.0	1.1	720.0	0.9	720.0	1.3
Plastic	40140.0	44.1	17640.0	25.7	25380.0	32.4	5040.0	8.8
Manure	7500.0	8.2	7500.0	10.9	7500.0	9.6	7500.0	13.0
Fertilizers	14179.7	15.6	11343.8	16.5	14179.7	18.1	11343.8	19.7
Plant protection chemicals	9239.4	10.2	11486.5	16.8	8963.3	11.4	10412.9	18.1
Irrigation water	2397.2	2.6	5207.3	7.6	2145.2	2.7	4733.2	8.2
Total	90965.3	100	68546.7	100	78451.1	100	57494.3	100
Direct energy	16635.6	18.3	14479.2	21.1	18886.4	24.1	17037.5	29.6
Indirect energy	74329.7	81.7	54067.5	78.9	59564.7	75.9	40456.9	70.4
Renewable energy	21601.0	23.7	22081.3	32.2	23221.2	29.6	23564.2	41.0
Nonrenewable energy	69364.3	76.3	46465.3	67.8	55230.0	70.4	33930.2	59.0

I_1F_3: Automated Scheduling of irrigation at 75 % ASM coupled with application of 125 % RDF through fertigation function (Model I) and using ordinary least square (OLS) estimation technique was assessed. The yield of capsicum (endogenous variable) was assumed to be a function DE, IDE and RE and NRE (exogenous variables). Autocorrelation test was performed using Durbine Watson (DW) test (Hatirli et al 2005). The regression coefficients of DE and RE forms were positive and significant (Table 5). The regression coefficients of NRE for were also significant. Among all the regression coefficients, the coefficient of IDE for capsicum cultivation was non-significant (The impacts of DE was higher in both the seasons (6.55 and 8.99, respectively) compared to IDE (0.50 and 0.36), which shows that an additional use of 1% of direct energy input would lead to 6.55 % increase in capsicum yield during *summer* season and 8.99 % increase during *kharif* season. RE also showed higher impacts during both the seasons compared to NRE.

Table 3. Direct and Indirect energy sources of capsicum (MJ. ha^{-1}) as influenced by irrigation regimes and fertigation levels

Type of energy	Direct energy (MJ. ha^{-1})			Indirect energy (MJ. ha^{-1})		
Treatments	Summer	*kharif*	Pooled	Summer	*Kharif*	Pooled
I_1F_1	15781.5	18421.7	17101.6	68657.8	53932.8	61295.3
I_1F_2	15831.8	18471.9	17151.9	71493.8	56728.8	64111.3
I_1F_3	16635.6	18886.4	17761.0	74329.7	59564.7	66947.2
I_1F_4	16786.3	19099.9	17943.1	77165.7	62400.6	69783.2
I_2F_1	15706.2	17894.2	16800.2	68771.2	53955.8	61363.5
I_2F_2	15731.3	18296.1	17013.7	71607.2	56791.8	64199.5
I_2F_3	16221.1	18622.7	17421.9	74443.1	59627.7	67035.4
I_2F_4	16497.4	18899.0	17698.2	77279.1	62463.6	69871.4
I_3F_1	15530.3	17718.3	16624.3	68865.7	54091.3	61478.5
I_3F_2	15630.8	18032.3	16831.6	71701.7	56927.2	64314.5
I_3F_3	16083.0	18446.8	17264.9	74537.6	59763.2	67150.4
I_3F_4	16309.0	18672.9	17491.0	77373.6	62599.1	69986.4
Control	14479.2	17037.5	15758.4	54067.5	40456.9	47262.2

I: Automated Sensor based irrigation (I_1: 75 % Available Soil Moisture (ASM), I_2: 50 % ASM, I_3: 25 % ASM)

F: Fertigation levels (F_1: 75 % Recommended Dose of Fertilizers (RDF), F_2: 100 % RDF, F_3: 125 % RDF, F_4: 150 % RDF). Control was maintained with 100 % RDF (150: 112.5: 150 kg NPK ha^{-1} + 25 t FYM ha^{-1})

Table 4. Renewable and non-renewable energy sources of capsicum (MJ. ha^{-1}) as influenced by irrigation regimes and fertigation levels

Type of energy	Renewable energy (MJ. ha^{-1})			Non-renewable energy (MJ. ha^{-1})		
Treatments	Summer	*kharif*	Pooled	Summer	*Kharif*	Pooled
I_1F_1	20746.9	22796.4	21771.7	63692.4	49558.1	56625.3
I_1F_2	20797.2	22806.7	21802.0	66528.4	52394.0	59461.2
I_1F_3	21601.0	23221.2	22411.1	69364.3	55230.0	62297.2
I_1F_4	21751.7	23434.7	22593.2	72200.3	58065.9	65133.1
I_2F_1	20785.0	22291.9	21538.5	63692.4	49558.1	56625.3
I_2F_2	20810.1	22693.8	21752.0	66528.4	52394.0	59461.2
I_2F_3	21299.9	23020.4	22160.2	69364.3	55230.0	62297.2
I_2F_4	21576.2	23296.7	22436.5	72200.3	58065.9	65133.1
I_3F_1	20703.6	22251.5	21477.6	63692.4	49558.1	56625.3
I_3F_2	20804.1	22565.5	21684.8	66528.4	52394.0	59461.2
I_3F_3	21256.3	22980.0	22118.2	69364.3	55230.0	62297.2
I_3F_4	21482.3	23206.1	22344.2	72200.3	58065.9	65133.1
Control	22081.3	23564.2	22822.8	46465.3	33930.2	40197.8

See Table 3 for treatment details

As can be seen, increase in 1 % of RE sources enhance yield by 4.03 and 5.70 % compared NRE sources (2.56 and 2.12 %, respectively). The whole analysis suggests that. Direct and Renewable sources play key role in enhancing the output of capsicum cultivation rather than NRE and IDE. Hatirli et al (2006) also observed similar trend in greenhouse tomato production. Presented in capsicum fruit yield under greenhouse situation increased as a function of the energy inputs Figure 1. The coefficients of determination (R^2) between yield and total energy input was 0.91 in first and 0.89 in *kharif* season. It implies that the variation in total energy input sources had a major influence (91 % and 89 %) on the fruit yield of capsicum in both seasons.

Returns to scale results: The return to scale (RTS) values for Models I to II Eqs. were calculated by gathering the regression coefficients (Table 5). RTS values of Model I, for capsicum yield in both seasons were 7.06 % and 9.36 %, respectively. This shows that 1% increase in the total energy inputs utilize would lead in 7.06 % and 9.36 % increase in the capsicum yield for this model. Similarly, RTS values of Model II, for capsicum yield in both seasons were 6.59 % and 7.82 %, respectively. This shows that 1% increase in the total energy inputs utilize would lead to increase in capsicum yield by 6.59 % and 7.82 %, respectively for this model. In the study of (Mobtaker et al 2010) and (Heidari and Omid 2011) the sum of the regression coefficients (i.e. values for RTS in Table 5) of energy inputs was calculated more than unity.

Influence of automated sensor-based irrigation and fertigation on energy balance: Energy auditing is one of the most common method to examine energy efficiency and

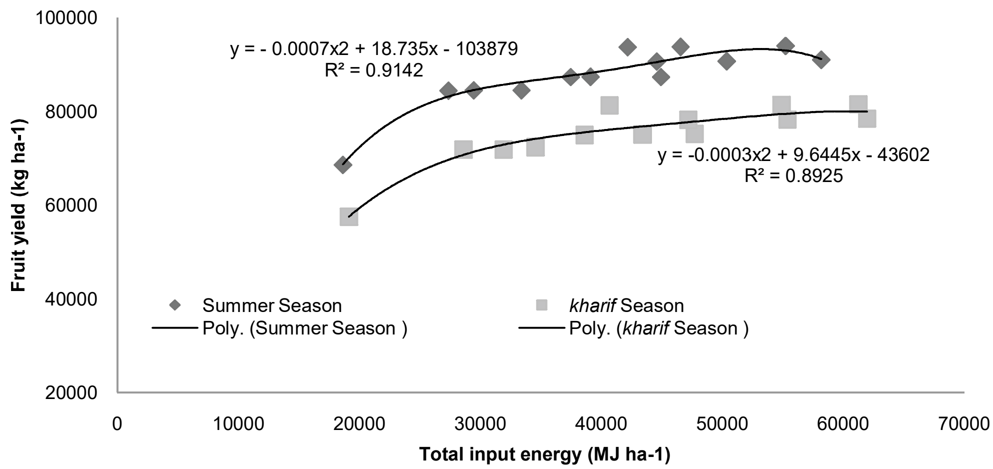

Fig. 1. Fruit yield versus total energy input for capsicum crop cultivation

Table 5. Econometric estimation of direct (DE) vs. indirect (IDE) based on Model I, and renewable (RE) vs. non-renewable (NRE) based on Model II

Endogenous variable	Summer		*Kharif*		Pooled	
Exogenous variables	Coefficient	t-Ratio	Coefficient	t-Ratio	Coefficient	t-Ratio
DE (β_1)	6.55	2.53*	8.99	3.47**	8.645368	3.40**
IDE (β_2)	0.50	0.48	0.37	0.52	0.148117	0.18
Durbine Watson	2.11		1.94		2.47	
R^2	0.86		0.89		0.89	
RTS	7.06		9.36		8.79	
RE (γ_1)	4.03	2.14*	5.70	2.45*	4.985487	2.40*
NRE(γ_2)	2.56	7.20**	2.12	7.12**	2.365395	7.38**
Durbine Watson	1.46		1.51		1.49	
R^2	0.83		0.84		0.84	
RTS	6.59		7.82		7.35	

environmental impact of the production system. The influence of different irrigation regimes and fertigation levels on input energy, output energy, net energy, output to input ratio, energy productivity and specific energy was calculated (Table 6). The output energy of capsicum cultivation ranged from 139452 MJ ha^{-1} to 307015 MJ ha^{-1} during *summer* season and 144509 to 328803 MJ ha^{-1} during *kharif* season. Automated scheduling of irrigation at 75 % ASM coupled with the application of 150 % RDF through fertigation resulted in higher output energy (317909 MJ ha^{-1}) and net energy (238966 MJ ha^{-1}). It was followed by scheduling of irrigation at 75 % ASM coupled with the application of 125 % RDF through fertigation was also attributed due to higher fruit yield (60090 kg ha^{-1}) and stalk yield (35553 kg ha^{-1}). The energy consumed was less with control (59358 MJ ha^{-1}), since it will not include energy consumed for construction, maintenance, automation system and other practices in the greenhouse. Among different treatments in greenhouse application of 75 % RDF through fertigation with all irrigation regimes consumed less energy due to reduced energy consumption in fertilizers as compared to higher doses of fertilizers application. Energy use efficiency was higher with scheduling irrigation at 75 % ASM with 125 % RDF through fertigation in both seasons (3.32 and 4.18, respectively) and lower was recorded with control (2.03 and 3.20, respectively). Ghorbani et al (2011) reported an energy use efficiency of 1.44 for wheat, while Heidari and Omid (2011) found a value of 1.48 for tomatoes. The enhanced energy use

Table 6. Energetics of capsicum as influenced by irrigation regimes and fertigation levels

Treatments	Input energy (MJ ha^{-1}) (1)	Yield (kg ha^{-1}) (2)	Stalk yield (kg ha^{-1}) (3)	Output energy (MJ ha^{-1}) (4)= 2*0.8+3*7.5	Net energy 5= (4-1)	Energy use efficiency 6= (4/1)	Energy productivity (kg MJ^{-1}) 7= (2/1)	Specific energy (MJ kg^{-1}) 8= (1/2)
Summer season								
I_1F_1	84439	33408	26337	224252	139813	2.66	0.40	2.53
I_1F_2	87326	44934	29878	260030	172704	2.98	0.51	1.94
I_1F_3	90965	58199	34042	301874	210909	3.32	0.64	1.56
I_1F_4	93952	55248	35042	307015	213063	3.27	0.59	1.70
I_2F_1	84477	29451	24542	207625	123148	2.46	0.35	2.87
I_2F_2	87338	39108	27494	237494	150155	2.72	0.45	2.23
I_2F_3	90664	50383	30432	268546	177882	2.96	0.56	1.80
I_2F_4	93776	46550	30904	269020	175243	2.87	0.50	2.01
I_3F_1	84396	27381	21619	184045	99649	2.18	0.32	3.08
I_3F_2	87332	37479	24987	217385	130052	2.49	0.43	2.33
I_3F_3	90621	44600	27376	240998	150378	2.66	0.49	2.03
I_3F_4	93683	42184	26151	229879	136196	2.45	0.45	2.22
Control	68547	18651	16604	139452	70905	2.03	0.27	3.68
Kharif season								
I_1F_1	72355	34562	30034	252901	180546	3.50	0.48	2.09
I_1F_2	75201	47721	33232	287414	212214	3.82	0.63	1.58
I_1F_3	78451	61980	37063	327557	249106	4.18	0.79	1.27
I_1F_4	81501	61257	37306	328803	247302	4.03	0.75	1.33
I_2F_1	71850	31927	27584	232420	160570	3.23	0.44	2.25
I_2F_2	75088	43405	30977	267052	191964	3.56	0.58	1.73
I_2F_3	78250	55392	33866	298306	220056	3.81	0.71	1.41
I_2F_4	81363	54893	34654	303816	222454	3.73	0.67	1.48
I_3F_1	71810	28603	25342	212946	141137	2.97	0.40	2.51
I_3F_2	74960	38624	27943	240471	165512	3.21	0.52	1.94
I_3F_3	78210	47191	30180	264103	185893	3.38	0.60	1.66
I_3F_4	81272	40685	27776	240872	159600	2.96	0.50	2.00
Control	57494	19143	17226	144509	99361	3.20	0.42	2.36

See Table 3 for treatment details

efficiency was primarily attributed to the increased output energy resulting from a higher capsicum yield. Energy productivity scheduling of irrigation at 75 % ASM with the application of 125 % RDF through fertigation produced 0.64 and 0.79 kg fruits by consuming 1 MJ energy whereas control took the same energy to produce only 0.27 and 0.42 kg of capsicum fruits in both seasons. The higher yield per unit energy was mainly attributed by higher absolute growth rate, crop growth rate, net assimilation rate and relative crop growth throughout the crop growth stage which might have resulted in rapid dry matter production and partitioning into reproductive parts. The specific energy required to produce 1 kg of fruit was also lesser (1.56 and 1.27 MJ kg^{-1}) with 75 % ASM coupled with 125 % RDF through fertigation. The higher specific energy was required in control (3.68 and 2.36 MJ kg^{-1}) in both seasons.

In total, energy auditing showed that, irrigation at 75 % ASM and application of 125 % RDF through fertigation was more energy efficient compared to other combinations and also with open field conditions (control). Similar results were reported by Hatirli et al (2005) in tomato; Heidari and Omid (2011) in cucumber and tomato; Kuswardhani et al (2013) in tomato, lettuce and chili and Naderi et al (2019) in bell pepper.

Influence of automated sensor based irrigation on yield of capsicum: Scheduling of irrigation at 75 % ASM coupled with application of 125 % RDF through fertigation resulted in significantly higher capsicum fruit yield during both seasons compared to control (open field condition). Irrigation at 75 % ASM with 125 % RDF registered 217 per cent higher yield compared to control (Table 6). Application of 125 % RDF through fertigation coupled with optimum moisture distribution around root zone resulted in uniform distribution of required quantity of nutrients in the rhizosphere throughout the crop growth period. This further enhanced the physiological processes and efficient translocation of photosynthates towards reproductive organs might resulted in higher fruit yield in capsicum. Split application of fertilizers through fertigation in solanaceous vegetables enhanced nutrient use efficiency, crop productivity and higher availability of N, P and K nutrient in the root zone of drip fertigated plot. Biwalkar et al (2015) also reported similar results with application of 120 per cent targeted dose of fertilizer with scheduling of irrigation at 100 per cent replenishment of $ET_{c.}$

Economics: The total cost of cultivation in capsicum and gross return was calculated treatment wise. The recurring and non-recurring cost incurred in the production were calculated separately. The total expenditure of capsicum cultivation ranged from Rs. 592204 to Rs. 1325376. Scheduling irrigation at 75 % ASM with the application of 125 % RDF through fertigation resulted in higher gross return (Rs. 2618946 and 2789090 ha^{-1}, respectively) and net return (Rs. 1315949 and Rs. 1481512 ha^{-1}, respectively) in both seasons (Table 7). The higher net return was mainly attributed to higher fruit yield during both the seasons. The lower gross and net returns were recorded with scheduling irrigation at 25 % ASM with the application of 75 % RDF through fertigation might be attributed to lower fruit yield in both seasons (28381 and 28603 kg ha^{-1}, respectively). The lower cost of cultivation with control (Rs. 594581 ha^{-1}) was due to growing of capsicum in open field condition, which eliminated the cost of

Table 7. Economics of capsicum as influenced by irrigation regimes and fertigation levels

Treatments	Cost of cultivation (Rs. ha^{-1})			Gross returns (Rs. ha^{-1})			Net returns (Rs. ha^{-1})			B:C ratio		
	Summer	*Kharif*	Pooled	Summer	*Kharif*	Pooled	Summer	*Kharif*	Pooled	Summer	*Kharif*	Pooled
I_1F_1	1258069	1262650	1260359	1503366	1555280	1529323	245297	292631	268964	1.19	1.23	1.21
I_1F_2	1280533	1285114	1282823	2022020	2147424	2084722	741487	862310	801898	1.58	1.67	1.63
I_1F_3	1302997	1307578	1305288	2618946	2789090	2704018	1315949	1481512	1398731	2.01	2.13	2.07
I_1F_4	1320795	1325376	1323085	2486161	2756576	2621368	1165366	1431200	1298283	1.88	2.08	1.98
I_2F_1	1258069	1262650	1260359	1325313	1436712	1381012	67244	174062	120653	1.05	1.14	1.10
I_2F_2	1280533	1285114	1282823	1759873	1953245	1856559	479340	668131	573735	1.37	1.52	1.45
I_2F_3	1302997	1307578	1305288	2267232	2492638	2379935	964235	1185059	1074647	1.74	1.91	1.82
I_2F_4	1320795	1325376	1323085	2094763	2470179	2282471	773969	1144803	959386	1.59	1.86	1.73
I_3F_1	1258069	1262650	1260359	1277138	1287138	1282138	19070	24489	21779	1.02	1.02	1.02
I_3F_2	1280533	1285114	1282823	1686545	1738081	1712313	406012	452967	429489	1.32	1.35	1.33
I_3F_3	1302997	1307578	1305288	2007004	2123601	2065302	704006	816023	760015	1.54	1.62	1.58
I_3F_4	1320795	1325376	1323085	1898286	1830819	1864552	577491	505443	541467	1.44	1.38	1.41
Control	596957	592204	594581	839286	861429	850357	242329	269224	255777	1.41	1.45	1.43

See Table 3 for treatment details

greenhouse construction, automated sensor based irrigation set up and drip layout. Higher cost of cultivation was recorded with scheduling irrigation at 25, 50 and 75 % ASM with 150 % RDF through fertigation was mainly due to higher cost incurring on fertilizers. The results are in line with earlier workers Choudhary and Bhambri (2014), Rekha et al (2017) and Sanjeev Kumar et al (2018). The benefit cost ratio was calculated and Scheduling irrigation at 75 % ASM with the application of 125 % RDF through fertigation recorded higher values in both seasons (2.01 and 2.13, respectively). Similar findings have been documented by other researchers, including 0.86 for cotton (Manzoni and Islam 2009), 1.74 for strawberries (Banaeian et al 2011) and 2.09 for canola (Unakitan et al 2010).

CONCLUSIONS

Among the different energy inputs plastic, chemical and fertilizers had higher energy utilization with notable reduction in *kharif* season. Direct and Non-renewable resources were the main source of energy in cultivation of capsicum. Renewable energy sources ranged from 23.7 to 29.6 per cent in green house cultivation and 32.2 to 41.0 in open cultivation. The use of renewable resources of energy like solar energy, roof water harvesting and reuse of inputs should be practiced to improve energy use efficiency. Automated sensor based irrigation at 75 % ASM with 125 % RDF through fertigation maintained higher productivity, higher energy output and higher profitability. Total energy input in greenhouse cultivation of capsicum was higher than the open field, which was mainly due increased use of fertilizers, plant protection chemicals and mulch paper. Whereas, output energy and energy productivity were higher with greenhouse cultivation. Even greenhouse cultivation found financially productive and energy efficient than open field.

AUTHORS CONTRIBUTION

Santosh Nagappa Ningoji: Conceptualization, Methodology, Data curation, Investigation, Project administration, Formal analysis, Writing. M. N. Thimmegowda: Conceptualization, Data curation, Project administration, Editing. Mudalagiriyappa: Conceptualization, Data curation, Project administration. B.G. Vasanthi: Project administration, Editing. Tulja Sanam: Data curation, Writing, Editing. H.S. Shivaramu: Project administration.

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