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Energy Indices, Productivity and Profitability of Rainfed Chickpea (*Cicer arietinum* L.) Influenced by Crop Geometry and Nutrient Management Practices

N.M. Kumbhar[1], P.D. Thombare[2], M.D. Gholkar[1], A.G. Wani[1]

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ABSTRACT

Background: A systematic assessment of energy balance and the economic feasibility of an agro-ecosystem can provide insights on the environmental impacts associated with crop production technologies and provide a basis for adopting best management practices.

Methods: A field experiment on "Energy indices, productivity and profitability of rainfed chickpea (*Cicer arietinum* L.) influenced by crop geometry and nutrient management practices" was conducted by Watershed Organisation Trust, India on farmer's field at Dhule, Maharashtra during the winter season of the year 2017 and 2018. The experiment was laid out in a randomized block design with the factorial concept. The treatments comprised three levels of nutrient management and four levels of crop geometry.

Result: The pooled data of two years indicated that application of 100 % RDF through organic manures recorded significantly higher grain yield (1.28 t/ha), energy ratio (10.78) and energy productivity (0.29 kg M^{-1}) and it was at par with the application of 50% RDF through chemical fertilizer + 50% RDF through organic manures. Among the crop geometry treatments, sowing behind the plough method produced significantly higher seed (1.38 t/ha) and straw yield (2.72 t/ha) and it was at par with the sowing of chickpea at 30 × 10 cm. In case of treatment combinations, N1S1 *i.e.* application of 50% RDF through organic manures + 50 RDF through chemical fertilizers along with sowing behind the plough method recorded maximum seed yield (1.42 t/ha) and net profit (45300 Rs/ha) as well as performed efficiently based on different energy indices.

Key words: Crop productivity, Economics, Energy use efficiency, STCR, Vermicompost.

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is one of the important major pulse crop cultivated and consumed in India. Chickpea is also known as Bengal gram, gram, chana *etc*. In India, chickpea accounts for about 45% of total pulses produced in the country. India is the major chickpea-producing country, contributing 75% of total production in the world (Shukla *et al.,* 2017). Chickpea has ability to fix atmospheric nitrogen in the soil (Mohsenzadeh Saeed, 2024). It leaves a substantial amount of residual nitrogen for subsequent crops and adds plenty of organic matter into the soil to maintain and improve soil health.

In India, chickpea is cultivated on 9.99 million hectares, producing 11.91 million tonnes with a productivity of 1,192 kg/ha (Meena *et al.,* 2024). However, in Maharashtra, chickpea is grown on 2.7 million hectares, yielding 3.1 million tonnes with productivity of 1,145 kg/ha (Sonawane *et al.,* 2023). Chickpea productivity is influenced by several agronomic factors, among which crop geometry is crucial for maximizing photosynthesis and optimizing resource use efficiency. Crop geometry plays an important role in maintaining optimum plant population and facilitates efficient use of agricultural resources. The optimum plant population enables plants to utilize land and other resources more efficiently to enhance better growth and development of the crop (Mathew *et al.,* 2018). In the Dhule district of Maharashtra, the common practice of broadcasting chickpea seeds results in lower yields, frequent crop failures and reduced input and energy use efficiency. The lack of proper crop geometry in the broadcasting method results in poor plant distribution, difficulties in intercultural operations, inefficient use of soil moisture and nutrients and higher competition among plants. Hence, the study aims to investigate the optimum crop geometry for rainfed chickpea cultivation in the selected geography. The optimizing chickpea crop geometry will increase crop productivity and resource use efficiency. Along with the crop geometry, nutrient management is one of the important aspects for getting sustainable production of chickpea under rainfed conditions.

[1]WOTR-Centre for Resilience Studies (W-CReS), Watershed Organisation Trust (WOTR), Pune-411 009, Maharashtra, India.
[2]Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH, New Delhi-110 029, India.

Corresponding Author: N.M. Kumbhar, WOTR-Centre for Resilience Studies (W-CReS), Watershed Organisation Trust (WOTR), Pune-411 009, Maharashtra, India.
Email: nitin.kumbhar@wotr.org.in

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The over-reliance on chemical fertilizers such as urea, DAP and MOP *etc*. has led to significant soil degradation (Gholkar *et al.,* 2022), nutrient imbalances and inefficient use of fertilizers in chickpea crop under rainfed conditions. The overuse of fertilizers, combined with inefficient resource management, deteriorate soil health and pose environmental risks (Yadav *et al.,* 2025). However, the integrated balanced use of organic manures, chemical fertilizers and biofertilizers will enhance chickpea yield and improve resource use efficiency. By developing a balanced, integrated nutrient management approach, the study aims to address soil degradation low productivity and nutrient imbalances under rainfed conditions. The nutrient requirement of the crop supply through various sources of organic manures like Compost, Vermicompost along with minimal use of mineral fertilizers plays a key role in sustaining crop productivity and soil health (Gudadhe *et al.,* 2015).

With the advent of the Green Revolution, Indian agriculture has become energy-intensive since early 1960s. Increasing food demand has resulted in increased use of agricultural inputs and thereby consumption of energy and natural resources are increased. Energy in agriculture is important in terms of crop production, economy and agro-processing for value addition. The relation between agriculture and energy is very important as it plays a vital role in productivity as well as profitability. Efficient use of these energies helps to achieve increasing demand for production and productivity enhancement and contributes to the economy, profitability and competitiveness of agriculture sustainability to rural living (Singh *et al.,* 2010).

Thus, to address the issues of broadcasting of chickpea seeds and indiscriminate application of chemical fertilizers and high energy-intensive agriculture production system. The study has been undertaken to determine optimum crop geometry and balanced nutrient management practice for getting sustainable production with efficient use of resource energy to sustain natural resources and the economy of the farmers.

MATERIALS AND METHODS

Site description

A field experiment on "Energy indices, productivity and profitability of rainfed chickpea influenced by crop geometry and nutrient management practices" was conducted by Watershed Organisation Trust (WOTR), Pune, India during the rabi season of 2016-17 and 2017-18 on farmer's field at Manjari village (latitude 20.867120° longitude 73.948316°, with an altitude of 659 from the above mean sea level) of Sakri Block of Dhule district of Maharashtra, India. The soil status of the experimental plot was clay loam, having pH of 6.87 with low in soil organic carbon (SOC) (0.39%) and available nitrogen (175 kg/ha), medium in available phosphorus (12.5 kg/ha) and high in available potassium (305 kg/ha). The soil properties were analysed using standard procedures. SOC was analysed using the wet oxidation method (Walkley and Black, 1934). This method involves treating the soil with potassium dichromate and sulfuric acid and measuring the amount of dichromate reduced to determine C content. Available nitrogen was determined using the alkaline potassium permanganate method (Subbaiah and Asija, 1956), which involves treating soil samples with potassium permanganate in an alkaline medium and measuring the nitrogen released. Available P was measured using 0.5 M sodium bicarbonate at pH 8.5, in which phosphorus is extracted from the soil and quantified by colourimetric analysis (Watanabe and Olsen, 1965). Available K was analyzed using extractant neutral normal ammonium acetate at pH 7.0 and measuring its concentration on a flame photometer (Page *et al.,* 1982).

Treatment details and field management

The field experiment consists of twelve treatment combinations having three levels of nutrient management *viz*, N1: 50% RDF through chemical fertilizer + 50% RDF through organic manures, N2:100% RDF through organic manures (50% RDF through Compost +50% RDF through Vermicompost) and N3: 100% RDF through chemical fertilizer. Whereas, four methods of crop geometry for the sowing of chickpea are S1: Sowing behind plough, S2: 30 × 10 cm, S3: 45 × 15 cm and S4: 60 ×20 cm. The experiment was laid out in a randomized block design with the factorial concept and replicated for three times. The recommended dose of fertilizer was calculated based on the soil test crop response (STCR) equation.

$$FN = 5.35\ T - 0.46,\ FP_2O_5 = 3.87\ T - 2.77 \text{ and } FK_2O = 1.39\ T - 0.04$$

Where,
FN= Field nitrogen.
FP= Field P_2O_5.
FK= Field K_2O.
T= Target yield and which is considered as 20 q/ha.

The recommended dose of fertilizer based on the STCR equation is 27 kg N, 43 kg P and 16 kg K/ha. Applications of the required quantity of organic manures were calculated as per the treatments based on the equivalent nitrogen requirement of the STCR-RDF and applied to the respective plots at the time of sowing. The source of organic manures *i.e*. Compost and vermicompost were tested for their available nitrogen, phosphorus and

Table 1: Nutrient content in vermicompost and compost.

Organic manures	Available N (%)	Available P (%)	Available K (%)
Vermicompost	1.5	0.5	0.5
Compost	0.5	0.2	0.5

potassium (Table 1). In this region, Paddy followed by chickpea is the dominant crop sequence. The farmers are using broadcasting and sowing of chickpea seeds behind the 'baliram' plough (Desi/indigenous plough) are the common method for sowing. The objective of this practice is to utilize the residual soil moisture for better germination and development of the crop in a rainfed region.

Energy analysis

The inputs and outputs in the agricultural production system were converted into energy units to perform the input output energy analysis. The conversion factors are the energy equivalents for each input or output in the crop production system. Energy can be classified in direct and indirect forms as well as renewable and non-renewable forms. Indirect energy includes the energy of seeds, chemical fertilizers, organic manures, agro- chemicals and static energy of machinery tools and farm implements whereas direct energy includes human labour and diesel energy (for sowing, threshing) that was used for chickpea production.

The total input and output energy for the different parameters has been calculated from the energy equivalent coefficient Table 2.

The input-output energy analysis for all three practices of nutrient management *i.e.* Integrated nutrient management (50% RDF through chemical fertilizers + 50% through organic manures), 100% RDF through organic manures and 100% RDF through chemical fertilizers and four methods of crop geometry (with varied seed rate) was calculated. The working hours of labours were determined in each activity *i.e* land preparation, sowing, weeding, hoeing, harrowing, irrigation, harvesting and threshing. These hours were used to calculate total human energy.

The treatments wise bioenergy of grain yield and crop residues of chickpea have been considered for the calculating output energy analysis. Grain yield and stover yield for each treatment were measured and recorded and then converted to energy value by multiplying with energy equivalent factor.

The energy indices *i.e.* energy ratio, energy productivity, energy intensiveness, specific energy and net energy gain were calculated by using the following formula (Mandal *et al.,* 2002) and (Unakitan *et al.,* 2010).

$$\text{Energy ratio} = \frac{\text{Energy output}}{\text{Eneegy input}}$$

$$\text{Energy productivity}\left(\frac{kg}{Mj}\right) = \frac{\text{Yield produced (Chickpea output)}\left(\frac{kg}{ha}\right)}{\text{Energy input}\left(\frac{Mj}{ha}\right)}$$

$$\text{Specific energy}\left(\frac{MJ}{kg}\right) = \frac{\text{Total energy input}\left(\frac{MJ}{ha}\right)}{\text{Yield}\left(\frac{MJ}{ha}\right)}$$

$$\text{Energy intensiveness}\left(\frac{MJ}{Rs}\right) = \frac{\text{Energy input}\left(\frac{MJ}{ha}\right)}{\text{Total cost of production}\left(\frac{Rs}{ha}\right)}$$

$$\text{Net energy gain}\left(\frac{MJ}{ha}\right) = \text{Total output energy}\left(\frac{MJ}{ha}\right) - \text{Total input energy}\left(\frac{MJ}{ha}\right)$$

Statistical analysis

The collected data were subjected to analysis of variance as described by Fisher (1935) using factorial design to evaluate the treatment and interaction effect of crop geometry and integrated nutrient management. The least significant differences (LSD) was used to compare the treatment means at the 5% level of significance.

RESULTS AND DISCUSSION

Effect of nutrient management

Effect of nutrient management on growth and yield attributing characteristics

The morphological characters like plant height, number of branches and number of pods per plant were recorded at the time of harvest except for root length. The nutrient management treatments significantly influenced the root length of chickpea at 60 days after sowing (Table 3). The application of 50% RDF through chemical fertilizers + 50% RDF through organic manures recorded significantly higher root length (17.8 cm) and which was at par with 100 % RDF applied through chemical fertilizers (17.5 cm).

Effect of nutrient management on seed and straw yields

The pooled data of two years were found a significant effect on the seed yield of chickpea. The significantly higher seed yield of 1.28 t/ha was recorded with the application of 100% RDF through organic manures and which was at par with 50% RDF applied through chemical fertilizer + 50% RDF through organic manures (1.27 t/ha). The increase in seed yield of chickpea might be due to the increased availability of soil moisture and ideal condition for soil microflora to enhance the availability of major and micro-nutrients to the crop. The individual yield attributing traits was not showing significant differences but their combined or compensatory effects, along with external factors resulted in a significant difference in the overall yield. Similar findings were also observed by (Nesar and Jammu, 2017). Sodavadiya *et al.* (2020) reported that the combined application of organic and inorganic sources of nutrients resulted in a better supply and absorption of nutrients, leading to a higher yield of chickpea. The application of 100% RDF through organic manures recorded a significantly higher harvest index

(35.9%) followed by 50% RDF applied through chemical fertilizer + 50% RDF applied through organic manures (35.4%). The Nutrient management treatments were found a non-significant effect on the number of branches per plant, number of pods per plant and straw yield of chickpea.

Effect of crop geometry

Effect of crop geometry on growth and yield attributing characteristics

The significantly higher root length of 9.1 cm at 30 days after sowing was recorded under the sowing behind the plough method of cultivation and it was at par with the cultivation of chickpea at 45 × 15 cm (8.6). The increase in root length of chickpea might be due to deeper sowing and more competition between the plant roots for water and nutrients. The pooled data of two years were found a significant effect on yield attributing characters like the number of branches and number of pods per plant. The sowing of chickpea at 45 × 15 cm recorded a significantly higher number of pods per plant (43.89) followed by sowing behind the plough method (43.78) and wider spacing of 60 × 20 cm (42.17). The higher number of pods per plant might be due to the proper adjustment of the plant in the field facilitate more aeration, space, greater light interception and more photosynthetic activity. The results agree with the findings of Choudhary *et al.* (2023) and Loria *et al.* (2022).

Interaction effect

The interaction effect of nutrient management practice and crop geometry was found significant in the case of number of pods per plant. The cultivation of chickpea at a wider spacing of 60 × 20 cm recorded significantly the highest number of branches per plant (7.1 plant^{-1}) as compared to the rest of the treatments.

Effect of crop geometry on seed and straw yields

The seed and straw yields of chickpea were significantly influenced due to various crop geometry treatments (Table 4). Sowing of chickpea behind the plough method (S1) produced significantly higher seed (1.38 t/ha) and straw yield (2.72 t/ha) as compared to other treatments and it was at par with sowing at 30 × 10 cm spacing (S2). Similar results were reported by (Mathew *et al.,* 2018). The increase in seed and straw yields might be due to the sowing was done at appropriate depth so the better utilization of residual soil moisture, higher germination percentage and maximum plant population resulted in higher seed and straw yield of chickpea. In sowing behind the plough method, the approximate distance between the rows was about 30-35 cm but the sowing depth was ideal and better

Table 2: Energy equivalent coefficient of inputs and outputs.

Source	Unit	Energy equivalent (MJ/ unit)
Input energy parameters		
Labours (human energy) for land preparation, harraowing, sowing, hoeing, irrigation, harvesting, threshing *etc*.	h	1.96
Bullock pair (animal energy)	h	10.1
Seed	Kg/ha	14.7
Diesel	l	56.31
Farm machinery and tools		
Tractor (h)	h	16.416
Plough (h)	h	0.627
Sickle(h)	h	0.836
Thresher (h)	h	7.524
Irrigation		
Water used (m3)	m3	0.63
Fertilizers		
- Nitrogen (N)	kg	60.6
- Phosphorus (P_2O_5)	kg	11.1
- Potassium (K_2O)	kg	6.7
Organic mannures		
Vermi-compost	kg	0.5
FYM	kg	0.3
Output energy parameters		
Grain energy	kg	14.7
Biomass (stems and leaves)	kg	12.5

Source: (Mandal *et al.,* 2002; Ram and Verma, 2017; Pokhrel and Soni, 2017 and Soni *et al.,* 2013).

Table 3: Effect of nutrient management practices and plant spacing on growth and yield of chickpea (Pooled data of 2 years).

Treatments		Plant height (cm)	Root length at 30 DAS (cm)	Root length at 60 DAS (cm)	No. of branches /Plant	No. of pods/ Plant	Seed yield (t/ha)	Straw yield (t/ha)	Test weight (g)	Harvest Index (%)
Nutrient management (N)										
N1	50% RDF through CF* + 50% RDF through organic manure	56.3	8.56	17.8	6.2	41.5	1.27	2.37	21.5	35.42
N2	100% RDF through Organic manures	56.4	8.33	15.7	6.0	42.0	1.28	2.31	22.7	35.97
N3	100% RDF through Chemical fertilizers	56.2	8.44	17.5	5.9	42.0	1.16	2.54	21.5	31.66
	CD (P =0.05)	NS	NS	1.1	NS	NS	0.10	NS	NS	2.8
Spacing (S)										
S1	Sowing behind plough (FP*)	58.8	9.1	17.8	5.29	43.78	1.38	2.72	22.7	33.9
S2	Recommended spacing: 30 × 10	54.6	8.0	17.1	5.38	37.39	1.32	2.62	21.7	34.0
S3	Spacing-1 : 45 × 15	55.1	8.6	16.6	6.31	43.89	1.17	2.15	21.9	35.4
S4	Spacing-2 : 60 × 20	56.6	8.1	16.4	7.10	42.17	1.08	2.14	21.2	34.2
	CD (P =0.05)	NS	0.72	NS	0.7	4.1	0.11	0.25	NS	NS
Interaction (N × S)										
N × S		NS	NS	NS	NS	6.52	NS	0.25	NS	NS
CV %		10.45	12.65	11.36	16.0	14.57	13.28	15.48	12.35	13.97

CF: Chemical fertilizer and *FP: Farmers practices.

utilization of the residual soil moisture. In the rainfed regions, the depth sowing is very important for the better utilization of residual soil moisture during the initial growth stages of the crop.

Economics

The total cost, net profit and B:C ratio of nutrient management and crop geometry treatment are depicted in Fig 1.

Effect of nutrient management

The nutrient management practice positively impacts the economics of chickpea cultivation. The maximum net profit of 37574 Rs/ha recorded with the application of 50% RDF through chemical fertilizers + 50% RDF through organic manures (N1) with benefit cost ratio of 2.05 followed by application of 100% RDF through chemical fertilizers (N3).

Effect of crop geometry

Among the crop geometry treatments, sowing behind the plough method (S1) recorded a maximum net profit of 42755 Rs/ha followed by sowing of chickpea at 30 × 10 cm (40353 Rs/ha). The higher benefit cost ratio of 2.16 and 2.11 was recorded under sowing behind the plough method and sowing of chickpea at 30 × 10 cm, respectively. Similar results were also reported by (Mathew *et al.,* 2018) in rainfed chickpea. The decrease in net income and benefit cost ratio with an increase in crop spacing due to the decreasing crop productivity with wider spacing.

Interaction effect

The effect of the treatment combinations on gross returns, net profit and benefit cost ratio is presented in Table 4. The

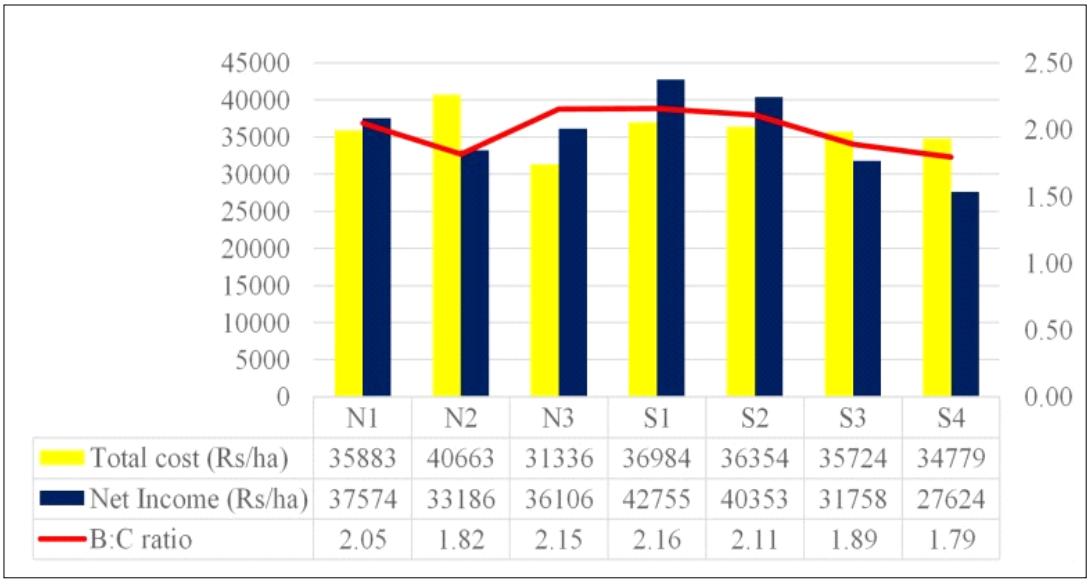


Fig 1: Effect of nutrient management practices and spacing on the total cost of production, net profit and B:C ratio.

Table 4: Effect of different treatment combinations on gross returns, net profit and benefit cost ratio of chickpea.

Treatment	Grain yield (t/ha)	Grain returns (Rs/ha)	Stover yield (t/ha)	Stover returns (Rs/ha)	Gross returns (Rs/ha)	Cost of Cultivation (Rs/ha)	Net profit (Rs/ha)	B:C ratio
N1S1	1.42	78141	2.71	4066	82207	36907	45300	2.23
N1S2	1.39	76572	2.63	3942	80514	36277	44237	2.22
N1S3	1.10	60709	2.01	3015	63724	35647	28077	1.79
N1S4	1.17	64202	2.12	3182	67384	34702	32682	1.94
N2S1	1.41	77749	2.58	3869	81618	41686	39932	1.96
N2S2	1.32	72473	2.67	4005	76478	41056	35422	1.86
N2S3	1.31	71974	2.18	3277	75250	40426	34824	1.86
N2S4	1.08	59354	1.80	2696	62050	39481	22569	1.57
N3S1	1.29	71082	2.87	4310	75393	32360	43033	2.33
N3S2	1.26	69300	2.55	3830	73130	31730	41400	2.30
N3S3	1.09	60093	2.25	3380	63473	31099	32373	2.04
N3S4	0.98	54043	2.49	3732	57774	30154	27620	1.92

Table 5: Effect of nutrient management practices and spacing on energy indices of chickpea.

Treatments		Energy ratio	Energy productivity (kg/M)	Specific energy (MJ/kg)	Energy Inten-siveness (MJ/Rs)	Net energy gain (MJ)
A. Nutrient management (N)						
N1	50% RDF through CF + 50% RDF through organic manure	9.36	0.24	4.27	0.132	42.776.1
N2	100% RDF through Organic manures	10.78	0.29	3.58	0.105	43.255.2
N3	100% RDF through Chemical fertilizers	8.63	0.20	5.08	0.165	43.136.5
	CD (P =0.05)	0.60	0.00	0.400	-	NS
B. Spacing (S)						
S1	Sowing behind plough (FP*)	10.26	0.26	3.96	0.137	48.909.0
S2	Recommended spacing : 30 × 10	10.29	0.26	4.01	0.135	47.037.3
S3	Spacing-1 : 45 × 15	8.96	0.24	4.56	0.134	39.058.4
S4	Spacing-2 : 60 × 20	8.85	0.22	4.70	0.131	37.219.0
	CD(P =0.05)	0.72	0.00	0.70	-	36.48.67
C. Interaction (N × S)						
CD (P =0.05)		NS	NS	NS	NS	NS
CV %		11.30	13.44	15.66	0.00	12.61

maximum gross returns of 82207 Rs/ha was obtained in treatment N1S1 (50% RDF through chemical fertilizer + 50% RDF through organic manures along with sowing behind the plough method) as compared to the rest of the treatment combinations. The maximum net profit of 45300 and 44237 Rs/ha was recorded under treatment N1S1 and N1S2 with benefit cost ratio of 2.23 and 2.22, respectively. The increase in net profit due to higher additional crop productivity and the less cost of cultivation of the crop. The maximum benefit cost ratio of 2.33 was recorded under treatment N3S1 followed by treatment N3S2 (2.30), N1S1 (2.23) and N1S2 (2.22). However, the lowest net profit of 22569 Rs/ha with the benefit cost ratio of 1.57 was recorded under the treatment N2S4 (100% RDF applied through organic manure + sowing at the wider spacing of 60 × 20 cm.

Energy analysis of chickpea

Effect of nutrient management on energy use efficiency

The energy indices *viz.* Energy ratio, energy productivity, specific energy, energy intensiveness and net energy gain were significantly influenced due to nutrient management and crop geometry treatments (Table 5). Treatment N2 (100% RDF applied through Organic manures) recorded a significantly higher energy ratio (10.78) and energy productivity (0.29 kg M^{-1}) and it was closely followed by treatment N1 (50% RDF through chemical fertilizers + 50% RDF through organic manures).

The lower specific energy of 3.58 and energy intensiveness of 0.13 was found with the application of treatment N2 and which was at par with the treatment N1. The higher energy productivity, energy ratio and lower specific energy and intensiveness might be due to the maximum biomass production with the application of 100% RDF through organic manures with lower input energy. Similar results of organic practices are more energy-efficient as compared to conventional chemical farming were reported by (Pimentel and Burgess, 2014).

Effect of crop geometry on energy use efficiency

The results indicated that sowing of chickpea at 30 × 10 cm obtained maximum energy ratio (10.29) and energy productivity (0.26) as compared to rest of the treatment and which was closely followed by sowing of chickpea behind the plough method. Whereas, the lowest energy ratio and energy productivity was recorded under treatment 60 × 20 cm. The significantly lower specific energy of 3.96 was registered with sowing behind the plough method and it was found at par with the sowing of chickpea at 30 × 10 cm and 60 × 20 cm. The maximum net energy gain 48909 MJ was recorded with sowing chickpea behind the plough method followed by sowing chickpea at 30 ×10 cm and 45 × 15 cm.

Interaction effect on energy use efficiency

The treatment combination N2S1 (N1:100% RDF through Organic manures + S1: sowing behind plough) shows higher energy productivity with lower specific energy followed by treatment N2S2, N2S3, N1S2 and N1S1. The crop geometry (S) treatment combinations with 100 % RDF through chemical fertilizers (N3) recorded lower energy ratio, energy productivity and higher specific energy as compared to N2 and N1 treatment combinations.

CONCLUSION

From the above findings, it can be concluded that based on the energy indices the treatment combination N2S1 *i.e.*

application of 100% RDF through organic manures along with sowing behind plough method were recorded significantly higher energy indices over the other treatment combinations followed by N2S2, N2S3, N1S2 and N1S1. However, treatment combination N1S1 *i.e.* application of 50% RDF through organic manures + 50 RDF through chemical fertilizers along with sowing behind the plough method produced significantly higher crop productivity and net profit as well as performed efficiently based on different energy indices as compared to the rest of the treatment combinations under rainfed condition. The treatment N1S1 is recommended to the rainfed areas where the cultivation of chickpea is done on residual soil moisture for getting maximum economic returns with efficient use of energy inputs.

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Conflict of interest

The authors have no conflict of interest to declare.

REFERENCES

Choudhary, S., Tyagi, P.K., Shukla, K.C., Khushwa, K., Shridhar, A.K. and Singh, S. (2023). Impact of sowing dates and crop geometry on chickpea yield attributes, production and profitability. *Annals of Agriculture Research New Series*. **44(2):** 169-176.

Fisher, R.A. (1935). The logic of inductive inference. *Journal of the Royal Statistical Society.* **98(1):** 39-82.

Gholkar, M., Thombare, P., Koli, U. and Kumbhar, N. (2022). Techno-economic assessment of agricultural land remediation measures through nutrient management practices to achieve sustainable agricultural production. *Environmental Challenges*. **7:** 100492.

Gudadhe, N., Dhonde, M.B. and Hirwe, N.A. (2015). Effect of integrated nutrient management on soil properties under cotton-chickpea cropping sequence in vertisols of Deccan plateau of India. *Indian Journal of Agricultural Research*. **49(3):** 207-214. doi: 10.5958/0976-058X.2015.00032.3.

Loria, K., Kumari, M., Sood, Y., Vikas, Lalita, Rani, S. and Himangini. (2022). Effect of seed rate and seed spacing on yield attributes of chickpea. *Agricultural Science Digest*. doi: 10.18805/ag.D-5565.

Mandal, K.G., Saha, K.P., Ghosh, P.K., Hati, K.M. and Bandyopadhyay, K.K. (2002). Bioenergy and economic analysis of soybean-based crop production systems in central India. *Biomass and Bioenergy*. **23(5):** 337-345. https://doi.org/10.1016/S0961-9534(02)00058-2.

Mathew, L., Sanbagavalli, S. and Chinnisamy, C. (2018). Yield and economics of rainfed chickpea as influenced by sowing time and sowing methods. *Internation Journal of Chemical Studies.* **6(5):** 1781-1784.

Meena, S., Meena, L., Yadav, S., Jadon, C., Dhakad, U., Lal, M. and Singh, P. (2024). Chickpea (*Cicer arietinum*)-based intercropping systems in Rajasthan's Hadoti region: Productivity and economic viability. *Indian Journal of Agronomy*. **69(1):** 54-60.

Mohsenzadeh, S. (2024). *Cicer arietinum* L. (chickpea): A mini review. *Agricultural Reviews*. **45(3):** 430-438. doi: 10.18805/ag.RF-269.

Nesar, N.A. and Jammu, T. (2017). Performance of chickpea under organic and inorganic sources of nutrients at different soil moisture regimes in chickpea-okra cropping system. *Himachal Journal of Agricultural Research.* **43(1):** 23-28.

Pimentel, D. and Burgess, M. (2014). An environmental, energetic and economic comparison of organic and conventional farming systems. *Integrated Pest Management: Pesticide Problems*. **55(7):** 141-166. https://doi.org/10.1007/978-94-007-7796-5_6.

Page, A.L., Miller, R.H. and Keeney, D.R. (1982). Methods of Soil Analysis Part 2. Chemical and Microbiological Properties; American Society of Agronomy, Inc.: Madison, WI, USA.

Pokhrel, A. and Soni, P. (2017). Performance analysis of different rice-based cropping systems in tropical region of Nepal. *Journal of Environmental Management.* **197:** 70-79. https://doi.org/10.1016/j.jenvman.2017.03.035.

Ram, R.A. and Verma, A.K. (2017). Energy input, output and economic analysis in organic production of guava (*Psidium guajava*) cv. Allahabad Safeda. *Indian Journal of Agricultural Sciences.* **87(4):** 462-466.

Shukla, R.D., Singh, A. and Verma, S. (2017). Effect of crop geometry and phosphorus levels on growth and productivity of chickpea (*Cicer arietinum* L.). *Journal of Pharmacognosy and Phytochemistry*. **6(5):** 659-661.

Singh, H., Kushwaha, H.L., Singh, A.K. and Singh, A. (2010). Energy use pattern in production agriculture of arid Western Rajasthan. *Annals of Arid Zone.* **49(1):** 53-63.

Sonawane, K., More, S. and Chavan, R. (2023). Performance of chickpea in Maharashtra: An analysis of growth and instability. *Journal of Food Legumes.* **36(1):** 84-88. https://doi.org/10.59797/jfl.v36.i1.135.

Sodavadiya H.B., Patel V.J. and Sadhu A.C. (2023). Effect of integrated nutrient management on the growth and yield of chickpea (*Cicer arietinum* L.) under chickpea - forage corghum (*Sorghum bicolor* L.) Cropping Sequence. *Legume Research.* **46(12):** 1617-1622. doi: 10.18805/LR-4465.

Soni, P., Taewichit, C. and Salokhe, V.M. (2013). Energy consumption and CO_2 emissions in rainfed agricultural production systems of Northeast Thailand. *Agricultural Systems*. **116:** 25-36. https://doi.org/10.1016/j.agsy.2012.12.006.

Subbaiah, B.V. and Asija, G.L. (1956). A rapid procedure for estimation of available nitrogen in soil. *Current Science*. **25:** 259-260.

Unakitan, G., Hurma, H. and Yilmaz, F. (2010). An analysis of energy use efficiency of canola production in Turkey. *Energy.* **35(9):** 3623 3627. https://doi.org/10.1016/j.energy. 2010. 05.005.

Walkley, A. and Black, I.A. (1934). An examination of the degtareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*. **37:** 29-38.

Watanabe, F.S. and Olsen, S.R. (1965). Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. *Soil Science Society of America Journal.* **29:** 677-678.

Yadav, S.L., Debnath, S., Singh, Y., Singh, S.K., Devi, Y.B., Ghosh, A., Ram, A., Kumar, S. and Arunachalam, A. (2025). Influence of varied nutrient management strategies on yield, nutrient absorption and grain protein content in chickpea (*Cicer arietinum* L.). *Indian Journal of Agricultural Research.* **59(7):** 1119-1125. doi: 10.18805/IJARe.A-6255.