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Energetics and Economics of *Rabi* Maize as Influenced by Smart Nutrient Management Under South Odisha Conditions

Check for updates

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Abstract: Cereal crop cultivation is one of the essential agricultural practices adopted worldwide to feed human beings, providing dietary energy and food security. Maize is important in different cereal crops' areas, production, and productivity. In high-input-demanding crops like maize, it is mandatory to evaluate the energy input and output along with the economics of the study for better optimization of resources and efficient management of inputs in maize cultivation. The present study was conducted at the Postgraduate Research Farm of Centurion University of Technology and Management, Odisha, India, for two consecutive years during the Rabi season (November-March) of 2021-22 and 2022-23. The experiment was carried out in brown forest soil, sandy loam in texture and a Randomized Complete Block Design with 13 treatments, and each treatment was replicated thrice. The treatments comprise various graded fertilizer levels, precision nitrogen management treatments, decision support systems-based nutrient management and nano nitrogen treatment. The results revealed that among the nutrient management treatments, the highest input energy (21546.8 MJ ha^{-1}) was recorded in the treatment T_4: 150% RDF. In terms of output energy and net energy, the highest values were recorded in the treatments T_{10}: CCM-based sufficiency index at 90%-95% and T_4: 150% RDF. The energy use efficiency and energy productivity were recorded as the highest values in the treatments T_9: CCM-based sufficiency index at 85%-90%. Further, among the nutrient management treatments, the maximum cost of cultivation was incurred in the treatment T_4: 150% RDF and it was closely followed by T_9: CCM-based sufficiency index at 85%-90% and T_{10}: CCM-based sufficiency index at 90%-95%. The highest gross and net returns were recorded in the treatment T_{10}: CCM-based SI at 90%-95%. In the case of the benefit-cost ratio, the highest value (1.29 and 1.24 for two consecutive years of the study, respectively) was recorded in the treatment T_{10}: CCM-based sufficiency index at 90%-95%. The findings of this study demonstrate the potential of precision nutrient management through the CCM Sufficiency index in *Rabi* maize cultivation under South Odisha for more sustainability and productivity with the highest profitability.

Introduction

Maize (*Zea mays*), also known as the "golden crop of tropics", is one of the staple foods for the world population. Maize is consumed not only for food but also for feed and fuel (Erenstein et al., 2022; Yohannes et al., 2024). The genetic diversity and adaptability of maize to diverse climatic conditions make it suitable for ensuring food security for the growing global population

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(Prasanna, 2012; Pahadi et al., 2017; Raut et al., 2017). With a total production of 987 million metric tons, maize is grown over 182 million hectares worldwide. In the case of India, 9.86 million hectares of maize were produced, yielding 31.65 million metric tons of grain (ICAR – IIMR, 2022). India's national average yield of 3.2 metric tons per hectare of maize is much lower than the world average of 5.42 metric tons per hectare (Tandzi and Mutengwa, 2020). Although maize is not a typical crop in Odisha, its area under cultivation has grown recently with an average yield of 2.97 t ha^{-1} and the state provides approximately 7.51 Mt of maize annually from an area of 2.69 lakh acres (GoO, 2020).

Maize, the "queen of cereals", is a C4 plant which produces a large amount of biomass in a short duration which in return removes a large quantity of nutrients, considered an exhaustive crop (Sairam et al., 2024; Wang et al., 2012). Additionally, conventional farming practices, practised over the years, often rely on blanket fertilizer applications, disregarding the nuanced needs of the crop and the soil fertility status (Midya et al., 2021). This approach can lead to a maelstrom of environmental and economic consequences, including soil degradation, water pollution, and diminished returns on investment (Moulik et al., 2024; Maitra et al., 2023). Under such a scenario, precision nutrient management emerges as a beacon of hope, promising to revolutionize how farmers interact with their soil, crops, and environment (Pramanick et al., 2022). Precision nutrient management enables farmers to tailor their nutrient inputs to the exact needs of their crops, minimizing waste, reducing environmental impact, and maximizing economic returns (Ray et al., 2024; Miao, 2023). Modern agriculture includes innovative nutrient management tools such as CCM (Chlorophyll content meter) (Kamarianakis and Panagiotakis, 2023), LCC (Leaf colour chart) (Fayaz et al., 2022) and so on for real-time plant data by analyzing the non-destructive samples leading in the accurate quantity of nutrient application to crop needs. Precision nutrient management can revolutionize maize production by optimizing fertilizer application, reducing waste, and enhancing crop productivity (Sairam et al., 2023a; Sarmah et al., 2024). It can lead to substantial cost savings for farmers by improving maize yields and quality, resulting in higher market prices and improved revenue streams. If considered from an economic perspective, precision nutrient management has the potential to significantly impact the profitability of maize cultivation by minimizing fertilizer overuse as well as reducing energy consumption (Sagar et al., 2023; Sairam et al., 2023b; Ren et al., 2021). Moreover, inclusion of nano materials as plant nutrients and agricultural inputs has open a new arena to the farming sector (Hossain et al., 2021; Durguge et al., 2022).

Global population growth will result in a massive increase in food consumption, necessitating a boost in grain output from 2.1 billion to 3 billion tons annually to ensure food security (Maitra et al., 2023; Molotoks et al., 2020). An additional 100 million hectares of land are predicted to be required for agricultural production (Zabel et al., 2019). Another major limitation will be a water shortage, especially in places where many water resources are used and production systems are subjected to high environmental and social stress (Santosh et al., 2024; He et al., 2021). Globally, significant progress in resource conservation and resource-use efficiency will be required to fulfil the growing and changing demand for food and halt and reverse environmental deterioration (Maitra et al., 2021). Therefore, increasing the productivity of maize is essential for meeting the world's food demand and achieving production sustainability.

Energy is essential to agricultural production because it allows crops to grow and adds value through agro-processing after harvest. Usually, efficiency and consumption are used to evaluate the energetics of a crop (Hercher-Pasteur et al., 2020). Today's agricultural output largely relies on high direct and indirect fossil energy usage. During the many stages of maize production (land preparation, tillage, weeding, irrigation, harvesting, threshing, input and output, transportation), energy resources in direct or indirect energy are consumed (Majeed et al., 2023). Crops' ability to use various energy resources and efficiently produce biomass is strongly related to how well the cropping system functions (Giller et al., 2021). Energy input-output analyses computation of energetics are frequently used to evaluate the effectiveness of energy consumption, its effects on the environment, and the overall performance of agro-production systems (Ghosh et al., 2020). The energy ratios used in the production of maize varied by location and were dependent on the area, and a major part of inputs in economics and energy is contributed through nutrients (Ghosh et al., 2021; Hafez et al., 2023).

Hence, efficient energy utilization for maize cultivation while giving special attention to precision nutrient management is necessary to ensure food sustainability by 2050 (Kumar et al., 2024). Numerous researchers have studied the energetics of different crops, including maize, but there is a research gap regarding the energetics and economics of maize while considering precision nutrient management (Jiang et al., 2024). This study focuses on the energetics of maize cultivation, emphasising precision nutrient management and its influence on economics.

Materials and Method

A field experiment was conducted at P.G. Research farm of M.S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Odisha, India, during *Rabi* season (Nov-March) of 2021-22 and 2022-23 in sandy loam soil. The experiment was laid in a randomized block design with 13 treatments which were replicated 3 times. The treatments comprised varying recommended nutrient dosages and precision nutrient treatments utilizing the Nutrient Expert (NE)-based nutrient management, the Chlorophyll Content Meter (CCM) (sufficiency index-based nitrogen (N) management), and the Leaf Colour Chart (LCC). The treatment were T_1: Recommended dose of fertilizer (RDF), T_2:125% RDF, T_3: 75% RDF, T_4: 150% RDF, T_5: RDF + nano urea foliar application, T_6: 75% RDF + nano urea foliar application, T_7: LCC 4-based nitrogen management, T_8: LCC 5-based nitrogen management, T_9: CCM sufficiency index (SI)-based nitrogen management at SI 85-90%, T_{10}: CCM SI-based N management at SI 90-95% T_{11}: Nutrient Expert (NE)-based nutrient recommendation for targeted yield of 7 t ha^{-1}, T_{12}: Nutrient Expert based nutrient recommendation for targeted yield of 9 t ha^{-1} and T_{13}: Control. To estimate the sufficiency index of maize, a reference plot with an ample dosage of nitrogen (200% recommended dose of nitrogen) was put out separately from the experimental treatments. For maize, the required amount of nutrients was 120:60:60 kg ha^{-1} of N, P_2O_5 and K_2O. The recommended dose of fertilizer was applied for potassium and phosphorus, with the exception of NE-based treatments.

The experimental location had a sub-humid climate and was located in a semi-arid tropical environment. Meteorological parameters such as temperature, precipitation, and relative humidity are monitored and recorded by the Meteorological Observatory, CUTM, Odisha. Both years' mean maximum temperatures were from 27 ^{0}C to 37°C and 28 ^{0}C to 36^{0}C, respectively. Over the growing period, the mean lowest temperature varied between 12°C to 23^{0}C and 14^{0}C to 21^{0}C, respectively. During the two years of the experimental period, the mean maximum and minimum relative humidity varied from 88% to 96% and 39% to 80% for 2021-22 and 79% to 91% and 37% to 68% for 2022-23, respectively. The experimental location was in a hot and humid zone, so the maximum humidity stayed above 80% during the cropping season.

Energy equivalence of different inputs and output components, variable cost and fixed cost of cultivation used in maize cultivation during the two years of study were mentioned in Tables 1,3 and 4, respectively. Additionally, a graphical representation of the energy input share of different components of the study and the cost of cultivation incurred for different activities of maize cultivation during both years of the study is represented in Figures 1 and 2, respectively. The energy input was calculated by summing the energy equivalents for each input utilized in the system, as shown in Table 2. Grain and stover energy were multiplied by the produce to determine the gross output energy. The energy indices were determined by using the following formulae.

Energy use efficiency (Pourmehdi and Kheiralipour, 2024)

$$\text{Energy use efficiency} = \frac{\text{Total output energy (MJ ha}^{-1}\text{)}}{\text{Total input energy (MJ ha}^{-1}\text{)}}$$

Energy productivity (kg MJ^{-1}) (Kazemi et al., 2023)

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

The cost of cultivation was worked out by taking into consideration all the expenses incurred. The cost of input and price of produce prevalent in the local market were considered for calculating the economics of cultivation in different treatments. The biological yield of maize was converted into gross return in rupees hectare^{-1} based on current price of the produce. Gross return was worked out by multiplying grain and stover yield with their prevailing local market prices and expressed in rupees per hectare.

The net return was calculated by deducting the cost of cultivation from the gross return. The net return was worked out by using the following formula.

Net return (Rs ha^{-1}) = Gross return (Rs ha^{-1}) – Cost of cultivation (Rs ha^{-1})

The benefit cost ratio was calculated based on net return per unit cost of cultivation.

$$\textbf{Benefit cost ratio} = \frac{\text{Net Return}}{\text{Cost of cultivation}}$$

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Table 1. Energy equivalence of different inputs and output components used in maize cultivation during 2021-22 and 2022-23.

Common inputs								
	2021-22				2022-23			
Input	Units ha-1	Quantity ha-1	EE (MJ)	TEE (MJ)	Units ha-1	Quantity ha-1	EE (MJ)	TEE (MJ)
Human labour	Male hours	80	1.96	156.8	Male hours	80	1.96	156.8
	Female hours	150	1.57	235.5	Female hours	150	1.57	235.5
Machinery	Hours	31.35	62.7	1965.6	Hours	31.35	62.7	1965.6
Diesel	Litre	27	56.3	1520.3	Litre	27	56.3	1520.3
Protection chemicals and other inputs								
Insecticides	kg	1	237	237	kg	2	237	474
Herbicides	litre	1.5	288	432	litre	3	288	864
Irrigation	M3	5000	0.6	3000	M3	6000	0.6	3600
Seed	kg	15	14.7	220.5	kg	15	14.7	220.5
Output								
Maize seed	Kg	-	14.7	-	Kg	-	14.7	-
Maize stover	Kg	-	2.25	-	Kg	-	2.25	-

EE, energy equivalent

TEE, total energy equivalent

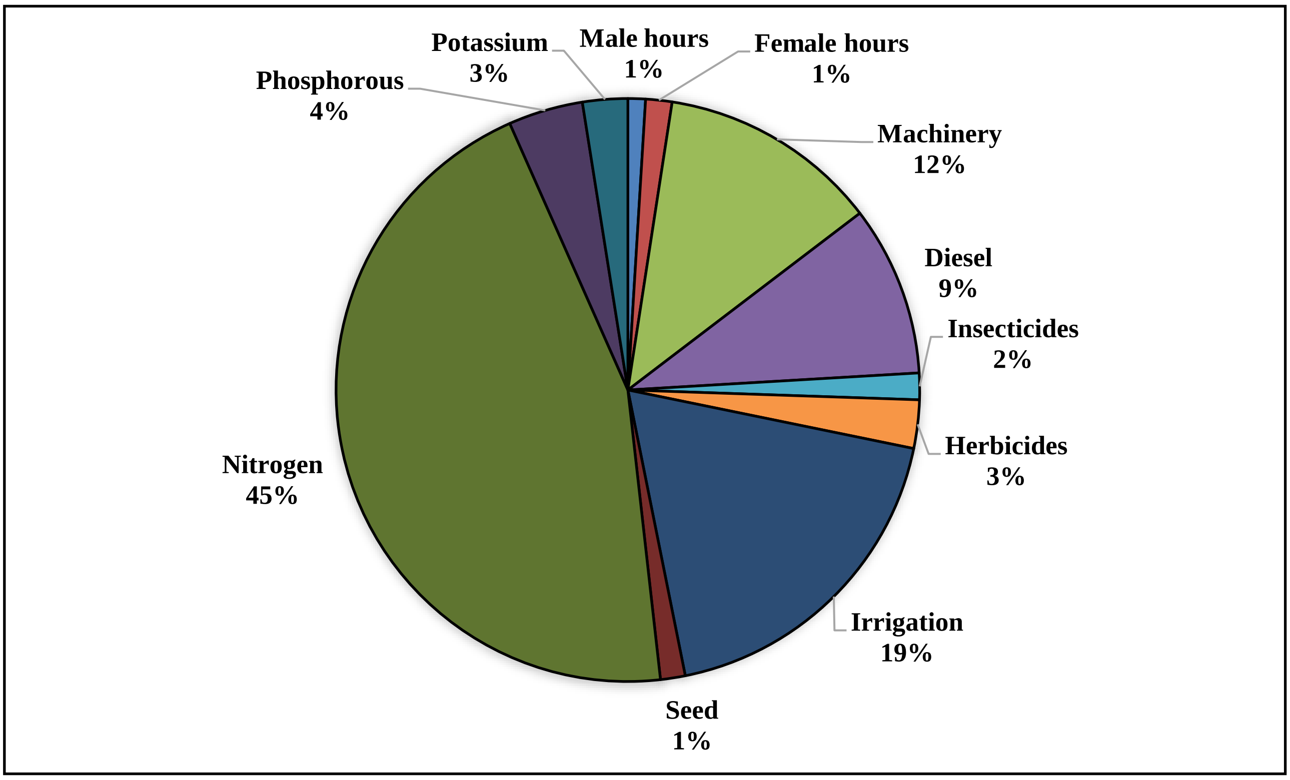

Figure 1. Energy input share of different components of the study (Average of two years).

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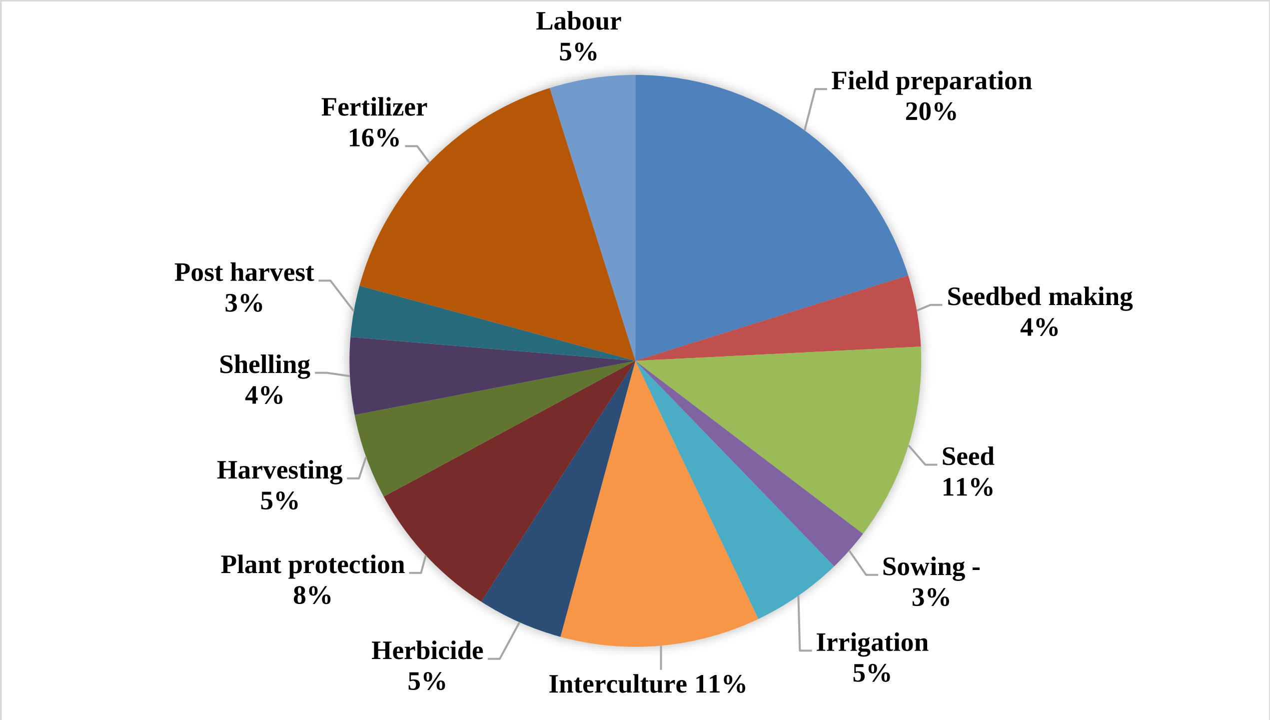

Figure 2. Cost of cultivation incurred for different activities of maize cultivation during the study (Average of two years).

Table 2. Treatment-wise input energy equivalence (MJ ha^{-1}) of *Rabi* maize during 2021-22 and 2022-23.

Treatments	Treatment-wise input energy used for fertilizer top dressing	Nitrogen (total energy equivalents)	Phosphorus (total energy equivalents)	Potassium (total energy equivalents)	Total input energy equivalents (MJ ha^{-1})
T_1	0	7272	666	402	8340
T_2	0	9090	832.5	502.5	10425
T_3	0	5454	499.5	301.5	6255
T_4	0	10908	999	603	12510
T_5	562.72	7272	666	402	8902.72
T_6	562.72	5454	499.5	301.5	6817.72
T_7	0	6969	666	402	8037
T_8	31.36	8484	666	402	9583.36
T_9	31.36	8484	666	402	9583.36
T_{10}	62.72	9999	666	402	11129.72
T_{11}	0	7999.2	543.9	475.7	9018.8
T_{12}	0	8665.8	577.2	522.6	9765.6
T_{13}	0	0	0	0	0

*For treatment details refer to materials and methods section

Table 3. Treatment-wise, the variable cost of maize will be between 2021-22 and 2022-23 in the study.

Variable cost (Rs ha^{-1})								
Treatments	2021-22				2022-23			
	Fertilizer	Labour	Other	Total	Fertilizer	Labour	Other	Total
T_1	9870	3000	0	12870	9870	3000	0	12870
T_2	12338	3000	500	15838	12338	3000	500	15838
T_3	7403	3000	0	10403	7403	3000	0	10403
T_4	14805	3000	5000	22805	14805	3000	5000	22805
T_5	9870	4000	1500	15370	9870	4000	1500	15370
T_6	7403	4000	1500	12903	7403	4000	1500	12903
T_7	9797	3000	0	12797	9797	3000	0	12797
T_8	10164	4000	0	14164	10164	4000	0	14164
T_9	10164	4000	4000	18164	10164	4000	4000	18164
T_{10}	10531	5000	5000	20531	10531	5000	5000	20531
T_{11}	9883	3000	200	13083	9883	3000	200	13083
T_{12}	10990	3000	200	14190	10990	3000	200	14190
T_{13}	0	0	0	0	0	0	0	0

*For treatment details refer to materials and methods section

Table 4. Fixed cost of cultivation of *Rabi* maize during 2021-22 and 2022-23 of the study.

Fixed cost			
S. No.	Operations	Total cost (Rs ha^{-1})	
		2021-22	2022-23
1	Ploughing	12500	13500
2	Seedbed making	2500	3000
3	Seed (kg)	6900	7500
4	Sowing - Labour	1500	1500
5	Irrigation	3200	3200
6	Earthing up and intercultural	7000	7000
7	Herbicide	3000	3000
8	Plant protection	5000	5000
9	Harvesting	3000	3350
10	Shelling	2700	2850
11	Post harvest	1800	2000
	Sub total	**49100**	**51900**

Result and Discussion

Energetics

During the two years of research, the energetics of the study, namely, input energy, output energy, net energy, energy use efficiency and energy productivity, were computed and presented in Table 5 and Table 6. The data revealed that among the nutrient management treatments, the highest input energy (21546.8 MJ ha^{-1}) was recorded in the treatment T_4: 150% RDF and this treatment was closely followed by T_{10}: CCM-based sufficiency index at 90%-95% and T_2:125% RDF during both the years of the study. As no exogenous nutrient input was applied, less input energy was involved in nutrients (9036.8 MJ ha^{-1}) in T_{13} (control). The application of nano urea twice (T_5) accounted for more input energy requirement than T_1: 100% RDF. Further, the application of more splits of nitrogen increased labour energy, resulting in more input energy requirements in the T_{10}: CCM-based sufficiency index, which was at 90%-95%.

In terms of output energy and net energy, the highest values were recorded in the treatments T_{10}: CCM-based sufficiency index at 90%-95% and T_4: 150% RDF. Further, these treatments were closely followed by T_2: 125% RDF, T_9: CCM-based sufficiency index at 85%-90% and T_{12}: NE-based nutrient management for a target yield for 9 t ha^{-1} during the two consecutive years of the study. However, all the precession nutrient management treatments registered higher output and net energy compared to 100% RDF. The lowest values of energy output and net energy were observed in the treatment T_{13} (control) which was followed by T_3: 75% RDF and T_6: 75% RDF + nano urea. The application of nano urea (T_5: RDF+ nano urea and T_6: 75% RDF + nano urea) did not influence much in achieving the greater energy output and net energy during both years of the study.

The energy use efficiency and energy productivity were recorded as the highest values in the treatments T_9: CCM-based sufficiency index at 85%-90% and T_{10}: CCM-based sufficiency index at 90%-95%. The CCM sufficiency index-based precision nutrient management treatment (T_{10}) accounted for the higher energy use efficiency and energy productivity. The application of higher dose of primary nutrients over the RDF, namely, T_4: 150% RDF and T_2: 125% RDF resulted in marginally higher values in terms of energy use efficiency and energy productivity during both the years of the experiment. The precession nutrient management treatments, except CCM-based sufficiency index, did not perform superiorly in obtaining the highest energy use efficiency and energy productivity. During both years of the study, the lowest energy use efficiency and energy productivity were rerecorded in treatment T_3: 75% RDF, which T1 closely followed: 100% RDF, T_5: RDF+ nano urea, T_6: 75% RDF + nano urea and T_{13}: control.

Due to more energy input involved with inorganic fertilizers and human labour, the highest energy input was recorded with treatments consisting of a higher amount of primary nutrient application and a greater number of nitrogen spilt applications (Mondal et al., 2021; Muduli and Sahu, 2019). The energy output was calculated by considering the energy equivalent of maize grain and maize stover. The treatments with more grain and stover yields (T_{10}: CCM SI-based N management at SI 90-95% and T_4: 150% RDF) registered the higher energy output of maize cultivation. The results are in conformity with the findings of Choudhary et al. (2020) and Hulmani et al. (2022). Similarly, the same treatments also recorded superior values in utilizing the energy input showing higher values of energy use efficiency and energy productivity to remanning nutrient management treatments studied. The results also corroborate with the findings of Kushwah et al. (2019).

The maize energetics calculated for both years of the study revealed a similarity to the maize economics. The highest energy input was recorded in treatments that applied more nitrogen split and more primary nutrients because these treatments required more energy input due to the labor-intensive nature of the application of inorganic fertilizers. (Mondal et al., 2021; Muduli and Sahu, 2019). The energy equivalent of maize stover and grain was considered while calculating the energy production. The treatments T_{10}: CCM SI-based N management at SI 90-95% and T_4: 150% RDF yielded more grain and stover, noting a higher energy production from *Rabi* maize cultivation. The findings of Choudhary et al. (2020) and Hulmani et al. (2022) were similar to the present study. Comparably, the same treatments showed superior values in terms of energy input utilization, demonstrating higher levels of energy production and usage efficiency than other nutrition management treatments. The outcomes are in tune with those of Kushwah et al. (2019).

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Table 5. Effect of precision nutrient management on the energetics of *Rabi* maize during 2021-22.

Energetics (2021-22)					
Treatments	**Input energy (MJ ha^{-1})**	**Output energy (MJ ha^{-1})**	**Net energy (MJ ha^{-1})**	**Energy use efficiency**	**Energy productivity (kg MJ^{-1})**
T_1	16107.8	79029.0	62921.2	4.9	0.70
T_2	18192.8	123153.0	104960.2	6.8	0.96
T_3	14022.8	63139.5	49116.7	4.5	0.62
T_4	20277.8	138435.0	118157.2	6.8	0.97
T_5	16670.5	80937.0	64266.5	4.9	0.69
T_6	14585.5	64690.5	50105.0	4.4	0.59
T_7	15804.8	89379.0	73574.2	5.7	0.79
T_8	17351.2	103915.5	86564.3	6.0	0.85
T_9	17351.2	113143.5	95792.9	8.4	1.18
T_{10}	18897.5	141324.0	122426.5	7.5	1.08
T_{11}	16786.6	94302.0	77515.4	5.6	0.80
T_{12}	17533.4	110115.0	92581.6	6.3	0.90
T_{13}	7767.8	42696.0	34928.2	5.5	0.71

*For treatment details refer to materials and methods section

Table 6. Effect of precision nutrient management on energetics of Rabi maize during 2022-23.

Energetics (2022-23)					
Treatments	**Input energy (MJ ha^{-1})**	**Output energy (MJ ha^{-1})**	**Net energy (MJ ha^{-1})**	**Energy use efficiency**	**Energy productivity (kg MJ^{-1})**
T_1	17376.8	80281.5	62904.7	4.6	0.66
T_2	19461.8	122752.5	103290.7	6.3	0.87
T_3	15291.8	64275.0	48983.2	4.2	0.60
T_4	21546.8	142501.5	120954.7	6.6	0.94
T_5	17939.5	88072.5	70133.0	4.9	0.67
T_6	15854.5	69781.5	53927.0	4.4	0.61
T_7	17073.8	91333.5	74259.7	5.3	0.75
T_8	18620.2	104844.0	86223.8	5.6	0.79
T_9	18620.2	116364.0	97743.4	7.6	1.21
T_{10}	20166.5	143010.0	122843.5	7.1	1.01
T_{11}	18055.6	94819.5	76763.9	5.3	0.75
T_{12}	18802.4	113857.5	95055.1	6.1	0.85
T_{13}	9036.8	44098.5	35061.7	4.9	0.62

Economics

Among the nutrient management treatments, the highest cost of cultivation was incurred in the treatment T_4: 150% RDF (Rs 71905 ha^{-1} and Rs 74705 ha^{-1} during both years of the study, respectively) and it was closely followed by T_9: CCM-based sufficiency index at 85%-90% and T_{10}: CCM-based sufficiency index at 90%-95% (Table 7). Further, the lowest cost of cultivation was accounted for in T_{13}: control. The quantity of fertilizer applied made a direct proportion for increasing or decreasing the cost of cultivation. In comparison to T_1: 100% RDF, there was Rs 9935 ha^{-1} and Rs 7661 ha^{-1} more cost involvement in T_4: 150% RDF and T_{10}: CCM-based sufficiency index at 90%-95% respectively.

Table 7. Effect of precision nutrient management on economics and benefit: cost ratio of *Rabi* maize during 2021-22 and 2022-23.

Treatments	Economics Rs ha^{-1}						B:C ratio	
	Cost of cultivation		Gross return		Net return			
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
T_1	61970	64770	89850	90965	27880	26195	0.45	0.40
T_2	64938	67738	140150	141065	75213	73328	1.16	1.08
T_3	59503	62303	72765	72850	13263	10548	0.22	0.17
T_4	71905	74705	157100	161685	85195	86980	1.18	1.16
T_5	64470	67270	91780	101565	27310	34295	0.42	0.51
T_6	62003	64803	75285	80265	13283	15463	0.21	0.24
T_7	61897	64697	102190	104465	40293	39768	0.65	0.61
T_8	63264	66064	118305	119850	55041	53786	0.87	0.81
T_9	67264	70064	128555	132450	61291	62386	0.91	0.89
T_{10}	69631	72431	159750	162300	90119	89869	1.29	1.24
T_{11}	62183	64983	107300	107415	45117	42432	0.73	0.65
T_{12}	63290	66090	124870	129885	61580	63795	0.97	0.97
T_{13}	49100	51900	50150	52135	1050	235	0.02	0.005

In gross return and net return, a similar trend was recorded during both years of the experiment. The highest gross return (Rs 159750 ha^{-1} and Rs 162300 ha^{-1} during both years of the study, respectively) and net return (Rs 90119 ha^{-1} and Rs 89869 ha^{-1} during both the years of the study, respectively) was recorded in the treatment T_{10}: CCM-based sufficiency index at 90%-95%. Further, this treatment was closely followed by T_4: 150% RDF with a gross return (Rs 157100 ha^{-1} and Rs 161685 ha^{-1} during both years of the study, respectively) and net returns (Rs 85195 ha^{-1} and Rs 86980 ha^{-1} during both the years of the study respectively). Moreover, the treatments T_9: CCM-based sufficiency index at 85%-90%, T_2: 125% RDF, T_{12}: NE-based nutrient management for a target yield for 9 t ha^{-1} and T_8: LCC 5-based nitrogen management recorded a satisfactory net return of more than Rs 50000 ha^{-1} during both years of the study. However, compared to T_1: 100% RDF, there was Rs 62239 ha^{-1} and Rs 63674 ha^{-1} more net profit in T_{10}: CCM-based sufficiency index at 90%-95%. The lowest value of gross return (Rs 50150 ha^{-1} and Rs 52135 ha^{-1} for two successive years, respectively) and net return (Rs 1050 ha-1 and Rs 235 ha^{-1} for two successive years, respectively) were recorded with control (T_{13}).

In the case of benefit-cost ratio, the highest value (1.29 and 1.24 for two years of the study respectively) was recorded in the treatment T_{10}: CCM-based sufficiency index at 90%-95% and it was closely followed by T_4: 150% RDF and T_2: 125% RDF. The remaining nutrient management treatments did not record a higher benefit cost ratio than T_{10}: CCM-based sufficiency index at 90%-95% during both years of the experiment. Among the treatments considered in the experiment, the treatments consisting of a higher level of fertilizer application incurred the highest cost of cultivation due to the higher price of chemical fertilizers (T_4: 150% RDF) (Hargilas et al., 2017). Further, the application of nitrogen through CCM and LCC also resulted in a higher cost of cultivation due to the involvement of more labourers or spilt applications (T_8: LCC5 based nitrogen management, T_9: CCM-based sufficiency index at 85%-90% and T_{10}: CCM SI-based N management at SI 90-95%) (Joshi et al., 2018). As no inorganic fertilizer was applied in the treatment T_{13} (control), it registered no fertilizer cost as well as the lowest cost of cultivation (Boregowda et al., 2019; Shyam et al., 2021). Due to more grain and stover yield produced with the treatments T_4: 150% RDF and T_{10}: CCM SI-based N management at SI 90-95% expressed the highest gross return, net return and benefit cost ratio during both the years of the experiment (Nagarjun and Yogananda, 2017). Interestingly, all the precision nutrient management treatments obtained higher benefit-cost ratio compared to T_1: 100% RDF. This clearly revealed the impact of precision nutrient tools on improving the profitability of maize cultivation.

Conclusion

The two-year study investigated the influence of precision nutrient management on the economics and energetics of *Rabi* maize cultivation under South Odisha conditions. Among various treatments, the CCM Sufficiency index 90-95% recorded a highest net return, B:C ratio, total and net energy output. However, the highest energy use efficiency and energy productivity was recorded with CCM Sufficiency index 85-90%. Hence, the results revealed that precision nutrient management significantly reduces fertilizer use, energy consumption, and enhanced economic viability. The findings of this study also demonstrated the potential of precision nutrient management through CCM Sufficiency index-based nutrient application to transform *Rabi* maize cultivation in South Odisha into a energy-efficient and profitable enterprise. Additionally, by adopting precision nutrient management, farmers can optimize fertilizers dose, their time of application and enhanced crop productivity resulting in higher net returns.

Future scope of the study

There is the scope for investigation of the efficiency of site-specific nitrogen (N) management strategies based on spectral indices for maize, accounting factors like cloud cover, time of sampling and their effects on leaf greenness index. Such research can provide valuable insights into optimizing nitrogen management practices under varying climatic conditions. Utilization of non-destructive methods such as normalized difference vegetation index (NDVI) and spectral imaging to assess nitrogen content in maize, offering alternative tools like Green Seeker and imaging for monitoring and guiding nutrient management decisions.

Developing artificial intelligence and machine learning-based models for site-specific and plant-specific nutrient management in maize. By leveraging data-driven algorithms, the models can provide tailored nutrient management recommendations to optimize nutrient requirements in maize and thereby optimizing nutrient inputs. Future researchers can evaluate the efficiency of alternative nitrogen sources in enhancing nitrogen use efficiency and benefit-cost ratio in maize cultivation. Experimenting with novel nitrogen sources, such as biofertilizers or organic amendments, can offer suitable solutions for improving maize productivity and agricultural sustainability.

Conflict of interest

The authors declare that they don't have any conflict of interest.

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