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Energy Efficiency Evaluation of Weed Management Techniques in Rabi Greengram (*Vigna Radiata* L.)

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ABSTRACT

Modern agriculture depends on improved crop varieties and supplementary energy sources like fertilizers, fuels, chemicals, and water to increase yields. However, these advanced technologies consume more energy and are less efficient than traditional practices. There is a necessity of energy balance studies to make agriculture more efficient, sustainable, and economically viable while promoting environmental conservation. Using a calorific measurement system, energetics studies quantify both inputs and outputs. So, a study was conducted on Energy balance studies of different weed control practices through chemical, mechanical and manual approaches in greengram at College Farm, College of Agriculture, Professor Jayashankar Telangana State Agriculture University, Rajendranagar, Hyderabad during rabi, 2020-21. By analyzing both direct and indirect energy consumption, the study determined the energy dynamics associated with each approach. Results indicated that while intercultivation with a power weeder at 20 days after sowing (DAS) required higher energy input, the weed-free check exhibited the highest energy output. Superior values of Energy ratio, Energy productivity and Productivity per day were also recorded with the weed-free check treatment followed by imazethapyr 10 % SL + quizalofop ethyl 5 % EC (tank mix) @ 125 g a.i ha^{-1} as post-emergence (PoE) at 20 DAS and pendimethalin 30 % EC + imazethapyr 2 % EC combination @ 960 g a.i ha^{-1} as pre-emergence (PE).

Keywords: *Energy input, Energy output, Greengram, Imazethapyr, quizalofop, pendimethalin.*

INTRODUCTION

The connection between agriculture and energy stands as a pivotal aspect of agricultural dynamics. Agriculture serves as both an energy consumer and a provider, chiefly through bio-energy resources (1). With the intensification of agricultural practices, there arises a heightened reliance on non-farm inputs such as fertilizers, insecticides, and herbicides, consequently elevating the energy demand (2). The efficiency of energy utilization and its environmental repercussions significantly influence crop production. Energy balance, defined as the comparison and analysis of energy input and output across various activities, sheds light on the energy consumption pattern within a system (3). This tool proves instrumental in fostering more sustainable and eco-friendly production systems tailored to diverse agro-climatic regions. Achieving this entails meticulous identification and conversion of inputs and outputs into energy equivalents using appropriate coefficients or measures. Emphasizing the judicious utilization of energy resources supplements economic perspectives, facilitating a comprehensive resource analysis and optimizing energy inputs while preserving crop production economics (4).

Green gram cultivation, characterized by its short growth cycle and initial slow development, is exposed to heavy infestation of weeds posing a considerable threat to achieving the expected yields. Weed competition results in a substantial decrease in green gram grain yield, ranging from 70-80% during the *rabi* season to 30-80% in both the summer and kharif seasons (5). Traditional weed management methods such as hand weeding and intercultivation, though effective, have become cost-intensive, laborious, and time-consuming. Alternatively, herbicide application emerges as a viable approach due to its affordability, ease of application, and efficacy in weed control. However, the modernization of agricultural practices through herbicide usage necessitates a thorough understanding of the energy implications, given the interdependence of energy and economics. Despite this critical linkage between agriculture, economics, and energy, scant information exists on this aspect. Hence, the present study endeavors to evaluate the energy balance associated with various weed control practices in *rabi* green gram cultivation, aiming to fill this gap in knowledge.

MATERIALS AND METHODS

The study was conducted during the rabi season of 2020-2021 at the College farm of Professor Jayashankar Telangana State Agriculture University, located in Rajendranagar, Hyderabad, Telangana. The farm is geographically located at an altitude of 542.6 m above the mean sea level (MSL), 78º 28′ E longitude, and 17º 19′ N latitude and falls under the Southern Zone of Telangana State. The experiment, comprising ten treatments, was arranged in a randomized complete block design with three replications. The soil texture at the experimental site was sandy loam, slightly alkaline in pH (7.96), with an electrical conductivity (EC) of 0.41 dS m^{-1}.

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Low in organic carbon (0.39 %) and available nitrogen (235.8 kg/ha), while high in available phosphorous (45.5 kg/ha) and potassium (384.6 kg/ha). The ten treatments are as follows: Diclosulam 84 % WDG @ 26 g a.i ha^{-1} as PE -W_1, Pendimethalin 30 % EC + Imazethapyr 2 % EC combination @ 960 g a.i ha^{-1} as PE- W_2, Imazethapyr 35 % + Imazamox 35% WG combination @ 70 g a.i ha^{-1} as PoE- W_3, Imazethapyr 3.75 % + Propaquizafop 2.5 % w/w ME @ 125 g a.i ha^{-1} as PoE- W_4, Sodium acifluorphen 16.5 % EC + Clodinafop propargyl 8 % EC @ 250 g a.i ha^{-1} as PoE- W_5, Diclosulam 84 % WDG @ 26 g a.i ha^{-1} as PE fb Imazethapyr 10 % SL @ 75 g a.i ha^{-1} as PoE- W_6, Imazethapyr 10 % SL + Quizalofop ethyl 5 % EC (tank mix) @ 125 g a.i ha^{-1} as PoE- W_7, Intercultivation at 20 DAS with power weeder- W_8, Unweeded check- W_9 and Weed free check- W_{10}. Greengram variety MGG-347 was sown on November 6, 2020, with a spacing of 30×10 cm, and a basal application of 20:50:20 kg ha^{-1} NPK was applied. Pre-emergence (PE) herbicides were applied one day after sowing, while post-emergence (PoE) herbicides were applied at 20 DAS.

The energy analysis approach utilized a system of calorific quantification for both input materials and output products. The energy input for different weed control methods in green gram cultivation was estimated using direct and indirect energy measures. A comprehensive inventory of all crop inputs, including fertilizers, seeds, plant protection chemicals, fuels, human labor, and machinery power, was recorded at various application stages, while seed yield was recorded as the output. The energy input for each treatment was calculated by multiplying the inputs by their respective energy equivalents and summing them. Pod yield was considered for calculating output energy, which was determined by multiplying the pod yield by the corresponding energy coefficient. Indirect energy use of agricultural machinery was calculated using specific equations.

Eim = (MTR x M) / (L x Ce)

Where: Eim = Machinery input energy, MJ ha^{-1}

MTR = Energy used to manufacture, transport, and repair

M = Mass of machinery,

L= Life of machinery

Ce = Effective field capacity of farm machinery, h ha^{-1}

Energy efficiencies of the different weed control treatments were estimated as

1. $\text{Energy ratio} = \frac{\text{Output energy (MJ ha}^{-1})}{\text{Input energy (MJ ha}^{-1})}$

2. $\text{Energy productivity (kg MJ}^{-1}) = \frac{\text{Total output (kg ha}^{-1})}{\text{Energy input (MJ ha-}^{-1})}$

3. $\text{Productivity per day (kg ha}^{-1}\text{ day}^{-1}) = \frac{\text{Seed yield (kg ha}^{-1})}{\text{Duration of the crop (days)}}$

4. $\text{Net energy returns} = \frac{\text{Output energy (MJ ha}^{-1})}{\text{Input energy (MJ ha}^{-1})}$

5. $\text{Specific energy} = \frac{\text{Input energy (MJ ha}^{-1})}{\text{Yield (t ha}^{-1})}$

6. $\text{Energy intensiveness} = \frac{\text{Input energy (MJ ha}^{-1})}{\text{Cost of cultivation (Rs ha}^{-1})}$

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

8. $\text{Human energy profitability} = \frac{\text{Output energy (MJ ha}^{-1})}{\text{Labor energy (MJ ha}^{-1})}$

Table 1: Equivalents for energy used in the experiment

Source of energy	Equivalentenergy	References
Input energy		
Adult man	1.96 MJ h^{-1}	(6).
Women	1.57 MJ h^{-1}	(6)
Farm machinery (Tractor)	64.80 MJ kg^{-1}	(7)
Power weeder	4.75 MJ kg^{-1}	(7)
Sprayer	0.94 MJ kg^{-1}	(8)
Diesel	56.31 MJ h^{-1}	(7)
Chemical fertilizers		
N	60.60 MJ kg^{-1}	(7)
P_2O_5	11.10 MJ kg^{-1}	(7)
K_2O	6.70 MJ kg^{-1}	(7)
Pesticides		
Diclosulam	621 MJ kg^{-1} a.i.	(9)
Pendimethalin	421 MJ kg^{-1} a.i.	(9)
Imazethapyr	518 MJ kg^{-1} a.i.	(10)
Imazamox	518 MJ kg^{-1} a.i.	(11)
Propaquizafop	561 MJ kg^{-1} a.i.	(10)
Sodium acifluorphen	568 MJ kg^{-1} a.i.	(11)
Quizalofop ethyl	561 MJ kg^{-1} a.i.	(9)
Imidacloprid	324 MJ kg^{-1} a.i.	(12)
Acephate	250 MJ kg^{-1} a.i.	(12)
Output energy		
Seed yield	14.7 MJ kg^{-1}	(13)
Haulm yield	12.5 MJ kg^{-1}	(6)

RESULTS AND DISCUSSION

The data on energetics in greengram production under various herbicide combinations are furnished in Table 2 and 3.

Seed and haulm yield (kg ha^{-1}):

Among the various treatments, the unweeded control exhibited notably lower seed and haulm yields. This can be attributed to the absence of any weed control measures, resulting in intense competition between crop plants and weeds for essential resources such as light, water, and nutrients. However, the application of pre and post-emergence herbicides led to a marginal increase in yields. The highest seed and haulm yields were recorded in the weed-free check treatment (1430 and 2570 kg ha^{-1}, respectively). Nevertheless, herbicide combinations such as imazethapyr 10 % SL + quizalofop ethyl 5 % EC (tank mix) @ 125 g a.i ha^{-1} as post-emergence at 20 DAS (1375 and 2503 kg ha^{-1}) and pendimethalin 30 % EC + imazethapyr 2 % EC combination @ 960 g a.i ha^{-1} as pre-emergence (1244 and 2418 kg ha^{-1}) demonstrated yields comparable to the weed-free check, exhibiting a 53.01 % increase in seed yield over the unweeded control.

ENERGY INDICES

Energy input: Of the various treatments, intercultivation with power weeder at 20 DAS showed the highest input energy (10,747 MJ ha^{-1}). This could be attributed to the increased fuel consumption required to operate the power weeder during the intercultivation process in the field. Conversely, the unweeded check exhibited the lowest energy input since no measures were undertaken for weed control.

Energy output: The weed-free check exhibited significantly higher energy output (53146 MJ ha^{-1}), which was comparable to the energy output of treatments involving imazethapyr 10 % SL + quizalofop ethyl 5 % EC (tank mix) @ 125 g a.i ha^{-1} as PoE at 20 DAS (51500 MJ ha^{-1}) and pendimethalin 30 % EC + imazethapyr 2 % EC combination @ 960 g a.i ha^{-1} as PE (48512 MJ ha^{-1}). This was attributed to the maximum seed and haulm yield achieved in these treatments.

Conversely, lower energy output was recorded with diclosulam 84 % WDG @ 26 g a.i ha^{-1} as PE (9798 MJ ha^{-1}) and diclosulam 84 % WDG @ 26 g a.i ha^{-1} as PE followed by imazethapyr 10 % SL @ 75 g a.i ha^{-1} as PoE at 20 DAS (9882 MJ ha^{-1}) compared to the unweeded check (32203 MJ ha^{-1}). This was due to herbicide toxicity in those treatments which led to severe yield loss.

Energy ratio, Energy productivity, and Productivity per day: The energy ratio varied significantly among all treatments, primarily due to the diverse herbicide combinations employed. The energy ratio provides insight into the efficiency of energy input utilization. The weed-free check demonstrated the highest energy.

Table 2: Effect of different herbicide combinations on Energy ratio, Energy productivity, and Productivity per day

	Treatment	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})	Energy input (MJ ha^{-1})	Energy output (MJ ha^{-1})	Energy ratio	Energy productivity (kg MJ^{-1})
W_1	Diclosulam 84 % WDG @ 26 g a.i ha^{-1} as pre-emergence application (PE)	164	591	9966	9798	0.9	0.0 2
W_2	Pendimethalin 30 % EC + Imazethapyr 2 % EC combination @ 960 g a.i ha^{-1} as PE	1244	2418	10360	48512	4.7	0.1 2
W_3	Imazethapyr 35 % + Imazamox 35% WG combination @ 70 g a.i ha^{-1} as post-emergence application (PoE) at 20 DAS	852	2108	9986	38874	3.9	0.0 9
W_4	Imazethapyr 3.75 % + Propaquizafop 2.5 % w/w ME @ 125 g a.i ha^{-1} as PoE at 20 DAS	1069	2292	10017	44364	4.4	0.1 1
W_5	Sodium acifluorphen 16.5 % EC + Clodinafop propargyl 8 % EC @ 250 g a.i ha^{-1} as PoE at 20 DAS	1207	2382	10043	46474	4.6	0.1 2
W_6	Diclosulam 84 % WDG @ 26 g a.i ha^{-1} as PE *fb* Imazethapyr 10 % SL @ 75 g a.i ha^{-1} as PoE at 20 DAS	168	593	10005	9882	1.0	0.0 2
W_7	Imazethapyr 10 % SL + Quizalofop ethyl 5 % EC (tank mix) @ 125 g a.i ha^{-1} as PoE at 20 DAS	1375	2503	10017	51500	5.1	0.1 4
W_8	Intercultivation at 20 DAS with power weeder	987	2201	10747	42021	3.9	0.0 9
W_9	Unweeded check	672	1786	9950	32203	3.2	0.0 7
W_{10}	Weed free check	1430	2570	10176	53146	5.2	0.1 4
	SEm±	69	116		1982.4	0.19	0.0 1
	CD (P=0.05)	205	344		5889.1	0.57	0.0 2

The energy ratio varied significantly among all treatments, primarily due to the diverse herbicide combinations employed. The energy ratio provides insight into the efficiency of energy input utilization. The weed-free check demonstrated the highest energy ratio, maximum energy productivity, and productivity per day (5.2, 0.14 kg MJ^{-1}, and 19.1 kg ha^{-1} day^{-1}, respectively). Following closely were treatments involving imazethapyr 10 % SL + quizalofop ethyl 5 % EC (tank mix) @ 125 g a.i ha^{-1} as PoE at 20 DAS (5.1, 0.14 kg MJ^{-1}, and 18.3 kg ha^{-1} day^{-1}) and pendimethalin 30 % EC + imazethapyr 2 % EC combination @ 960 g a.i ha^{-1} as PE (4.7, 16.6 kg MJ^{-1}, and 19.1 kg ha^{-1} day^{-1}), which were comparable to the weed-free check. This resulted from their lower energy input and the production of higher seed yield, allowing for maximum energy output and thus more output per input utilized. The lowest energy ratio was observed in plots treated with diclosulam. Similar results were reported by (14) for pendimethalin + imazethapyr (ready mix) @ 1 kg ha^{-1} in chickpeas and by (15) in chickpea cultivation.

Energy intensiveness (MJ ha^{-1})

The energy intensity required to produce one kilogram of green gram seed was notably higher in the unweeded check condition. Among the herbicidal applications, diclosulam 84 % WDG @ 26 g a.i ha^{-1} as PE (0.36), pendimethalin 30 % EC + imazethapyr 2 % EC combination @ 960 g a.i ha^{-1} as PE (0.36), and diclosulam 84 % WDG @ 26 g a.i ha^{-1} as PE followed by imazethapyr 10 % SL @ 75 g a.i ha^{-1} as PoE (0.36) exhibited higher energy intensity. In contrast, the weed-free check showed the lowest energy intensity (0.30) compared to all other treatments.

Energy profitability: Among the herbicidal treatments, diclosulam application resulted in lower energy profitability compared to the unweeded check, primarily due to significant yield reduction caused by herbicidal phytotoxicity. Imazethapyr 10 % SL + quizalofop ethyl 5 % EC (tank mix) @ 125 g a.i ha^{-1} as PoE at 20 DAS achieved the highest profitability of 4.14 MJ ha^{-1}. Nonetheless, the weed-free check outperformed all other treatments, demonstrating the highest

Table 3. Effect of weed management practices on productivity per day, energy intensiveness, energy profitability, net energy return, specific energy, and human energy profitability of Green gram.

	Treatment	Productivity per day (kg ha^{-1} day^{-1})	Energy intensiveness (MJ ha^{-1})	Energy profitability (MJ ha^{-1})	Net energy return (MJ ha^{-1})	Specific energy (× 10^{-3} MJ ha^{-1})	Human energy profitability
W_1	Diclosulam 84 % WDG @ 26 g a.i ha^{-1} as pre-emergence application (PE)	2.2	0.36	-0.02	-168	60.8	18.4
W_2	Pendimethalin 30 % EC + Imazethapyr 2 % EC combination @ 960 g a.i ha^{-1} as PE	16.6	0.36	3.68	38152	8.3	91.3
W_3	Imazethapyr 35 % + Imazamox 35% WG combination @ 70 g a.i ha^{-1} as PoE at 20 DAS	11.4	0.35	2.89	28888	11.7	74.5
W_4	Imazethapyr 3.75 % + Propaquizafop 2.5 % w/w ME @ 125 g a.i ha^{-1} as PoE at 20 DAS	14.3	0.35	3.43	34347	9.4	83.5
W_5	Sodium acifluorphen 16.5 % EC + Clodinafop propargyl 8 % EC @ 250 g a.i ha^{-1} as PoE at 20 DAS	16.3	0.36	3.63	36431	8.3	87.4
W_6	Diclosulam 84 % WDG @ 26 g a.i ha^{-1} as PE *fb* Imazethapyr10 % SL @ 75 g a.i ha^{-1} as PoE at 20 DAS	2.2	0.34	-0.01	-123	59.6	17.6
W_7	Imazethapyr 10 % SL + Quizalofop ethyl 5 % EC (tank mix) @ 125 g a.i ha^{-1} as PoE at 20 DAS	18.3	0.34	4.14	41483	7.3	97.0
W_8	Intercultivation at 20 DAS with power weeder	13.2	0.36	2.91	31274	10.9	70.0
W_9	Unweeded check	9.0	0.37	2.24	22253	14.8	64.4
W_{10}	Weed free check	19.1	0.30	4.22	42970	7.1	73.8

energy profitability at 4.22 MJ ha^{-1}. Energy profitability exhibited an inverse relationship with management intensity, with higher profitability associated with lower management intensity, and showed a strong correlation with total biomass productivity.

Net energy return

The weed-free check exhibited the highest net energy return. Among the herbicidal +quizalofop ethyl 5 % EC (tank mix) @ 125 g a.i ha^{-1} as PoE at 20 DAS, attributed to its higher output energy. Conversely, the lowest net energy return was recorded in diclosulam-treated plots.

Specific energy (× 10^{-3} MJ ha^{-1}) and Human energy profitability: Specific energy indicates the quantity of energy required to produce a single unit of the product. The specific energy needed was lowest in the weed-free check, while the highest was observed in diclosulam-treated plots. Human energy profitability was assessed based on manpower and its energy equivalent utilized in producing the output. Diclosulam-treated plots exhibited the lowest index compared to the unweeded check. However, with the application of herbicides, this index showed a positive increase. The treatment involving Imazethapyr 10 % SL + quizalofop ethyl 5 % EC (tank mix) @ 125 g a.i ha^{-1} as PoE at 20 DAS recorded the highest human energy profitability.

CONCLUSION

Based on the above findings it can be inferred that the best energy indices were observed in the weed-free check followed by the application of imazethapyr 10 % SL + quizalofop ethyl 5 % EC (tank mix) @ 125 g a.i ha^{-1} as PoE at 20 DAS and pendimethalin 30 % EC + imazethapyr 2 % EC combination @ 960 g a.i ha^{-1} as PE due to their positive impact on yield attributes and overall yield.

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Conflict of Interest: The authors state no conflict of interest.

Future Scope of Study: Future studies could explore integrating these chemical treatments with sustainable practices, such as biological control, to enhance resource efficiency and maximize crop potential.

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