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Energy Budgeting and Economic Analysis of Cowpea Varieties under *Rainfed* Condition

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ABSTRACT

Background: Cowpea is a versatile leguminous pulse crop that exhibits resilience to drought and adapts well to various climates. It serves multiple purposes and can be enjoyed both in its raw form and as a grain pulse. Various studies established that cowpea has the potential vegetable crops with nitrogen fixation capacity. Thus, the study of environmentally safety and clean production of cowpea for better crop yield along with energy use efficiency and carbon budgeting for sustainable crop production is an important issue for the upcoming future.

Methods: The present study was carried out at the experimental farm of Krishi Vigyan Kendra-Sepahijala, Latiacherra, Tripura under CAU (I) on 2022 and 2023 with three high yielding cowpea varieties (Kashi Kanchan, Kashi Gauri and Kashi Unnati). The design followed in the experiment adhered to a Randomized block design (RBD) with five replications.

Result: Experiments result revealed that Kashi Kanchan perform outstanding by showing maximum pod yield. In the context of energy equivalent and Carbon budgeting, Kashi Kanchan is showing high energy use efficiency (45.01) and high carbon efficiency (1.59).

Key words: Carbon budgeting, Carbon input and output, Carbon sustainability index, Energy productivity, Energy use efficiency.

INTRODUCTION

Cowpea (*Vigna unguiculata*), also known as black-eyed pea or Southern pea, is a versatile legume crop widely cultivated in tropical and subtropical regions, particularly in India. Cowpea, also known as *Vigna unguiculata*, recognized for its resilience to drought, owes its reputation to its broad and drooping leaves, which effectively conserve soil and moisture through shading. Additionally known as southern pea or black-eyed pea, this versatile crop serves a multitude of purposes, encompassing its utilization in food, feed, forage, fodder, green manure and as a vegetable. It is a valuable source of protein, vitamins and minerals, making it an essential component of food security in developing countries. Cowpea seed is both an affordable source of animal feed and a nutrient-rich ingredient in human diets. The green and dried seeds are both perfect for boiling and canning. It contains Carbohydrate: 55-66%, Protein: 22-24%, Calcium: 0.08-0.11%, Iron: 0.005% on an average along with essential amino acids (lysine, leucine and phenylalanine). Cowpea (*Vigna Unguiculata)* is a very important crop which is grown in many parts of Tripura as well as the Sepahijala district. It is also known as black eye bean, black eye pea, southern pea, marble pea, china pea, chowli and lobiya. Cowpea is referred to as vegetables meat due to its high protein content and higher biological value on a dry weight basis. Cowpea is a short duration crops and fixes atmospheric nitrogen, can fitted as a catch crop.

Cowpea also plays a significant role in sustainable agriculture due to its ability to fix nitrogen from the atmosphere, thereby reducing the need for chemical fertilizers. From an economic standpoint, cowpea cultivation offers several benefits to Indian farmers. Cowpea is a relatively low-input crop, requiring less labor and water compared to other legumes like soybeans. Its short growing season allows for multiple cropping cycles within a year, increasing land productivity and economic returns. Additionally, cowpea's adaptability to diverse agro-climatic conditions makes it a suitable crop for marginal lands, providing farmers with a reliable income source even in challenging environments (Choudhuury and Kuma, 2013). Cowpea is a very important crop which is grown in many parts of Tripura as well as the Sepahijala district. The

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cultivation of cowpea in India holds immense potential for enhancing food security, improving agricultural sustainability and generating economic benefits for farmers. By optimizing cultivation practices, adopting energy-efficient technologies and expanding market linkages, cowpea can play a pivotal role in India's agricultural development and economic growth (Choudhuury and Kuma, 2013).

In the developed countries, increase in crop yields was mainly depends on increase in the various commercial energy inputs in addition to improved crop varieties (Rao *et al.*, 2018). In development process of mankind energy plays very important role (Prasad *et al*., 2015). Energy stands out as one of the most crucial inputs within the agricultural production system (Rao *et al.*, 2018). Renewable and non-renewable energy sources are used in the agriculture and food production systems (Prasad *et al.*, 2015). Large energy inputs in large quantities of locally accessible non-commercial energies, like manures and seed energies, as well as commercial energies used directly or indirectly in the form of diesel, electricity, fertilizers, pesticides, irrigation water, machinery, *etc*., have been used for crop production as a result of increasing modernization (Heidari and Omid, 2011). It was found that the availability of a suitable source of energy and its efficient and effective use are directly and indirectly related to crop yields and food supplies. Cowpea cultivation exhibits a favorable energy input-output ratio and the energy output from cowpea production, in the form of grain, fodder and other by-products, significantly exceeds the energy inputs associated with cultivation practices, including land preparation, sowing, irrigation and harvesting. This positive energy balance contributes to the overall sustainability of cowpea production systems (Choudhuury and Kuma, 2013). Utilizing different energy sources effectively enables the achievement of desired productivity, which boosts the nation's economy, profitability and agricultural sustainability competitiveness (Ezeaku *et al.*, 2015; Kulkarni *et al*., 2018). Excessive consumption of energy has negative effects on profitability, market competitiveness and unit costs of production. Therefore, for food security, energy budgeting and doubling farmers income of the state introducing less input intensive crops like cowpea and achieving higher crop yield per unit area is one of the most important factor for the agricultural development.

MATERIALS AND METHODS

Experimental procedure

The present study was carried out at the experimental farm of Krishi Vigyan Kendra-Sepahijala, Latiacherra, Tripura under CAU (I) on 2022 and 2023 with three high yielding cowpea varieties (Kashi Kanchan, Kashi Gauri and Kashi Unnati). The design used in the experiment adhered to a Randomized block design (RBD) with three treatment and 5 replications. The crops were grown following standard protocol at a spacing of 45 cm × 30 cm. Each variety sown in an area of 20 m^2 in each plot and the recommended cultivation practices were followed with recommended dose of 25 kg ha^{-1} seed rate, 5 t FYM ha^{-1} and 20 kg ha^{-1} N as starter dose, 50 kg ha^{-1} P_2O_5 and 50 kg ha^{-1} K_2O. The crop was sown in 1st fortnight of July for both the year. Entire dose of nitrogen, phosphorus and potash were applied at basal as per the soil test value.

Growth attributes

Periodic plant sampling was done for monitoring plant growth attributes. Plant samples were collected randomly from selected plots.

Plant height

Plant height was recorded 15, 30 and 45 DAS of crops. Plant height (cm) was taken from five randomly selected plants in each plot.

Dry matter

Plant dry matter was recorded at 45 days after sowing of crops. Five plant samples were collected from the second outer most rows at each sampling. Plants are gently removed with the help of spade (10 cm × 10 cm × 15 cm). Roots and shoots were separated. Roots are washed properly with water. Samples were kept in paper bags and kept in oven for drying at 65°C till the samples attained a fixed weight. The biomass was converted to gram per meter square (g m^{-2}) (Anele *et al*., 2011).

Pod length

Pod length (cm) was taken from five randomly selected pods in five plants in each plot excluding the outer line of the plots.

Yield attributes

The Kashi Kanchan, Kashi Gauri and Kashi Unnati were harvested separately from each plot leaving the outer two border rows (net plot) and threshed separately. Pod yields were recorded as kg $plot^{-1}$ and extrapolated to get the yield for one hectare and expressed in kg ha^{-1} (Dey *et al.,* 2023).

Energy equivalents

The energy equivalents of the inputs and output (Table 1 and 2) were converted to energy units from physical units, measured through conversion coefficient. Subsequently, calculations were performed to determine energy use efficiency, energy productivity and net energy gain, as given below.

$$\text{Energy use efficiency (EUE)} = \frac{\text{Energy output (MJ)}}{\text{Energy input (MJ)}} \quad \text{...(1)}$$

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

$$\text{Net energy (MJ ha}^{-1}\text{)} = \text{Energy output (MJ ha}^{-1}\text{)} - \text{Energy input (MJ ha}^{-1}\text{)} \quad \text{...(3)}$$

To calculate the energy equivalents of the input and output of cowpea crop, a complete inventory of cowpea crop inputs (viz., seeds, human labor, fertilizers, pesticides, machines, fuels *etc*.) and output of both economic and by product were taken into count. The energy equivalent of cowpea was estimated based on energy production and energy input. Energy use efficiency (EUE) serves as a vital indicator, illustrating the effectiveness of energy utilization in agriculture. Additionally, it reveals the crop production efficiency or inefficiency prevalent in developed countries (Unakitan *et al*., 2010).

To express energy indices, they are converted from physical to energy unit measures with multiplication of suitable conversion coefficients (Hedau *et al.*, 2014; Singh *et al*., 2008; Heidari and Omid, 2011). All cowpea energy equivalents for inputs were added to provide an estimate for total energy input (Hedau *et al.*, 2014). The amount of production and its corresponding energy equivalent were multiplied to determine the energy output from the product (economic yield). The quantity of the byproduct and its equivalent were multiplied to determine the amount of energy produced by the byproduct (leaves/stalk/vine). The net energy gain is the difference between the total energy input and the gross output energy produced (Hedau *et al.*, 2014). According to Singh *et al*. (2010) and Heidari and Omid (2011), the input energy is categorized into two main types: direct and indirect and further divided into renewable and non-renewable sources. The direct energy encompasses fuel and human labor employed during the production process. In contrast, indirect energy comprises organic mulches, seeds, pesticides, fertilizers and machinery. Non-renewable energy sources encompass fuel, fertilizers, chemicals, electricity, while renewable energy sources include organic mulches and human power. Each operation's total manual labor was recorded in working hours, which were multiplied by a suitable conversion factor to get the total labor hours in man-hours.

Carbon budgeting

The carbon equivalent per hectare (Ce ha^{-1}) for both of the input and output was calculated using equivalent carbon emissions (Pandey and Agrawal, 2014). The total carbon content in the biomass was determined by multiplying the yield by a carbon content of 40%, which is used to calculate total carbon input and output because biomass is assumed to contain 40% C (Chaudhary *et al*., 2017). The carbon efficiency (CE) and carbon sustainability index (CSI) were determined by using following equations (Chaudhary *et al*., 2017):

$$\text{Carbon efficiency} = \frac{\text{Carbon output}}{\text{Carbon input}} \quad \ldots(4)$$

Carbon sustainability index =

$$\frac{\text{Carbon output - Carbon input}}{\text{Carbon input}} \quad \ldots(5)$$

Economic equivalents

Economic analysis gives an opportunity to the farmers to decide what to grow with profitability (Khan *et al*., 2009). The economic analysis of cowpea varieties was calculated by assessing a range of components (Yadav *et al.*, 2018) including net return, benefit-cost ratio and economic productivity. Net return, benefit-cost ratio and economic productivity were calculated by using equations 7, 8 and 9 (Yadav *et al*., 2017; Yadav *et al*., 2018). Foe economic calculation components were taken into account based on the prevailing market prices of both inputs and outputs.

Net return (Rs ha^{-1}) =

$$\text{Gross return (Rs ha}^{-1}\text{) - Cost of cultivation (Rs ha}^{-1}\text{)} \quad \ldots(6)$$

$$\text{Benefit-cost ratio} = \frac{\text{Net return (Rs ha}^{-1}\text{)}}{\text{Cost of cultivation (Rs ha}^{-1}\text{)}} \quad \ldots(7)$$

Economic productivity (Kg Rs^{-1}) =

$$\frac{\text{Pod yield (Kg/ha)}}{\text{Cost of cultivation (Rs ha}^{-1}\text{)}} \quad \ldots(8)$$

Statistical analysis

Data obtained from the study were done in randomized block design (RBD). The pooled data were generated from the experiment by making average of 2022 and 2023 data. The difference between the varietal treatment mean were tested to their statistical significance of critical difference (CD) value at 5% level of probability was obtained by using t-test. (Reddy *et al.*, 2023).

RESULTS AND DISCUSSION

Plant height

There was less variation of plant height among different variety of cowpea. Among the variety, Kashi Kanchan recorded maximum height followed by Kashi Unnati and Kashi Gauri. The plant height of Kashi Kanchan variety of Cowpea was 2.20% higher than Kashi Unnati variety of

Table 1: Inputs requirement of crop grown.

Item	Cowpea
Crop variety	Kashi Kanchan, Kashi Gauri, Kashi Unnati
Nitrogen-N (kg ha^{-1})	20
Phosphorus-P (kg ha^{-1})	60
Potassium-K (kg ha^{-1})	60
FYM (Mg ha^{-1})	5
Seed (kg ha^{-1})	20
Pesticides solid (kg ha^{-1})	2
Pesticides liquid (L ha^{-1})	0
Diesel (L ha^{-1})	16
Machine (hr ha^{-1})	16
Labour (Men-8-hr days^{-1} ha^{-1})	50
Labour (Women-8-hr days^{-1} ha^{-1})	60

cowpea (Table 3). The height of this variety is less compared to other variety of cowpea might be due to dwarf bush type and photo-insensitive (Kandel *et al*., 2020).

Dry matter

There were little differences of dry matter between Kashi Kanchan, Kashi Gouri and Kashi Unnati. Among the three variety of cowpea Kashi Kanchan variety found maximum dry matter followed by Kashi Unnati and Kashi Gouri. The dry matter of Kashi Kanchan variety of Cowpea was 9.83% higher than Kashi Unnati variety of cowpea (Table 4).

Flowering

Minimum days to 50% flowering (42.60 DAS) was found in Kashi Kanchan, followed by Kashi Unnati (43.40 DAS). And the Maximum number of days to 50% flowering (46.80 DAS) was found in the Kashi Gauri (Table 5). The result may be due to individual varietal characteristic (Sharma *et al*., 2019).

Pod length

Length of the pod varied from 34.20 cm to 24.50 cm. Maximum pod length (34.20 cm) was found in the Kashi Kanchan followed by Kashi Unnati (32.00 cm) and minimum pod length (24.50 cm) was found in Kashi Gauri. Each and every variety has their special characteristic and features, pod length is one of them, showing different pod length among the varieties may be due to their different genetical characteristic (Gupta *et al*., 2017).

Pod yield

Maximum yield per hectare was recorded in the variety Kashi Kanchan (14440.74 kg), followed by Kashi Unnati (12188.89 kg) and minimum yield per hectare was recorded in the variety Kashi Gauri (10107.41 kg) (Table 6). The higher yield in case of variety Kashi Kanchan may be due to agro climatic suitability and less disease incident of the variety in the region (Kandel *et al*., 2020; Mohiddin *et al*., 2022).

Energy equivalents

Energy output

There was less variation of energy input among three varieties. Energy output was highest in Kashi Kanchan followed by Kashi Unnati. There was 15.59% higher energy output in Kashi Kanchan than Kashi Unnati variety of cowpea. The higher energy output in Kashi Kanchan was due to relatively higher yield of cowpea as compared to other variety of cowpea. Devasenapathy *et al*. (2009) reported higher yield in a cropping system always gives maximum energy output.

Table 2: Energy equivalents of inputs and outputs in the experiment.

Inputs	Units	Equivalent energy (MJ)
Human labour		
Men	Hour (hr)	1.97
Women	Hour (hr)	1.57
Diesel	Litre (L)	56.31
Tractor	Hour (hr)	62.7
Chemical fertilizers		
Nitrogen-N	Kilogram (kg)	60.6
Phosphorus-P	Kilogram (kg)	11.1
Potassium-K	Kilogram (kg)	6.7
Farm yard manure (FYM)	Kilogram (kg) (Dry mass)	0.3
Plant protection		
Granular chemical	Kilogram (kg)	120
Liquid chemical	Litre (L)	120
Seeds		
Cowpea	Kilogram (kg)	14.7
Stalk	Kilogram (kg)	12.5

Source: Chaudhary *et al*., 2017; Yadav *et al*., 2017; Yadav *et al*., 2018.

Table 3: Plant height of cowpea under different varieties.

Treatment	15 DAS (cm)	30 DAS (cm)	45 DAS (cm)
Kashi kanchan	18.90	47.50	63.20
Kashi gauri	16.10	39.40	52.20
Kashi unnati	17.60	42.80	61.40
Sem±	2.98	3.47	3.45
CD ($p \leq 0.05$)	NS	*	*

NS: Non-significant; *: Significant

Net energy

Net energy is an important indicator for production system planning and design. These indicators additionally assist with firm composition and management practise adoption decisions, as well as evaluating the possibility of a production system's energy requirements. In present study, higher net energy was recorded in Kashi Kanchan (2075562.75 MJ ha^{-1}) followed by Kashi Unnati (174460.53 MJ ha^{-1}). The higher net energy in Kashi Kanchan was due to higher pod yield as compared to other variety. Lowest net energy was recorded in Kashi Gauri (143862.75 MJ ha^{-1}).

Energy use efficiency (EUE)

Energy use efficiency is a key indication for production system planning and design. These indicators also aid in enterprise composition, management practice and adoption decisions, as well as analyzing the viability of a production system's energy requirements. In the current study, Energy use efficiency (EUE) was noted maximum in Kashi Kanchan (45.01) system may be due to the higher energy output, followed by Kashi Unnati (37.99) and minimum Energy Use Efficiency was recorded in Kashi Gauri (31.50). The lowest EUE in Kashi Gauri was due to higher energy input requirement and comparatively low energy output. Similar findings were recorded by (Kachroo *et al*., 2012; Hadau *et al*., 2014).

Energy productivity

Highest energy productivity was obtained under variety Kashi Kanchan (3.06 t ha^{-1}) followed by Kashi Unnati variety (2.58 t ha^{-1}). Lowest energy productivity was recorded in variety of Kashi Gauri (2.14 t ha^{-1}) (Table 7). The higher energy productivity under these treatments was due to maximum productivity of the crop.

Carbon budgeting

In our present study three treatments are equal input. The highest CSI (0.59) and CE (1.59) in Kashi Kanchan were due to higher C output comparing to other treatments (Table 8). Reason behind Kashi Kanchan variety is higher grain yield (Shahan *et al.,* 2008; Chaudhary *et al.,* 2017; Pratibha *et al.,* 2015).

Economics

Gross return

The maximum average gross return (Rs 151500 ha^{-1}) was involved from kashi Kanchan followed by Kashi Unnati (Rs 182833.33 ha^{-1}). Minimum gross return was get from Kashi Gauri (Rs 151611.11 ha^{-1}) due to may be the lower yield. Srivastava *et al*. (2017) reported similar data on Kashi Kanchan variety, due to adoption of improved crop management practices.

BC ratio

The higher benefit cost ratio was found in Kashi Kanchan (3.89) variety followed by Kashi Unnati (3.29) and lower benefit cost ratio was found in Kashi Gauri (2.73). Maximum benefit cost ratio found in Kashi Kanchan due to maximum gross return come out almost similar result was found under front line demonstration in eastern part of Uttar Pradesh, India.

Table 4: Dry matter accumulation cowpea under different varieties at 45 DAS.

Treatment	Dry matter at 45 DAS (g m^{-2})
Kashi Kanchan,	91.60
Kashi Gauri,	74.60
Kashi Unnati	83.40
Sem±	15.03
CD (p≤0.05)	NS

NS: Non-significant; *:Significant.

Table 5: Flowering of cowpea under different cowpea varieties.

Treatment	Flowering (days)
Kashi Kanchan,	42.60
Kashi Gauri,	46.80
Kashi Unnati	43.40
Sem±	2.10
CD (p≤0.05)	*

NS: Non-significant; *:Significant.

Table 6: Yield attributes of cowpea under different cowpea varieties.

Treatment	Length of pod (cm)	Yield of pod (kg ha^{-1})
Kashi kanchan,	34.20	14440.74
Kashi gauri,	24.50	10107.41
Kashi unnati	32.00	12188.89
Sem±	1.27	1765.46
CD (p≤0.05)	*	*

NS: Non-significant; *:Significant.

Table 7: Energy equivalents of cowpea under different cowpea varieties.

Treatment	Energy output (MJ ha^{-1})	Net energy (MJ ha^{-1})	Energy use efficiency (EUE)	Energy productivity (kg MJ^{-1})
Kashi kanchan,	212278.89	207562.75	45.01	3.06
Kashi gauri,	148578.89	143862.75	31.50	2.14
Kashi unnati	179176.67	174460.53	37.99	2.58
Sem±	25952.23	25952.23	5.50	0.37
CD (p≤0.05)	*	*	*	*

NS: Non-significant; *:Significant.

Table 8: Carbon budgeting of cowpea under different cowpea varieties.

Treatments	Carbon input (kg ha^{-1})	Carbon output (kg ha^{-1})	Carbon efficiency	Carbon sustainable Index (CSI)
Kashi kanchan	2010	3200	1.59	0.59
Kashi gauri	2010	2840	1.41	0.41
Kashi unnati	2010	3040	1.51	0.51
Sem±			0.052	0.052
CD (p≤0.05)			*	*

NS: Non-significant; *:Significant.

Table 9: Economic analysis of cowpea under different cowpea varieties.

Treatment	Gross return (Rs ha^{-1})	B:C ratio	Economic productivity (kg Rs^{-1})
Kashi kanchan,	216611.11	3.89	0.26
Kashi gauri,	151611.11	2.73	0.18
Kashi unnati	182833.33	3.29A	0.22
Sem±	26481.87	0.48	0.02
CD (p≤0.05)	*	*	*

NS: Non-significant; *:Significant.

Economic productivity

The higher economic productivity was found in Kashi Kanchan (0.26 kg Rs^{-1}) followed by Kashi Unnati (0.22 kg Rs^{-1}) and Kashi Gauri (0.18 kg Rs^{-1}) due to higher pod yield (Table 9) (Hedau *et al*., 2014).

CONCLUSION

From the present study and data it can be support the following conclusions.

i. Kashi Kanchan had the highest pod yield (14440.74 kg ha^{-1}), followed by Kashi Unnati (12188.89 kg ha^{-1}). Kashi Gauri had the lowest pod yield (10107.41 kg ha^{-1}).

ii.Energy output was highest in Kashi Kanchan, followed by Kashi Unnati. Kashi Kanchan had 15.6% higher energy output than Kashi Unnati. Net energy was highest in Kashi Kanchan (2075562.75 MJ ha^{-1}), followed by Kashi Unnati (174460.53 Mt ha^{-1}). EUE was highest in Kashi Kanchan (45.01), followed by Kashi Unnati (37.99). Kashi Gauri had the lowest EUE (31.50). Energy productivity was highest in Kashi Kanchan (3.06 t ha^{-1}), followed by Kashi Unnati (2.58 t ha^{-1}). Kashi Gauri had the lowest energy productivity (2.14 t ha^{-1}). Kashi Kanchan had the highest carbon sequestration index (CSI) and carbon emission (CE) due to its higher carbon output.

iii. Kashi Kanchan had the highest gross return (Rs 151500 ha^{-1}), followed by Kashi Unnati (Rs 182833.33 ha^{-1}). Kashi Gauri had the lowest gross return (Rs 151611.11 ha^{-1}). Kashi Kanchan had the highest benefit-cost ratio (3.89), followed by Kashi Unnati (3.29). Kashi Gauri had the lowest benefit-cost ratio (2.73). Kashi Kanchan had the highest economic productivity (0.26 kg Rs^{-1}), followed by Kashi Unnati (0.22 kg Rs^{-1}) and Kashi Gauri (0.18 kg Rs^{-1}).

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Conflict of interest

No competing interests have been declared by the authors.

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