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Organic input incorporation for enhancing sustainability and economic viability of cowpea in North-Western Himalayan region

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Cowpea (*Vigna unguiculata* L. [Walp.]) cultivation encounters a plethora of challenges such as suboptimal productivity levels, declined income levels, and poor soil health under conventional fertilization systems. Therefore, the present field investigation was undertaken at the Research Farm, Department of Agronomy, CSKHPKV, Palampur in the rainy season of 2019 to evaluate eight combinations of organic farming and Zero Budget Natural Farming (NF) based inputs, i.e., *Beejamrita* (100 ml kg^{-1} of seed) + *Jeewamrita* (187.5 L ha^{-1}); *Beejamrita* (100 ml kg^{-1} of seed) + *GhanaJeewamrita* (250 kg ha^{-1}); *Beejamrita* (100 ml kg^{-1} of seed) + *Jeewamrita* (187.5 L ha^{-1}) + *GhanaJeewamrita* (250 kg ha^{-1}); farm yard manure (FYM) 10 Mg ha^{-1}; FYM (10 Mg ha^{-1}) + *GhanaJeewamrita* (250 kg ha^{-1}); biofertilizers (PSBs and Rhizobium at 10 g kg^{-1} of seed) + FYM (10 Mg ha^{-1}) + vermiwash (1:10); biofertilizers (PSBs and Rhizobium at 10 g kg^{-1} of seed) + vermicompost (7.5 Mg ha^{-1}) + vermiwash (1:10); absolute (untreated) control; in a randomized complete block design with three replications for their influence over cowpea productivity, profitability, and energetics. The results of the investigation revealed that applying FYM (10 Mg ha^{-1}) and *GhanaJeewamrita* (250 kg ha^{-1}) in combination resulted in significantly higher grain yield(1,070.5 kg ha^{-1}), economic net returns (766.61 USD ha^{-1}), net energy gains (78,230 MJ ha^{-1}), and considerably improved soil microbial biomass carbon (133.92 mg g^{-1} of soil), nitrogen (27.40 mg g^{-1} of soil), urease (52.20 (mg g^{-1} urea of soil h^{-1}), and dehydrogenase activity (5.21mg g^{-1} TPF of soil h^{-1}). Improved soil biological properties in the present study might have been responsible for considerable increment in cowpea yield and profitability. Therefore, in-combination application-based module of FYM (10 Mg ha^{-1}) and *GhanaJeewamrita* (250 kg ha^{-1}) can be recommended for enhancing productivity and profitability of cowpea cultivation under North-Western Himalayan agro-ecological conditions. This study contributes valuable insights for organic input strategies in regions facing similar challenges.

KEYWORDS

cowpea, energetics, organic, profitability, soil biology, yield

1 Introduction

Cowpea (*Vigna unguiculata* L. [Walp.]) holds a significant place as a valuable legume crop of the Fabaceae family cultivated globally, with a particular dominance in Africa and Asia, where it serves as a prominent protein source in human vegetarian diet (Duraipandian et al., 2022). Cowpea is cultivated globally across 15.19 million hectares of area with an estimated output of 9.77 million tonnes and a biomass productivity of approximately 6,435 kg ha^{-1} (FAOSTAT, 2024). Raw cowpea is a rich source of protein (23.8%), total dietary fibre (10.7%), carbohydrates (59.6%), and vitamin B_3 (2.08 ppm) (United States Department of Agriculture (USDA), 2024). Among the mineral elements, cowpea serves as a substantial source of calcium (85 mg), magnesium (333 mg), and phosphorus (438 mg) in human and animal diets (United States Department of Agriculture (USDA), 2024). Besides acting as a quality enhancer in human diet, cowpea can fix significant amounts of atmospheric nitrogen (337 kg nitrogen ha^{-1}) and supply substantial amount of food to soil microbes as organic matter and thus helps in improving the quality of soil (Yahaya, 2019; Mndzebele et al., 2020).

Field investigations have categorically highlighted the deleterious effects of inorganic fertilisers on soil quality (Mandal et al., 2020; Tripathi et al., 2020; Pahalvi et al., 2021), necessitating sustainable approaches to intensify cowpea production. In the context of sustainable farming, inclusion of organic inputs as an alternative to chemical farming represents a strong stance to improve soil quality while enhancing crop productivity. This encompasses variety of formulation derivatives of animal dung, urine, green manure crops, biofertilizers, etc. Recently, there have been noticeable surge in global interest with respect to (w.r.t.) organic and natural inputs and their influence over crop productivity and soil quality especially in case of minor pulses such as cowpea (Ulzen et al., 2020; Adegbite et al., 2021; Hossain and Sarkar, 2021; Dhunagana et al., 2022). Incorporation of organic inputs have demonstrated significant positive impacts over cowpea production across field investigations conducted in diverse agro-ecological conditions. For instance, a field investigation conducted in East Africa reported 25% increment in grain yield when cowpea seed was inoculated using organic inputs (Kyei-Boahen et al., 2017). Similarly, in Bangladesh, application of kitchen compost and bio-slurry led to a 2.23- and 5-fold increase in cowpea grain yield, respectively, when compared to untreated crop (Hossain and Sarkar, 2021). Furthermore, in Nepal, farmyard manure (FYM) application enhanced cowpea yield by 70% in comparison to the application of recommended dose of inorganic fertilisers (Dhunagana et al., 2022).

In addition to organic farming, Zero Budget Natural Farming (ZBNF) has emerged as a noble production system, particularly in India. This approach relies predominantly on inputs such as *Beejamrita*, *GhanaJeewamrita*, and *Jeewamrita*, emphasising low-cost, low-energy, and soil-biology-friendly practices (Duddigan et al., 2022). The term “zero-budget” does not signify no cost cultivation; however, it implies zero dependence over external financing or avoidance of external input application (Bharucha et al., 2020). The distinguishing feature of ZBNF system lies in its strict reliance on indigenous cow species for variable inputs and utilisation of on-farm resources to produce solid and liquid formulations (Sharma et al., 2023). The affordability and ecosystem-friendly nature of ZBNF-based inputs make them particularly suitable for marginalized farmers of drylands of India, where conventional inputs may be financially burdensome and less effective due to poor soil conditions (Bharucha et al., 2020; Sharma et al., 2023).

However, despite its such potential benefits, cowpea cultivation has not gained widespread traction in India with only, 0.32 million hectares of area under cultivation and gross production reaching 0.198 million tonnes (Indiastat, 2024). The low-cost input systems such as organic farming and ZBNF have the potential to serve the marginal farming community owing to characteristics such as low cost, low energy intensity, and enhanced productivity of pulse legume crops through supply of substantial organic matter levels. Organic matter supply can boost up food availability for soil microbes and thus enhance the availability of soil nutrients in soil active pool and thus crop productivity. Recognising the benefits of cowpea in north-western drylands, particularly for marginal farming community, it was imperative to explore the cowpea as a potential dry land legume crop, which can serve well in crop rotations with cereals or as contingent crop in dry land ecosystems especially under low-cost input farming. Therefore, this investigation was planned and carried out with the hypothesis that organic inputs alone or in combination with ZBNF-based inputs may sustain cowpea productivity and profitability particularly under rainfed conditions while maintaining soil health. The objectives of the present investigation were to explore the effect of organic nutrient sources based on organic farming and ZBNF system on cowpea productivity, profitability, energetics, and soil biology.

2 Experimental materials and employed methods

2.1 Study site details

The field investigation was carried out during the rainy season of 2019 at a research farm affiliated with Department of Agronomy, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya (CSKHPKV), Palampur. The investigation site was located at a longitude of 76°3′E and a latitude of 32°6′N with an altitude of 1,290.8 m above mean sea level. The study site region falls under the mid-hill sub-humid zone of Himachal Pradesh agro-climatically, characterised by mild summers (March to June) and cool winters (October to February). The predominant soil texture was identified as silty clay loam, categorised within the “Alfisols” order with “Hapludalfs” as the great group. Historically, the field was managed under integrated nutrient management systems involving conjunctive soil application of FYM and chemical fertilisers for maize (rainy season) and fodder oat (winter season) cultivation. Pre-sowing composite sample was derived based on five soil samples collected at random locations within the designated field area from soil depth of 0–15 cm using stainless steel auger.

TABLE 1 Experimental details.

S. No.	Treatment details
Trt1	*Beejamrita* (100 ml kg^{-1} of seed) + *Jeewamrita* (187.5 L ha^{-1})
Trt2	*Beejamrita* (100 ml kg^{-1} of seed) + *GhanaJeewamrita* (250 kg ha^{-1})
Trt3	*Beejamrita* (100 ml kg^{-1} of seed) + *Jeewamrita* (187.5 L ha^{-1}) + *GhanaJeewamrita* (250 kg ha^{-1})
Trt4	FYM (10 Mg ha^{-1})
Trt5	FYM (10 Mg ha^{-1}) + *GhanaJeewamrita* (250 kg ha^{-1})
Trt6	Biofertilizers (PSBs and *Rhizobium* at 10 g kg^{-1} of seed) + FYM (10 Mg ha^{-1}) + Vermiwash
Trt7	Biofertilizers (PSBs and *Rhizobium* at 10g kg^{-1} of seed) + vermicompost (7.5 Mg ha^{-1}) + vermiwash
Trt8	Absolute control

Application method and timings employed; *Beejamrita*: seed inoculation; *Jeewamrita*: soil drenching at 21 days, 42 days, and 63 days after sowing (DAS); *GhanaJeewamrita*: soil application at sowing; FYM: soil application 15 days prior to sowing; biofertilizers: seed inoculation 1 day before sowing; vermicompost: soil application 15 days prior to sowing; vermiwash: soil drenching at 15 DAS, 30 DAS, and 45 DAS (at 1:10).
Units of measurement used: ml, millilitre; kg, kilogram; L, litre; ha, hectare; Mg, megagram; g, gram.

Subsequently, the sample was further taken to the departmental laboratory for comprehensive analysis of soil biological properties. However, post-harvest samples were collected treatment wise, and subsequently stored at 4°C until used for biological analysis.

2.2 Experimental layout

A semi-determinate type cultivar Himachal Lobia-2 (C-519) recommended and released by CSKHPKV for organic farming systems was used in the experiment. The cultivar was selection from the germplasm received from IITA Nigeria through IARI, New Delhi. Biofertilizer cultures, namely, *Rhizobium* and phosphorus-solubilising bacteria (PSBs) and organic inputs such as farmyard manure (FYM), vermiwash, vermicompost, *GhanaJeewamrita*, *Jeewamrita*, and *Beejamrita* were acquired from the Department of Organic Agriculture and Natural Farming, CSKHPKV, Palampur. The experiment employed a randomised complete block design (RCBD) wherein eight treatments were replicated three times for robust validation.

The treatment combinations were formulated based on organic and ZBNF-based input combinations, integrating biofertilizer inoculation and organic inputs, sole application of organic inputs, and a non-inoculated control. The input combinations were formulated to explore the synergistic impact of organic and ZBNF-based inputs over crop productivity and cost effectiveness for cowpea cultivation. Table 1 further elucidates the eight treatment combinations. Gross size of experimental plots was 13.23 m^2 (6.3 m × 2.1 m) wherein 14 rows of cowpea were arranged at a spacing of 45 cm each. The recommended spacing of 45 ×15 cm was used in the experiment.

Before initiation of field investigation, soil was acidic in reaction with pH of 5.38 and organic carbon content of 0.64%, whereas the available nitrogen, phosphorus, and potassium content were 172.30 kg/ha, 21.03 kg/ha, and 248.40 kg/ha, respectively. The land was ploughed using a power tiller followed by manual levelling and layout of the experimental field. The land preparation, experimental layout, and sowing of the crop were carried out on 24 June 2019. Before sowing, the seed was inoculated using biofertilizers and *Beejamrita* at 10 g and 100 ml kg^{-1} of seed, respectively. The sowing was done at a recommended rate (by state agricultural university, i.e., CSKHPKV, Palampur) of 20 kg ha^{-1}. To avoid contamination in non-inoculation-based treatments, the sowing for inoculation-based plots was carried out first. The line sowing and the weeding was carried out manually. The hand weeding carried on 24 July 2019. Except for the pre-sown irrigation, which was carried out on 21 June 2019, no further irrigation was done during the cropping season. Among the plant protection practices, the application of fermented butter milk was done to prevent crop damage following anthracnose infection. The crop was harvested manually on 15 November 2019 using stainless steel sickles.

2.3 Experimental inputs

Beejamrita, a liquid formulation for seed inoculation, was derived through mixing of farm-based inputs such as 5 kg of cow dung, 20 L of water, 5 L of cow urine, 50 g of lime, and a handful of soil serving as the microbial inoculum sourced from the field intended for application of the formulation. The formulation was kept overnight and used for seed treatment the subsequent day. The nutrient composition of the *Beejamrita* is given in Table 2 (Kumar et al., 2023).

TABLE 2 Nutrient concentration for ZBNF based inputs.

S. No.	Input	Nitrogen (%)	Phosphorus (%)	Potassium (%)
1.	*Beejamrita*	0.75	0.15	0.25
2.	*Jeewamrita*	0.3	0.18	0.20
3.	*GhanaJeewamrita*	1.2	1.00	0.70
4.	FYM	0.65	0.36	0.58
5.	Vermicompost	2.9	1.4	1.67
6.	Vermiwash	1.80	2.0	1.30

Jeewamrita, a liquid formulation for soil drenching was derived by mixing the farm available inputs such as 10 kg of cow dung, 2 kg of gram flour, 10 L of cow urine, 2 kg of jaggery, 200 L of water, and a bit of soil from the field where the crop was to be sown. The liquid formulation was hermetically sealed and subjected to a 20-day incubation period, and subsequently, it was used in soil application. The nutrient composition of the *Jeewamrita* is given in Table 2 (Kumar et al., 2023).

GhanaJeewamrita was formulated utilising farm-based inputs such as 100 kg of cow dung, 100 g of jaggery and gram flour, 100 L of cow urine, and a bit of soil from the field to be cultivated serving as a starter inoculum. *GhanaJeewamrita* as a distinguished ingredient was derived by mixing the ingredients using cow urine instead of water. The mixture was spread in the shade and allowed to dry. It was pulverized and spread directly in the soil. The nutrient composition of the *GhanaJeewamrita* is given in Table 2 (Choudhary et al., 2022).

Farm yard manure was prepared using trench method wherein farm and animal shed wastes were put into a trench and allowed to decompose. The farm yard manure had 0.65%, 0.36%, and 0.58% nitrogen, phosphorus, and potassium content, respectively, on dry matter basis.

Vermicompost was prepared using 15 days old cow dung, which was mixed with organic farm waste such as farm litter and crop residues. The vermicompost was prepared using peat method and layer-wise arrangement of raw materials. The earthworm species utilised was *Eudrilus eugienae*. The primary macronutrient composition is given in Table 2.

Vermiwash was prepared using the pitcher method wherein cow dung, biomass, and earthworms were used to prepare vermiwash. The vermiwash has to be utilised at the ratio of 1:10 to water. The nutrient composition of the vermiwash is given in Table 2.

Biofertilizer ready for application cultures of *Rhizobium* and phosphate-solubilising bacteria (PSBs) were procured from Department of Organic and Natural Farming, CSKHPKV, Palampur.

2.4 Data collection

For data collection pertaining to the yield contributing characters of cowpea such as pod count/plant, grain count/pod, and pod weight, five plants were selected randomly for each plot (Rana and Kumar, 2014). Following crop harvest and sun drying for a week, the crop was manually threshed to separate the grains and determine the grain yield. After separating grains, the rest of the biomass was quantified as the straw yield for respective treatments. The biological yield was determined based on summation of grain and straw yields observed for respective treatments (Rana and Kumar, 2014).

The crude protein concentration of the grains was determined by multiplying the total grain nitrogen concentration by 6.25 (Sosulski and Imafidon, 1990), whereas the protein yield was the crop that was derived using the below given Equation 1:

$$\text{Protein yield (kg ha}^{-1}) = \frac{\text{Grain Yield (kg ha}^{-1}) \times \text{Protein concentration (\%)}}{100} \quad (1)$$

The cultivation cost was assessed based on contemporary input market prices (seed, *Beejamrita*, *Jeewamrita*, *GhanaJeewamrita*, FYM, vermicompost, vermiwash, and biofertilisers) and cost of cultural operations (irrigation, land preparation, seed inoculation, sowing, weeding, nutrient application, harvesting, and threshing). The returns for the respective treatments were derived based on yield harvested and the prevailing market prices of cowpea grain and straw.

2.5 Estimation of microbial biomass carbon and microbial biomass nitrogen

Soil microbial biomass carbon (MBC) is an important metric of microbial activity and nutrient cycling potential. The method prescribed for soil MBC determination was by Vance et al., 1987, i.e., fumigation extraction method was employed to determine soil MBC (Debnath et al., 2017). Based on this, 20 g of soil sample was weighed and fumigated with 50 ml of chloroform (ethanol-free) in a desiccator. The samples were then incubated for 24 h and extracted using potassium sulphate, followed by filtering. A similar process was done for the unfumigated sample except the exposure to chloroform. The samples were refluxed using potassium dichromate and heated using an acid mixture. It was then titrated against ammonium ferrous sulphate. To determine soil MBC, the difference in extractable carbon for the unfumigated and fumigated samples was computed.

For the estimation of microbial biomass nitrogen (MBN), 20 ml of K_2SO_4 extract was combined with 10 ml of digestion mixture and 300 mg of zinc powder, left to stand for 2 h. Then, 0.6 ml of 0.19 M $CuSO_4$ and 5 ml of concentrated H_2SO_4 were added, and digestion occurred using a Kjeldatherm digester for 2 h. A boric acid solution of 10 ml was placed in a marked 100-ml Erlenmeyer flask under a steam distillation apparatus. The digested mixture was transferred to the distillation flask, and distillation was initiated. Distillate was titrated with 0.005 M H_2SO_4, and the resulting extractable N was calculated by multiplying 2.22 with the difference of extractable nitrogen in fumigated soil and the unfumigated soil.

2.6 Estimation of dehydrogenase and urease activity

For the estimation of soil dehydrogenase enzymatic activity, the method prescribed by Casida et al. (1964) was employed (Małachowska-Jutsz and Matyja, 2019). Triphenyl tetrazolium chloride (TTC) was added and incubated to the soil sample for 24 h at 30°C. TTC is reduced to red-coloured water-insoluble triphenyl formazan (TPF) by microbial activity. TPF was extracted using methanol and measured spectrophotometrically at a recommended wavelength of 485 nm.

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For the determination of urease enzymatic activity, a fresh sample of 5 mg was placed in a 125-ml of volumetric flask. Following this, a millimetre of urea solution was introduced, and the derived mixture underwent incubation at 37°C for 5 h. Subsequently, 2M of KCl-PMA (potassium chloride-phenyl mercuric acetate) solution was introduced, and the combination was agitated for 1 h. The resulting mixture underwent infiltration using Whatman No. 2 filter paper. Subsequently, 2 ml of the obtained extractant was transferred into a 50-ml volumetric flask. To this, 2M of KCl-PMA solution and 30 ml of colouring agent were added. The amalgam was subjected to boiling using water bath for 30 min, followed by immediate cooling. The red colour of the solution was measured at 527 nm wavelength (Douglas and Bremner, 1970).

2.7 Energy indices

Energies were assessed quantitatively for the variable organic input application-based treatments. Energy inputs or expenses were assessed based on farming operations and inputs involved, whereas the energy outputs were derived using the produce obtained for cowpea. Corresponding energy coefficients (unit basis) were multiplied by the unit quantities utilised or produced to calculate the energy inputs and outputs (Table 3). Followed by this, energy indices for the respective treatments such as energy use efficiency, net energy, energy productivity, and profitability were derived based on equations given below (Mittal et al., 1985; Ram and Verma, 2017; Vijayakumar et al., 2019; Hulmani et al., 2022):

$$\text{Energy Use Efficiency} = \frac{\text{Energy Output}}{\text{Energy Input}} \tag{2}$$

$$\text{Net Energy} = \text{Energy output} - \text{Energy input} \tag{3}$$

$$\text{Energy Productivity (kg/MJ)} = \frac{\text{Cowpea grain yield}}{\text{Energy Input}} \tag{4}$$

$$\text{Energy Profitability} = \frac{\text{Net Energy}}{\text{Input Energy}} \tag{5}$$

2.8 Data analysis

ANOVA was conducted using R-software as prescribed by Gomez and Gomez for RCBD (1984) (Version 4.3.1) (R Core Team, 2023). Parameters analysed include pod count/plant, grain count/pod, grain, straw, biological and protein yield, protein concentration, soil dehydrogenase activity, urease activity, biomass carbon, biomass nitrogen, and pod weight. The normality of the data was determined using Shapiro–Wilk normality test. The *post-hoc* mean separation test employed was Duncan's multiple range test (DMRT). The R-Studio Version 4.3.1 based "agricolae" package was used for the respective data analysis. To determine the relationship between yield contributing characters, yield attributes, quality attributes, and soil biological properties, a Pearson's correlation matrix was generated using "Hmisc" and "ggplot2" packages. The R-Studio Version 4.3.1 based "ggplot2" and "patchwork" packages were employed for data visualisation.

TABLE 3 Energy coefficients.

S. No.	Particulars	Energy coefficients (MJ unit^{-1})	References
1.	**Human power**		
	Field preparation	1.96	Kumar et al. (2021)
	Sowing and seed treatment	1.96	Virk et al. (2017)
	Spraying	1.96	Ram and Verma (2015)
	Cultural practices	1.96	Ram and Verma (2015)
	Harvesting	1.96	Ram and Verma (2015)
	Threshing and winnowing	1.96	Virk et al. (2017)
2.	**Machinery**		
	Tractor	64.8	Kumar et al. (2021)
3.	**Inputs**		
	Seed	14.7	Virk et al. (2017; Kumar et al. (2021)
	FYM	0.3	Ram and Verma (2017)
	Vermicompost	0.5	Ram and Verma (2017)
	Vermiwash	0.1	Ram and Verma (2015)
	GhanaJeewamrita	0.05	Rana (2021)
	Jeewamrita	0.05	Rana (2021)
	Beejamrita	0.05	Rana (2021)
	Biofertilisers (*Rhizobium* and PSB)	10	Virk et al. (2017)
	Fermented butter milk	0.1	Ram and Verma (2015)
4.	**Output**		
	Grain	14.7	Virk et al. (2017)
	Straw	12.5	Virk et al. (2017)

2.9 Weather

Data for weather parameters were recorded from the agro-meteorology laboratory of the Department of Agronomy, CSKHPKV, Palampur (Figure 1). The average weekly rainfall and temperature recorded for the growing season were 56 mm and 21.7°C. The average weekly rainfall for the growing season was above the average during the mid of growing season (July–August), whereas it remained below average for the remaining growing season. The average weekly temperature remained above average for the growing season, except the later part especially after second fortnight of September wherein it decreased continuously for the rest of the growing season.

3 Results

3.1 Yield and yield contributing characters

The application of organic and ZBNF-based natural inputs improved the yield contributing characters substantially (Figures 2, 3). Pod count/plant, grain count/pod, and pod weight were improved to an extent of 3%–55%, 4%–19%, and 4%–27%, respectively, under the influence of treatment-based inputs. Conjunctively applying FYM and *Ghana*Jeewamrita increased the pod count/plant, grain count/pod, and pod weight by 55%, 19%, and 27%, respectively, in comparison to the crop receiving no external supply of organic inputs. Conjoint application of ZBNF-based inputs, i.e., *Beejamrita, GhanaJeewamrita*, and *Jeewamrita*, was found to be responsible for 10%, 10%, and 6% improvements in pod weight, pod count/plant, and grain count/pod as compared to uninoculated control. The impact on yield contributing characters was further reflected in yield levels wherein grain yield improved by 2%–39% under the influence of conjunctive application of FYM and *GhanaJeewamrita*. Similarly, in straw, biological yield increments ranging from 3% to 48% and 3% to 47%, respectively, were observed. ZBNF-based inputs (*Beejamrita, GhanaJeewamrita*, and *Jeewamrita*) (Trt3) when applied in combination improved the grain yield levels by 20% in comparison to control. However, applying only *Beejamrita* and *GhanaJeewamrita* (Trt2) in combination did not improve the grain yield significantly as compared to untreated control.

3.1.1 Protein yield

Protein yield was significantly under the influence of treatments based on organic nutrient inputs. Protein yield varied from 156.3 kg/ha to 236.5 kg/ha wherein the highest protein yield was recorded for the treatment involving application of conjoint application of FYM and *GhanaJeewamrita*. Protein yield was recorded to be improved by 51% in comparison to absolute control under the influence of conjoint application of FYM and *GhanaJeewamrita*. ZBNF-based inputs (*Beejamrita* + *GhanaJeewamrita* + *Jeewamrita*) increased the protein yield by 25% compared to untreated control. Similarly, organic-farming-based inputs (biofertilisers + vermicompost + vermiwash) increased the protein yield by 39%.

3.2 Quality attributes

Protein concentration was significantly affected under the influence of organic nutrient application (Figures 4). Protein concentration was recorded to be varying from 20.4% to 22.1%. The highest protein concentration was recorded to be the highest with the combined application of FYM and *GhanaJeewamrita* (Trt5). Protein concentration improved by 8.6% with the application of FYM and *GhanaJeewamrita* (Trt5). The lowest protein concentration was recorded in absolute control. ZBNF-based inputs (*Beejamrita* + *GhanaJeewamrita* + *Jeewamrita*) (Trt3) increased the protein concentration by 4.6% compared to untreated control. Similarly, organic farming-based inputs (biofertilisers + farm yard manure + vermiwash) increased the protein concentration by 6.4%.

3.3 Soil biological properties

The mean activities of dehydrogenase and urease enzyme were significantly influenced under the influence of treatment-based inputs (Table 4). Dehydrogenase (15.62 µg g^{-1} TPF of soil h^{-1}) and urease activity (52.2 µg g^{-1} urea of soil h^{-1}) were highest with the conjunctive application of FYM and *GhanaJeewamrita*. Similarly, applying FYM and *GhanaJeewamrita* conjunctively

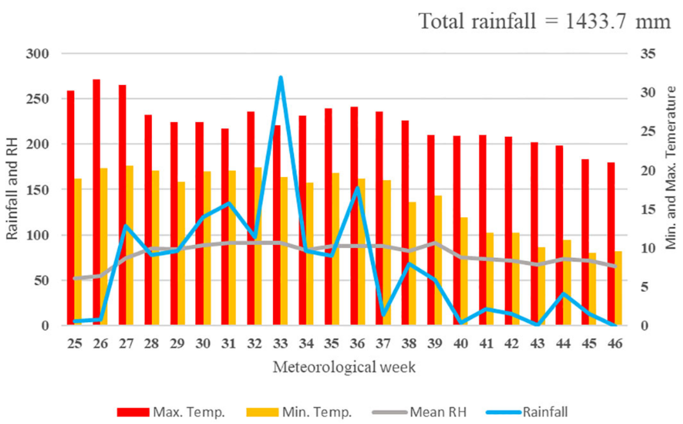

FIGURE 1
Weather parameters for the growing season (June–November).

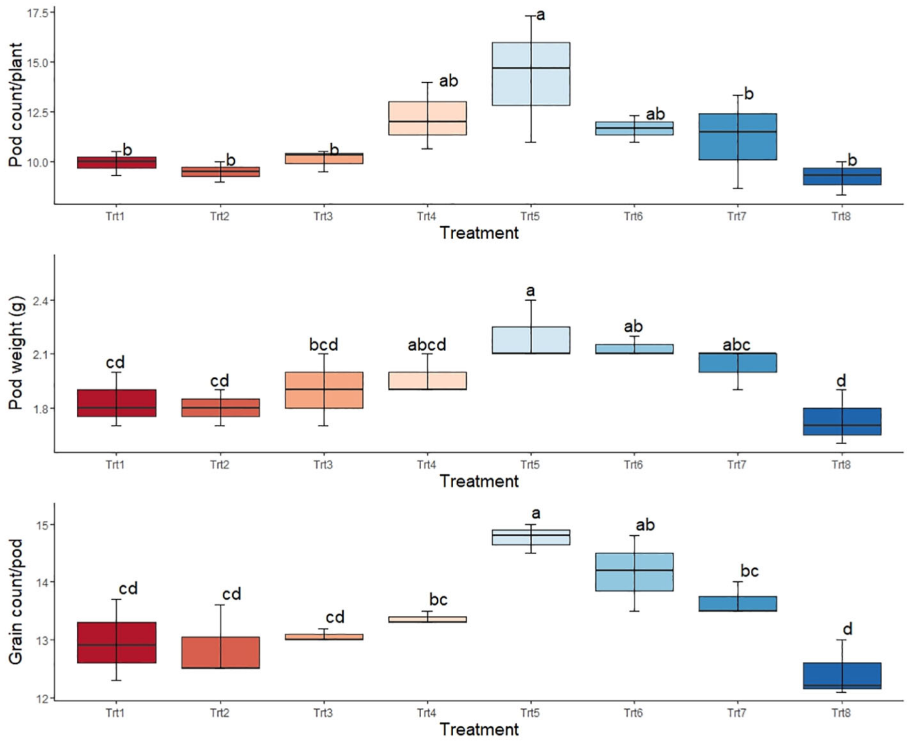

FIGURE 2
Effect of in-combination application of organic nutrient inputs on yield attributes of cowpea. Error bars display associated standard errors. Treatment means with different alphabetical letters are significantly different by DMRT. Trt1, *Beejamrita* (100 ml kg^{-1} of seed) + *Jeewamrita* (187.5 L ha^{-1}); Trt2, *Beejamrita* (100 ml kg^{-1} of seed) + *GhanaJeewamrita* (250 kg ha^{-1}); Trt3, *Beejamrita* (100 ml kg^{-1} of seed) + *Jeewamrita* (187.5 L ha^{-1}) + *GhanaJeewamrita* (250 kg ha^{-1}); Trt4, FYM (10 Mg ha^{-1}); Trt5, FYM (10 Mg ha^{-1}) + *GhanaJeewamrita* (250 kg ha^{-1}); Trt6, biofertilisers (PSBs and *Rhizobium* at 10 g kg^{-1} of seed) + FYM (10 Mg ha^{-1}) + vermiwash (1:10); Trt7, biofertilisers (PSBs and *Rhizobium* at 10 g kg^{-1} of seed) + vermicompost (7.5 Mg ha^{-1}) + vermiwash (1:10); Trt8, absolute control.

resulted in the highest values for MBC (133.92 µg g^{-1} of soil) and MBN (27.4 µg g^{-1} of soil). However, abandoning of organic input application in untreated control was found to be responsible for the lowest mean enzymatic activities of dehydrogenase and urease and the lowest MBC and MBN.

3.4 Economic benefits with organic and natural inputs-based cowpea cultivation

Economic analysis of the data showed that applying organic inputs significantly improved the gross and net margins in comparison to the crop wherein no organic inputs were applied (Table 5). Gross margins ranged from 916.33 to 1,294.65 USD ha^{-1}, whereas the net margins generated ranged from 394.17 to 766.61 USD ha^{-1}. Applying FYM and *GhanaJeewamrita* in combination improved the gross and net margins acquired by 378.32 and 220.88 USD ha^{-1}, respectively, when compared to untreated control. Similarly, conjoint application of ZBNF-based inputs (*Beejamrita* + *GhanaJeewamrita* + *Jeewamrita*) improved the gross and net margins acquired by 17 (158.49 USD ha^{-1}) and 15% (81.24 USD ha^{-1}), respectively. Among organic-farming-based inputs, conjunctive application of FYM, biofertilisers (PSBs and *Rhizobium*), and vermiwash improved the gross and net returns by 289.90 and 137.91 USD ha^{-1}, respectively, when compared to untreated control. Benefit/cost ratio was highest for conjoint application of *Beejamrita* and *Jeewamrita* (2.62) followed by combined application of *GhanaJeewamrita* and FYM (2.45).

3.5 Energy indices

Energies of cowpea cultivation were significantly influenced by various organic inputs (Figure 5). Energy input varied from 926 to 4714 MJ ha^{-1} wherein control (no inputs) recorded the lowest energy input, whereas the biofertiliser + vermicompost + vermiwash-based application had the highest energy expenses. The magnitude for the energy output ranged from 55,921 to 82,161 MJ ha^{-1}. Applying FYM in combination with *GhanaJeewamrita* yielded 47% more energy than control. ZBNF-based input application consumed considerably lesser energy than organic-farming-based inputs. Although net energy gains (78230 MJ ha^{-1}) were significantly higher for conjunctive application of *GhanaJeewamrita* and FYM, energy use efficiency (64.9), profitability (63.9 MJ ha^{-1}), and productivity (0.96 MJ ha^{-1}) were recorded to be substantially higher for conjoint application of *Beejamrita* + *Jeewamrita* + *GhanaJeewamrita*. Contrary to this, the application of biofertiliser + vermicompost +

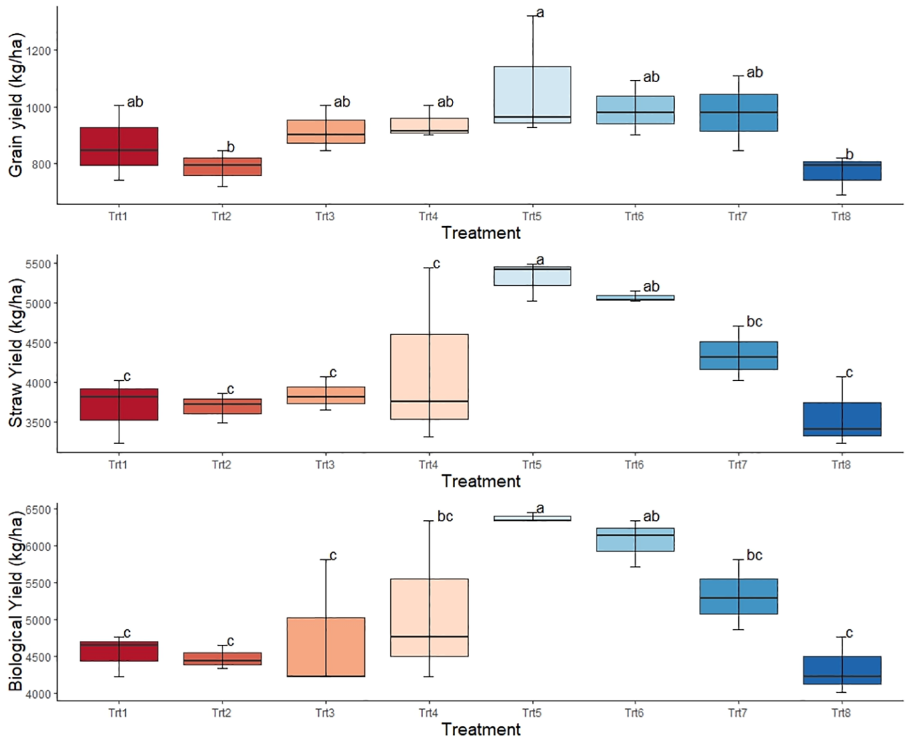

FIGURE 3
Effect of in-combination application of organic nutrient inputs on yield levels of cowpea. Error bars display associated standard errors. Treatment means with different alphabetical letters are significantly different by DMRT. Trt1, *Beejamrita* (100 ml kg^{-1} of seed) + *Jeewamrita* (187.5 L ha^{-1}); Trt2, *Beejamrita* (100 ml kg^{-1} of seed) + *GhanaJeewamrita* (250 kg ha^{-1}); Trt3, *Beejamrita* (100 ml kg^{-1} of seed) + *Jeewamrita* (187.5 L ha^{-1}) + *GhanaJeewamrita* (250 kg ha^{-1}); Trt4, FYM (10 Mg ha^{-1}); Trt5, FYM (10 Mg ha^{-1}) + *GhanaJeewamrita* (250 kg ha^{-1}); Trt6, biofertilisers (PSBs and *Rhizobium* at 10 g kg^{-1} of seed) + FYM (10 Mg ha^{-1}) + vermiwash (1:10); Trt7, biofertilisers (PSBs and *Rhizobium* at 10 g kg^{-1} of seed) + vermicompost (7.5 Mg ha^{-1}) + vermiwash (1:10); Trt8, absolute control.

vermiwash resulted in the lowest energy use efficiency (14.6), profitability (13.6 MJ ha^{-1}) and productivity (0.20 MJ ha^{-1}).

3.6 Correlation studies

Correlation studies for the grain yield, protein concentration, soil biological properties, and energy indices are presented in Figure 6. Grain yield was observed to be positively correlated with protein yield (r=1), dehydrogenase (r=0.92) and urease activity (r=0.94), biomass carbon (r=0.93), nitrogen (r=0.94), and net energy gains (r=0.90). However, a significant but negative correlation was observed across grain yield and energy use efficiency (r=0.79), productivity (r=0.76), and profitability (r=0.79). Soil biological properties such as dehydrogenase (r=0.78) and urease activity (r=0.77), biomass carbon (r=0.81), and nitrogen (r=0.76) were also observed to be positively related to the net energy gains. However, a negative correlation was observed among net energy grains and energy use efficiency (r=–0.71), productivity (r=–0.72), and profitability (r=–0.71).

4 Discussion

Crop productivity potential lies with variable factors such as innate production potential, environment, and the agronomic practices adopted (Mahmood et al., 2022). Among agronomic practices, nutrient inputs play a significant role in sustaining and promoting crop growth and productivity. Leguminous crops or plants prefer organic nutrient sources as opposed to synthetic chemical fertilisers due to the presence of nitrogen fixing bacteria, *Rhizobium*, in their root nodules. The presence of chemical fertilisers might induce salt stress that may lead to comparatively low rhizobacterial population (Ladha et al., 2022). In the present field investigation, conjunctive application of farm yard manure (10 t ha^{-1}) and Ghanajiwamrita (at 250 kg ha^{-1}) resulted in the highest crop yield levels for cowpea. Applying organic inputs in combinations have been observed across several scientific studies to be highly efficient in terms of their benign impact over crop productivity (Avasthe et al., 2016; Singh et al., 2023; Vinutha et al., 2023). The reason is the active influence of higher microbial population resulting in notable enhancement in soil biomass carbon and enzymatic activity. The enhanced microbial activity ensures a steady supply of nutrients from the soil native pool due to solubilisation processes and the mineralisation of the organic inputs (Dey et al., 2019; Choudhary et al., 2022). Enhanced nutrient availability that resulted under the influence of significant elevated microbial activity and nutrient availability might have considerably improved the cowpea yield under the influence of in-combination application of FYM and *GhanaJeewamrita*.

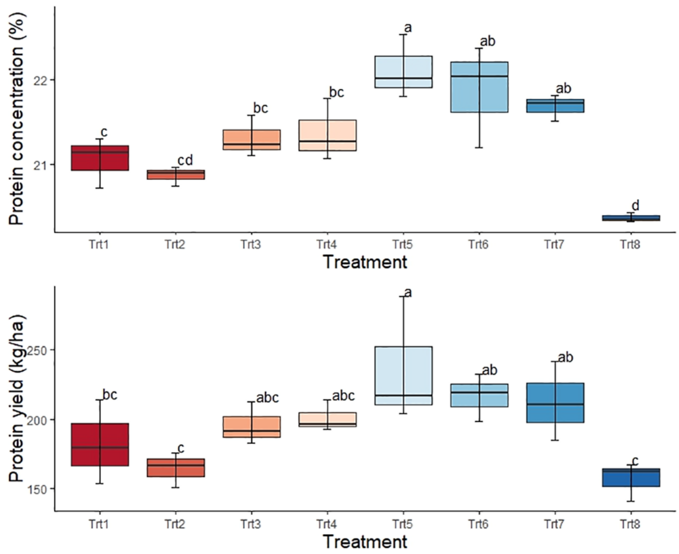

FIGURE 4
Effect of in-combination application of organic nutrient inputs on quality attributes of cowpea. Error bars display associated standard errors. Treatment means with different alphabetical letters are significantly different by DMRT. Trt1, *Beejamrita* (100 ml kg^{-1} of seed) + *Jeewamrita* (187.5 L ha^{-1}); Trt2, *Beejamrita* (100 ml kg^{-1} of seed) + *GhanaJeewamrita* (250 kg ha^{-1}); Trt3, *Beejamrita* (100 ml kg^{-1} of seed) + *Jeewamrita* (187.5 L ha^{-1}) + *GhanaJeewamrita* (250 kg ha^{-1}); Trt4, FYM (10 Mg ha^{-1}); Trt5, FYM (10 Mg ha^{-1}) + *GhanaJeewamrita* (250 kg ha^{-1}); Trt6, biofertilisers (PSBs and *Rhizobium* at 10 g kg^{-1} of seed) + FYM (10 Mg ha^{-1}) + vermiwash (1:10); Trt7, biofertilisers (PSBs and *Rhizobium* at 10 g kg^{-1} of seed) + vermicompost (7.5 Mg ha^{-1}) + vermiwash (1:10); Trt8, absolute control. The treatments were replicated thrice.

A 40% increase in grain yield of cowpea was recorded under the influence of combined application of *GhanaJeewamrita* and FYM as compared to control (uninoculated treatment). Similar result was reported by Choudhary et al. (2022) wherein the integrated organic input application (*GhanaJeewamrita* and *Jeewamrita*) in wheat and gram resulted in 43% and 48% increase in grain yield under the influence of *GhanaJeewamrita* and *Jeewamrita* application. Kour et al. (2021) also reported a 68% increase in cowpea grain yield with the in-combination application of organic farming-based inputs such as FYM, compost, and vermiwash over the untreated control. Improved grain yields were mainly ascribed to cumulative effect of significantly higher yield contributing characters, augmented nutrient supplies, and optimised source–sink relationship in terms of photosynthate supply under the influence of combination application of FYM and *GhanaJeewamrita* (Kumar et al., 2023). Contrary to this, the absence of external input led to drastic reduction in pod weight, pod count/plant, and grain count/pod (Kour et al. 2021). Furthermore, the integration of organic inputs sustains the crop cultivation systems with their benign influence over soil health especially the soil biological properties such as microbial biomass carbon and microbial biomass nitrogen (Choudhary et al., 2022; Gupta et al., 2022). Enzymatic activity especially of dehydrogenase and urease also saw considerable improvements with regular supply of organic substrates (Kumari et al., 2024).

Economic viability of any research outcome significantly influences the probability of its adoption by farmers (Kumar et al., 2023). Economic analysis in the present investigation revealed highest returns under the influence of in-combination application of *GhanaJeewamrita* and FYM owing to significantly higher yield levels observed for the treatment. FYM application has earlier been reported to enhance the gross margins by 30% in cowpea cultivation by Joshi et al. (2016). Singh et al. (2023) also revealed a similar impact of integrated application of FYM with organic inputs on margins acquired under French bean cultivation. Applying vermicompost along with vermiwash and biofertilisers led to second best gross returns; however, the net returns generated declined drastically mainly because of higher cost of vermicompost (Babu et al., 2020). Returns per USD invested were considerably higher for combined application of *Beejamrita* and *Jeewamrita* mainly because of least costs or expenses involved in their production. Thus, owing to low cost of such inputs, their application in dry land farming systems pose a greater potential to uplift the economic status of marginal farmers in Indian drylands.

Organic and ZBNF-based inputs have been characterised as low-energy inputs especially while compared to energy-intensive inorganic inputs (Chmelíková et al., 2021). Considerable higher yield levels with combined application of *GhanaJeewamrita* and FYM must have been responsible for substantially higher energy outputs and net energy gains obtained for the respective input combination. However, in spite of substantially lower energy outputs and net energy gains, ZBNF-based inputs such as *Beejamrita*, *Jeewamrita*, and *GhanaJeewamrita* were observed to be responsible for significantly higher energy use efficiency, productivity, and profitability owing to least energy expenses in their production. ZBNF-based inputs such as *Beejamrita*,

TABLE 4 Effect of application of organic inputs on soil biological properties.

Treatment	Microbial biomass		Enzymatic activity	
	MBC* (µg g^{-1} of soil)	MBN** (µg g^{-1} of soil)	Dehydrogenase (µg g^{-1} TPF of soil h^{-1})	Urease (µg g^{-1} urea of soil h^{-1})
Trt1	122.50^{de} ± 1.389	21.90^{d} ±0.749	3.60^{ef} ± 0.086	44.70^{b} ± 1.008
Trt2	121.37^{de} ± 1.369	21.30^{de} ±0.179	3.33^{f} ± 0.092	43.20^{bc} ± 0.562
Trt3	123.10^{d} ± 1.375	23.70^{c} ±0.404	3.72^{de} ± 0.140	46.10^{b} ± 0.765
Trt4	129.30^{bc} ± 0.937	25.10^{bc} ±0.624	4.15^{c} ± 0.057	50.80^{a} ± 0.630
Trt5	133.92^{a} ± 1.285	27.40^{a} ±0.609	5.21^{a} ± 0.059	52.20^{a} ± 0.702
Trt6	127.80^{c} ± 1.307	24.00^{c} ±0.508	3.97^{cd} ± 0.104	49.20^{a} ± 1.811
Trt7	131.60^{ab} ± 0.750	26.50^{ab} ±0.919	4.83^{b} ± 0.116	51.70^{a} ± 1.017
Trt8	119.00^{e} ± 0.065	19.80^{e} ±0.452	2.81^{g} ± 0.071	41.00^{c} ± 0.999
CD (p=0.05)	3.536	1.754	0.308	3.202
SEm±	1.155	0.573	0.101	1.046
CV	1.586	4.184	4.412	3.824

*MBC, microbial biomass carbon; **MBN, microbial biomass nitrogen.
Parameter data are displayed as mean along with the respective standard errors. Treatment means with different alphabetical letters are significantly different by DMRT. Trt1, *Beejamrita* (100 ml kg−1 of seed) + *Jeewamrita* (187.5 L ha−1); Trt2, *Beejamrita* (100 ml kg−1 of seed) + *GhanaJeewamrita* (250 kg ha−1); Trt3, *Beejamrita* (100 ml kg−1 of seed) + *Jeewamrita* (187.5 L ha−1) + *GhanaJeewamrita* (250 kg ha−1); Trt4, FYM (10 Mg ha−1); Trt5, FYM (10 Mg ha−1) + *GhanaJeewamrita* (250 kg ha−1); Trt6, biofertilisers (PSBs and Rhizobium at 10 g kg−1 of seed) + FYM (10 Mg ha−1) + vermiwash (1:10); Trt7, biofertilisers (PSBs and Rhizobium at 10 g kg−1 of seed) + vermicompost (7.5 Mg ha−1) + vermiwash (1:10); Trt8, absolute control.

Jeewamrita, and *GhanaJeewamrita* being based on renewable and recycled farm wastes or resources conserve a vast amount of energy and thus sustain the crop production systems (Sharma et al., 2023). Organic input-based treatments, although resulted in significantly higher energy outputs and net gains, their efficiency, productivity, and profitability were drastically reduced owing to their substantially higher energy expenses. As such, utilisation of less energy intensive inputs or input combinations will play a vital role in reducing dependence over high-cost and energy-intensive inputs while sustaining crop productivity and profitability levels.

5 Conclusion

The outcomes of the investigation indicate that integrating organic input applications, especially the combination of FYM

TABLE 5 Effect of in-combination application of organic inputs on economic benefits.

Treatment	Economic benefits		
	Gross (USD ha^{-1})	Net (USD ha^{-1})	Benefit/cost ratio
Trt1	1,016.11^{bc} ± 63.136	628.57^{ab} ± 63.138	2.62^{a} ± 0.163
Trt2	941.02^{c} ± 33.125	509.82^{bc} ± 33.124	2.18^{b} ± 0.077
Trt3	1,074.82^{bc} ± 42.282	626.97^{ab} ± 42.281	2.39^{ab} ± 0.094
Trt4	1,113.01^{abc} ± 33.256	621.30^{ab} ± 33.254	2.26^{ab} ± 0.068
Trt5	1,294.65^{c} ± 115.768	766.61^{a} ± 115.768	2.45^{ab} ± 0.219
Trt6	1,206.23^{ab} ± 55.119	683.64^{ab} ± 55.119	2.30^{ab} ± 0.105
Trt7	1,158.98^{ab} ± 83.616	394.17^{c} ± 83.613	1.51^{c} ± 0.109
Trt8	916.33^{c} ± 28.104	545.73^{bc} ± 28.108	2.47^{ab} ± 0.076
SEm±	44.184	44.184	0.086
CD (P=0.05)	135.316	135.316	0.263

*1 USD = 82.57 INR (USD, United States dollar).
Parameter data is displayed as mean data along with respective standard errors. Treatment means with different alphabetical letters are significantly different by DMRT. Trt1- *Beejamrita* (100 ml kg-1 of seed) + *Jeewamrita* (187.5 l ha-1); Trt2- *Beejamrita* (100 ml kg-1 of seed) + *GhanaJeewamrita* (250 kg ha-1); Trt3- *Beejamrita* (100 ml kg-1 of seed) + *Jeewamrita* (187.5 l ha-1) + *GhanaJeewamrita* (250 kg ha-1); Trt4- FYM (10 Mg ha-1); Trt5- FYM (10 Mg ha-1) + *GhanaJeewamrita* (250 kg ha-1); Trt6- Biofertilizers (PSBs and Rhizobium at 10 g kg-1 of seed) + FYM (10 Mg ha-1) + Vermiwash (1:10); Trt7- Biofertilizers (PSBs and Rhizobium at 10 g kg-1 of seed) + Vermicompost (7.5 Mg ha-1) + Vermiwash (1:10); Trt8- Absolute control.

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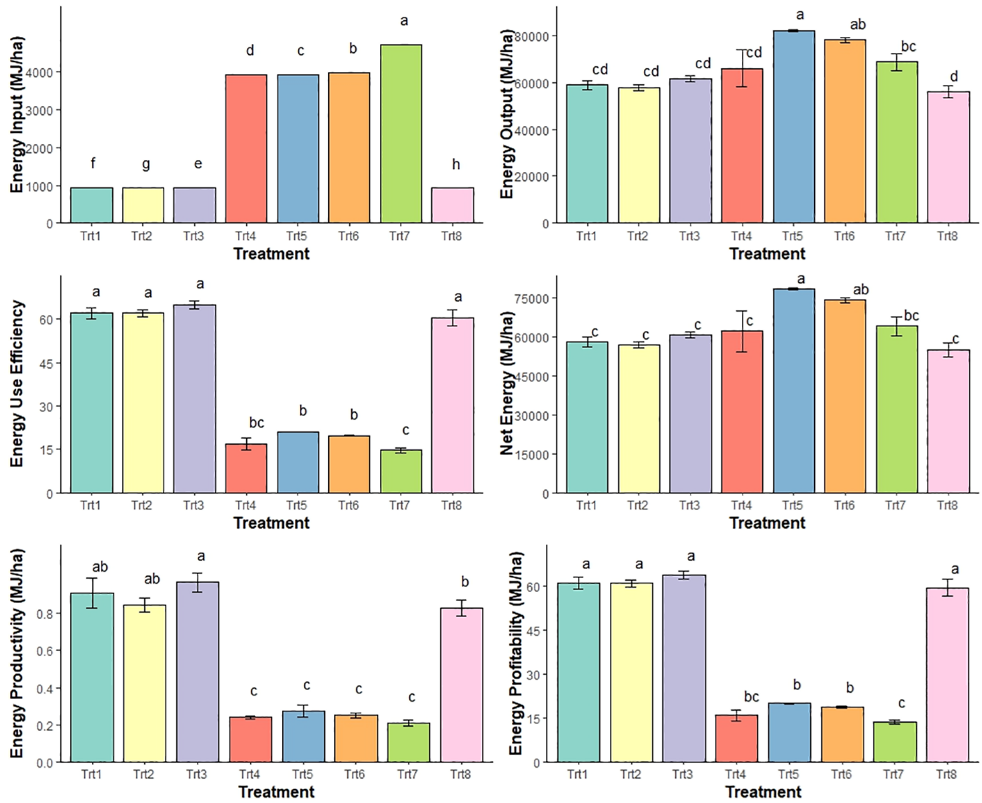

FIGURE 5
Effect of application of organic inputs on energy indices. Error bars display the associated standard error. Treatment means with different alphabetical letters are significantly different by DMRT. Trt1, *Beejamrita* (100 ml kg^{-1} of seed) + *Jeewamrita* (187.5 L ha^{-1}); Trt2, *Beejamrita* (100 ml kg^{-1} of seed) + *GhanaJeewamrita* (250 kg ha^{-1}); Trt3, *Beejamrita* (100 ml kg^{-1} of seed) + *Jeewamrita* (187.5 L ha^{-1}) + *GhanaJeewamrita* (250 kg ha^{-1}); Trt4, FYM (10 Mg ha^{-1}); Trt5, FYM (10 Mg ha^{-1}) + *GhanaJeewamrita* (250 kg ha^{-1}); Trt6, biofertilisers (PSBs and *Rhizobium* at 10 g kg^{-1} of seed) + FYM (10 Mg ha^{-1}) + vermiwash (1:10); Trt7, biofertilisers (PSBs and *Rhizobium* at 10 g kg^{-1} of seed) + vermicompost (7.5 Mg ha^{-1}) + vermiwash (1:10); Trt8, absolute control. The treatments were replicated thrice.

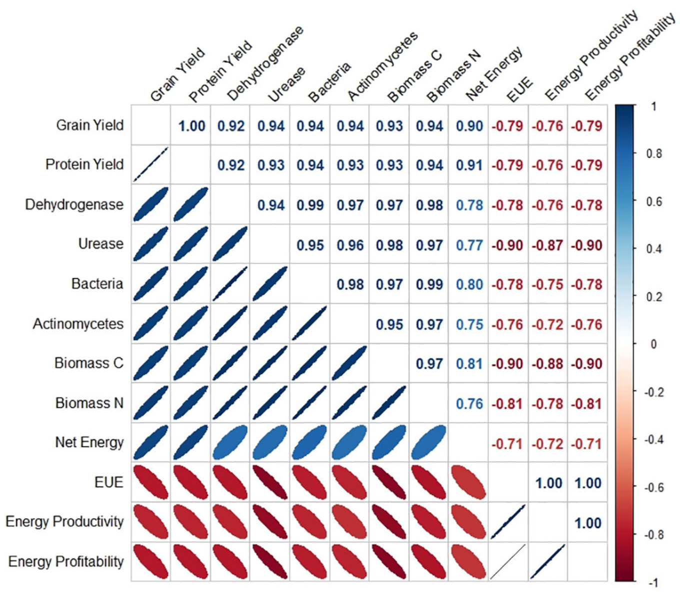

FIGURE 6
Correlation studies among cowpea productivity, quality, energetics, and soil biological properties. Dehydrogenase, dehydrogenase activity; urease, urease activity; biomass C, biomass carbon; biomass N, biomass nitrogen; EUE, energy use efficiency. Red and blue colour indicate negative and positive correlation, respectively.

(10 Mg ha^{-1}) + *GhanaJeewamrita* (250 kg ha^{-1}), significantly enhanced the productivity, profitability, energy gains, and soil biology in cowpea cultivation. The treatment based on conjunctive application of FYM (10 Mg ha^{-1}) + *GhanaJeewamrita* (250 kg ha^{-1}) was the best in terms of cowpea productivity, profitability, and energy gains. The findings strongly suggest that application of FYM (10 Mg ha^{-1}) + *GhanaJeewamrita* (250 kg ha^{-1}) represents a promising organic input strategy for augmenting cowpea productivity and profitability under the agro-ecological conditions of North-Western Himalayas. Diversifying the low cost and energy-intensive organic input applications from cowpea monocropping to cereal-pulse intercropping or other mixed systems can emphasise the benefits of cowpea towards improving farmer's income, food security, and ecosystem health in the future especially taking in consideration the long-term field experiments.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

TS: Data curation, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. JS: Conceptualization, Methodology, Resources, Supervision, Writing – review & editing. SM: Writing – review & editing. PK: Conceptualization, Methodology, Supervision, Writing – review & editing. AS: Formal Analysis, Writing – original draft, Writing – review & editing, Software, Visualization. BR: Data curation, Writing – review & editing. GC: Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Adegbite, E. A., Atere, C. T., and Olayinka, A. (2021). Growth, nitrogen fixation and yields of cowpea (Vigna unguiculata L. Walp) and chemical properties of an acid Alfisol in response to applications of organic amendments and inorganic N. *J. Plant Nutr.* 44, 692–703. doi: 10.1080/01904167.2020.1849291

Avasthe, R. K., Raghavendra, S., and Subhash, B. (2016). Organic pulses production in India: perspectives and opportunities. *Indian J. Agron.* 61, 144–152.

Babu, S., Mohapatra, K. P., Yadav, G. S., Lal, R., Singh, R., Avasthe, R. K., et al. (2020). Soil carbon dynamics in diverse organic land use systems in North Eastern Himalayan ecosystem of India. *Catena* 194, 104785. doi: 10.1016/j.catena.2020.104785

Bharucha, Z. P., Mitjans, S. B., and Pretty, J. (2020). Towards redesign at scale through zero budget natural farming in Andhra Pradesh, India. *Int. J. Agric. Sustainability* 18, 1–20. doi: 10.1080/14735903.2019.1694465

Casida, J. L.E., Klein, D. A., and Santoro, T. (1964). Soil dehydrogenase activity. *Soil Sci.* 98, 371–376. doi: 10.1097/00010694-196412000-00004

Chmelíková, L., Schmid, H., Anke, S., and Hülsbergen, K. J. (2021). Nitrogen-use efficiency of organic and conventional arable and dairy farming systems in Germany. *Nutrient Cycling Agroecosystems* 119, 337–354. doi: 10.1007/s10705-021-10126-9

Choudhary, R., Kumar, R., Sharma, G. D., Sharma, R. P., Rana, N., and Dev, P. (2022). Effect of natural farming on yield performances, soil health and nutrient uptake in wheat+ gram inter cropping system in sub-temperate regions of Himachal Pradesh. *J. Crop Weed* 18, 01–08. doi: 10.22271/09746315.2022.v18.i2.1566

Debnath, S., Patra, A. K., and Purakayastha, T. J. (2017). Assessment of methods for measuring soil microbial biomass carbon in temperate fruit tree-based ecosystems. *Commun. Soil Sci. Plant Anal.* 48, 2534–2543. doi: 10.1080/00103624.2017.1416132

Dey, A., Srivastava, P. C., Pachauri, S. P., and Shukla, A. K. (2019). Time-dependent release of some plant nutrients from different organic amendments in a laboratory study. *Int. J. Recycling Organic Waste Agric.* 8, 173–188. doi: 10.1007/s40093-019-0287-1

Dhunagana, B., Adhikari, A., Regmi, V., Dhungana, S., and Subedi, S. (2022). Effect of organic manures on growth and yield of cowpea in chitwan, Nepal. *Plant Physiol. And Soil Chem.* 2 (2), 66–69. doi: 10.26480/ppsc.02.2022.43.46

Douglas, L. A., and Bremner, J. M. (1970). Extraction and colorimetric determination of urea in soils. *Soil Sci. Soc. America J.* 34, 859–862. doi: 10.2136/sssaj1970.03615995003400060015x

Duddigan, S., Collins, C. D., Hussain, Z., Osbahr, H., Shaw, L. J., Sinclair, F., et al. (2022). Impact of zero budget natural farming on crop yields in Andhra Pradesh, SE India. *Sustainability* 14, 1689. doi: 10.3390/su14031689

Duraipandian, M., Poorani, K. E., Abirami, H., and Anusha, M. B. (2022). Vigna unguiculata (L.) walp: A strategic crop for nutritional security, well being and environmental protection. *Legumes Res.* 2. doi: 10.5772/intechopen.103025

FAOSTAT (2024). *Food and agriculture organization (FAO)*. Available online at: https://www.fao.org/faostat/en/#data/QCL (Accessed 17 February 2024).

Gupta, A., Singh, U. B., Sahu, P. K., Paul, S., Kumar, A., Malviya, D., et al. (2022). Linking soil microbial diversity to modern agriculture practices: A review. *Int. J. Environ. Res. Public Health* 19, 3141. doi: 10.3390/ijerph19053141

Hossain, M. Z., and Sarkar, S. (2021). Effect of organic amendments on the growth, yield and nutrient status of cowpea (Vigna unguiculata (L.) Walp.). *Plant Physiol. Rep.* 26, 535–540. doi: 10.1007/s40502-021-00603-2

Hulmani, S., Salakinkop, S. R., and Somangouda, G. (2022). Productivity, nutrient use efficiency, energetic, and economics of winter maize in south India. *PloS One* 17, e0266886. doi: 10.1371/journal.pone.0266886

Indiastat (2024). Available online at: https://www.Indiastatagri.com/table/cowpea-lobia/selected-state-season-wise-area-production-product/1214823 (Accessed on 17 February 2024).

Joshi, D., Gediya, K. M., Gupta, S., and Birari, M. M. (2016). Effect of organic manures on soil and quality parameters of cowpea [Vigna unguiculata (L.) Walp] under middle Gujarat conditions. *Agric. Sci. Digest-A Res. J.* 36, 216–219. doi: 10.18805/asd.v36i3.11445

Kour, S., Bairwa, H. L., Lakhawat, S. S., and Sharma, S. K. (2021). Effect of organic manures and vermiwash on growth, yield and quality of cowpea [Vigna unguiculata (L.) Walp.] cv. *Pusa Komal. Pharma Innovation J.* 10, 543–548. doi: 10.22271/tpi.2021.v10.i9h.7659

Kumar, R., Kumar, S., Yashavanth, B. S., Venu, N., Meena, P. C., Dhandapani, A., et al. (2023). Natural farming practices for chemical-free agriculture: implications for crop yield and profitability. *Agriculture* 13, 647. doi: 10.3390/agriculture13030647

Kumar, A., Rana, K. S., Choudhary, A. K., Bana, R. S., Sharma, V. K., Prasad, S., et al. (2021). Energy budgeting and carbon footprints of zero-tilled pigeonpea–wheat cropping system under sole or dual crop basis residue mulching and Zn-fertilization in a semi-arid agro-ecology. *Energy* 231, 120862. doi: 10.1016/j.energy.2021.120862

Kumari, M., Sheoran, S., Prakash, D., Yadav, D. B., Yadav, P. K., and Jat, M. K. (2024). Long-term application of organic manures and chemical fertilizers improve the organic carbon and microbiological properties of soil under pearl millet-wheat cropping system in North-Western India. *Heliyon*. 10(3), e25333. doi: 10.1016/j.heliyon.2024.e25333

Kyei-Boahen, S., Savala, C. E., Chikoye, D., and Abaidoo, R. (2017). Growth and yield responses of cowpea to inoculation and phosphorus fertilization in different environments. *Front. Plant Sci.* 8, 646. doi: 10.3389/fpls.2017.00646

Ladha, J. K., Peoples, M. B., Reddy, P. M., Biswas, J. C., Bennett, A., Jat, M. L., et al. (2022). Biological nitrogen fixation and prospects for ecological intensification in cereal-based cropping systems. *Field Crops Res.* 283, 108541. doi: 10.1016/j.fcr.2022.108541

Mahmood, T., Ahmed, T., and Trethowan, R. (2022). Genotype x Environment x Management (GEM) Reciprocity and Crop Productivity. *Front. Agron.* 4, 800365. doi: 10.3389/fagro.2022.800365

Małachowska-Jutsz, A., and Matyja, K. (2019). Discussion on methods of soil dehydrogenase determination. *Int. J. Environ. Sci. Technol.* 16, 7777–7790. doi: 10.1007/s13762-019-02375-7

Mandal, A., Sarkar, B., Mandal, S., Vithanage, M., Patra, A. K., and Manna, M. C. (2020). "Impact of agrochemicals on soil health," in *Agrochemicals detection, treatment and remediation* (Oxford, United Kingdom: Butterworth-Heinemann), 161.

Mittal, V. K., Mittal, J. P., and Dhavan, K. C. (1985). Research project on energy requirements in agriculture sector coordinating cell, Agricultural Engineering, PAU. *Ludhiana*, 62.

Mndzebele, B., Ncube, B., Nyathi, M., Kanu, S. A., Fessehazion, M., Mabhaudhi, T., et al. (2020). Nitrogen fixation and nutritional yield of cowpea-amaranth intercrop. *Agronomy* 10, 565. doi: 10.3390/agronomy10040565

Pahalvi, H. N., Rafiya, L., Rashid, S., Nisar, B., and Kamili, A. N. (2021). Chemical fertilizers and their impact on soil health. *Microbiota Biofertilizers* 2, 1–20. Ecofriendly Tools for Reclamation of Degraded Soil Environs. doi: 10.1007/978-3-030-61010-4_1

Ram, R. A., and Verma, A. K. (2015). Energy input, output and economic analysis of organic production of mango (Mangifera indica L.) cv. Dashehari. *ICAR*. 85 (6), 827–32. doi: 10.56093/ijas.v85i6.49250

Ram, R. A., and Verma, A. K. (2017). Energy input, output and economic analysis in organic production of guava (Psidium guajava) cv. Allahabad Safeda. *ICAR*. 87 (4), 462–6. doi: 10.56093/ijas.v87i4.69339

Rana, B. B. (2021). Phytosociology and diversity of weeds in different cropping systems under natural farming. CSKHPKV, Palampur, India. Ph.D. Thesis.

Rana, S. S., and Kumar, S. (2014). *Research techniques in agronomy* Vol. 64 (Palampur: Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya). doi: 10.13140/RG.2.2.27074.58562

R Core Team (2023). *R: A Language and Environment for Statistical Computing* (Vienna, Austria: R Foundation for Statistical Computing). Available at: https://www.R-project.org/.

Sharma, S., Ravisankar, N., Jain, N., and Sarangi, S. (2023). Natural farming: current status, research and case studies. *Indian Journal of Agronomy* 68, S1:S15. XXII Biennial National Symposium Special issue.

Singh, R., Kumar, A., Babu, S., Avasthe, R., Das, A., Rathore, S. S., et al. (2023). Development of organic nutrients management system for profitable and soil-supportive French bean (Phaseolus vulgaris L.) farming in North Eastern Himalayas, India. *Front. Sustain. Food Syst.* 7, 1115521. doi: 10.3389/fsufs.2023.1115521

Sosulski, F. W., and Imafidon, G. I. (1990). Amino acid composition and nitrogen-to-protein conversion factors for animal and plant foods. *J. Agric. Food Chem.* 38, 1351–1356. doi: 10.1021/jf00096a011

Tripathi, S., Srivastava, P., Devi, R. S., and Bhadouria, R. (2020). "Influence of synthetic fertilizers and pesticides on soil health and soil microbiology," in *Agrochemicals detection, treatment and remediation* (Oxford, United Kingdom: Butterworth-Heinemann), 25–54.

Ulzen, J., Abaidoo, R. C., Ewusi-Mensah, N., and Masso, C. (2020). Combined application of inoculant, phosphorus and organic manure improves grain yield of cowpea. *Arch. Agron. Soil Sci.* 66, 1358–1372. doi: 10.1080/03650340.2019.1669786

United States Department of Agriculture (USDA) (2024). *FoodData central (usda.gov)* (Accessed 17 February 2024).

Vance, E. D., Brookes, P. C., and Jenkinson, D. S. (1987). Microbial biomass measurements in forest soils: the use of the chloroform fumigation-incubation method in strongly acid soils. *Soil Biol. Biochem.* 19, 697–702. doi: 10.1016/0038-0717(87)90051-4

Vijayakumar, S., Kumar, D., Shivay, Y. S., Sharma, V. K., Sharma, D. K., Saravanane, P., et al. (2019). Energy budgeting of aerobic rice (Oriza sativa)-wheat (Triticum aestivum) cropping system as influenced by potassium fertilization. *Indian J. Agric. Sci.* 89, 1911–1915. doi: 10.56093/ijas.v89i11.95341

Vinutha, M., Somasundaram, E., Sanbagavalli, S., Sivakumar, U., Ganesan, K., and Sunitha, R. (2023). Effect of organic and liquid manures on productivity and profitability of blackgram. *Agric. Sci. Digest* 43, 466–471. doi: 10.18805/ag.D-5702

Virk, H. K., Singh, G., and Sharma, P. (2017). Productivity, nutrient uptake, energy indices and profitability of soybean (Glycine max) as influenced by planting methods, Bradyrhizobium and plant growth promoting rhizobacteria. *Indian J. Agron.* 62, 341–347. doi: 10.59797/ija.v62i3.4305

Yahaya, D. (2019). Evaluation of cowpea (Vigna unguiculata (L.) walp) genotypes for drought tolerance. Tennessee State University, Nashville, TN, USA.