PLANT SCIENCE TODAY
Vol 13(sp9): 01-09
https://doi.org/10.14719/pst.15607

eISSN 2348-1900
OPEN ACCESS

Research Article | Agriculture
2026, Volume 13, Issue sp9, pp. 01-09

Productive, profitable and energy-efficient *Brassica juncea* (L.) Czern. based vegetable intercropping system under Northern Telangana zone

K Ramakrishna[1*], Ch Pragathi Kumari[1], Sreedhar Chauhan[1], Sravani Arem[1], Gouraram Manoj Kumar Goud[1], Boppidi Manasa Reddy[1], Sagarla Sowmyasri[1] & G M Imran[2]

[1]Department of Agronomy, Professor Jayashankar Telangana Agricultural University, Rajendranagar, Hyderabad 500 030, Telangana, India

[2]Department of Agronomy, Navsari Agricultural University, Navsari 396 450, Gujarat, India

***Correspondence:** K Ramakrishna, palavaikrishna@gmail.com

Abstract

Brassica juncea (L.) Czern. based intercropping systems offer considerable scope for improving productivity, profitability and resource-use efficiency (RUE) under sustainable agricultural production systems. An experiment was conducted in rabi season 2022 at the Agricultural Research Station, Adilabad, Telangana to test the efficiency of intercropping different vegetables in mustard with different row ratios. A total of 13 treatments comprising sole crops such as mustard, sole root vegetables (radish, beetroot, carrot and potato) and their combination under 2 : 2 and 3 : 3 row ratios were considered in the randomised block design (RBD) of the experiment. It was found that the highest total economic yield (24212 kg ha^{-1}), mustard equivalent yield (5775 kg ha^{-1}), gross returns (₹338968 ha^{-1}), net returns (₹264526 ha^{-1}) and benefit-cost ratio (B : C) ratio (4.55) were obtained from the monocropping of radish. While among intercropping combinations, mustard with radish under 3 : 3 row ratio yielded the highest total economic yield (13515 kg ha^{-1}), mustard equivalent yield (3964 kg ha^{-1}), mustard oil yield (351 kg ha^{-1}), gross returns (₹216033 ha^{-1}), net returns (₹160966) and B : C ratio (3.92). These results were statistically comparable with mustard with radish at ratio 2 : 2. An energetic efficiency analysis concluded that the performance of the mustard with radish (3 : 3 and 2 : 2) was favourable with respect to high energy productivity (0.60 and 0.61 kg MJ^{-1}) and low specific energy (1.66 and 1.63 MJ kg^{-1}) among the intercropping methods. Therefore, mustard intercropping with radish at 3 : 3 and 2 : 2 row ratios could be considered the most beneficial and lucrative intercropping method in northern Telangana. Further multi-season and multi-location studies are required to validate the findings before making broader recommendations.

Keywords: economics; energetics; intercropping; mustard; productivity; radish

Received: 18 May 2026. **Accepted:** 15 September 2026. **Available online:** Version 1.0: 05 November 2026.

Cite this article: Ramakrishna K, Ch Pragathi K, Sreedhar C, Sravani A, Gouraram MKG, Boppidi MR, Sagarla S, Imran GM. Productive, profitable and energy-efficient *Brassica juncea* (L.) Czern. based vegetable intercropping system under Northern Telangana zone. Plant Science Today. 2026;13(sp9):01-09. https://doi.org/10.14719/pst.15607

1. Introduction

Indian agriculture is now faced with the dual challenge of food and nutritional security and ecological sustainability in the context of shrinking land holdings, rising input costs and climate variability (1). Conventional monocropping systems although productive during the green revolution era have displayed increasing limitations in the form of declining soil fertility, reduced biodiversity, deterioration of soil physical properties and inefficient resource utilisation (2, 3). Therefore, diversification of cropping systems through intercropping has emerged as a sustainable strategy for improving productivity, profitability and resource-use efficiency (RUE) under intensive agricultural systems (4).

Brassica juncea (L.) Czern. is one of the important rabi oilseed crops of India grown under diverse agro-climatic conditions and plays an important role in edible oil production (5). Rapeseed-mustard contributes about 28–30 % of the total edible oilseed production in the country and considered as the second most important oilseed crop after soybean (6). However, productivity remains relatively low compared to global standards owing to suboptimal crop management, abiotic stresses and poor RUE (7). In Telangana, mustard cultivation has expanded rapidly in northern districts such as Adilabad, Nirmal and Komaram Bheem Asifabad due to favourable winter temperatures and increasing market demand for edible oils (8). Nevertheless, mustard cultivation under sole cropping often results in inefficient utilisation of available land, solar radiation, nutrients and moisture during early crop growth stages (9). Effective intercropping practices help to achieve better resource partitioning in time and space, thus producing better yields than monoculture practices because of complementary or differential use of available resources by component crops (10). Besides the higher yield, intercropping provides effective weed control, lower incidence of pests and diseases, enhanced biological

activities of the soil and stabilised farm incomes (11). Crop diversification through intercropping system can contribute to sustainable agricultural intensification by increasing production per area while increasing the efficiency of nutrient utilisation by 15–30 % and lowers the dependence on external inputs (12). The selection of component crops is a crucial factor in designing a productive intercropping system. Vegetable-based intercropping systems have gained considerable attention for their potential to improve economic returns and nutritional security. Radish (*Raphanus sativus* L.), carrot (*Daucus carota* L.), beetroot (*Beta vulgaris* L.) and potato (*Solanum tuberosum* L.) are root vegetables with quick initial growth, contrasting root architecture and high market value, which makes them good intercrops with mustard (13). The selected vegetable crops differ in their growth habits, canopy development, crop duration and the nature of their economic produce. Such differences provide opportunities for diversification and more efficient utilisation of available land and growing space. Moreover, vegetable intercrops generate early returns and create employment opportunities compared to sole cropping systems which is particularly important for small and marginal farmers (14). The productivity of intercropping systems is greatly influenced by crop geometry and row arrangement, which determine resource sharing and interspecific competition among component crops (15). Suitable row proportions improve light interception, canopy structure and nutrient utilisation, resulting in higher productivity and RUE (16). This may also help to balance crop competition and complementarity, thereby improving weed suppression, yield and economic returns (17).

With an increasing focus on economic viability and energy conservation in agriculture in recent times, there is a requirement for sustainable measures that increase RUE (18). Higher RUE is typical of intercropping systems because of the effective use of light, water and nutrients (19). Vegetable based intercropping systems are especially efficient since they produce more output energy owing to increased biomass and yields (20). Mustard based intercropping systems under Telangana conditions remain relatively underexplored, particularly with respect to economic viability and energetics of vegetable intercrops. The northern Telangana region has suitable agro-climatic conditions for cultivation of mustard and root vegetables during rabi season. However, scientific information on the best crop combinations and row arrangements is limited. Therefore, this study evaluated the performance of mustard-based vegetable intercropping systems with different row ratios in the Adilabad region of Telangana.

2. Materials and Methods

Description of experimental site and soil characterisation

A field experiment was conducted at Agricultural Research Station, Adilabad, Telangana during the rabi season of 2022. Before sowing, soil samples were collected randomly from 0–15 cm depth and analysed using standard procedures. Bouyoucos hydrometer test revealed sandy clay texture (21). Soil with neutral pH (7.29) and non-saline soil (electrical conductivity (EC) 0.19 dS m^{-1}) were determined in a 1 : 2.5 soil-to-water suspension using a combined electrode pH meter and a digital EC meter, respectively (22). Soil organic carbon content was medium in range as determined by the Walkley and Black method (23). The available nitrogen (N) content was 276 kg ha^{-1} (low), determined by the alkaline potassium permanganate method (24). The available phosphorus content was 49.5 kg ha^{-1} (medium), estimated by Olsen's method (25), while the available potassium content was 432 kg ha^{-1} (high), determined using a flame photometer method (26).

Weather

Meteorological parameters prevailing during the course of the investigation were recorded at the meteorological observatory, Agricultural Research Station, Adilabad. Weather data indicated that mean maximum temperature throughout the crop growth period ranged from 34.2–36 ℃ with an average of 32.24 ℃. The weekly mean minimum temperature during the crop period ranged from 9.2–20 ℃ with an average of 14.32 ℃. Whereas relative humidity during morning hours ranged from 40–84 %, with an average level of 62.1 %. On the other hand, relative humidity in the afternoons was relatively low ranging from 29–72 %, with an average of 50.1 %. The amount of bright sunshine hours ranged between 4.1 and 7.9 h day^{-1}. Precipitation was minimal during this period, ranging from 0.3–0.9 mm. Evaporation ranged between 0.22–2.314 mm day^{-1}, averaging 0.92 mm day^{-1}. Mean wind velocity at this place ranged between 0.08–3.14 km hr^{-1} with average wind velocity of 0.49 km hr^{-1} (Fig. 1).

Experimental treatments and design

In this study, a randomised block design (RBD) was used with three replications and 13 treatment combinations including monocropping and radish, carrot, beetroot and potato intercropping at 2 : 2 and 3 : 3 ratios.

Crop husbandry

Quality seeds of mustard and intercrops were sown manually according to the specifications of the respective treatments (Table 1). Gap filling was carried out 10 days after sowing (DAS), followed by thinning at 15 DAS to retain one healthy plant per hill. Recommended fertiliser doses (60 : 40 : 40 N : P : K) were applied as urea, single superphosphate and muriate of potash; total of 6 irrigations were applied during the growing period. Weeds were controlled by pre-emergence application of pendimethalin 30 % EC at 1 kg active ingredient ha^{-1} followed by hand weedings (intra-row) at 30–35 and 60 DAS, in both inter-crops and the mustard crop. Sucking pests were controlled with acephate 75 % SP at 2 g L^{-1} and white rust was controlled with propiconazole 25 % EC at 1.5 mL L^{-1}.

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.15607

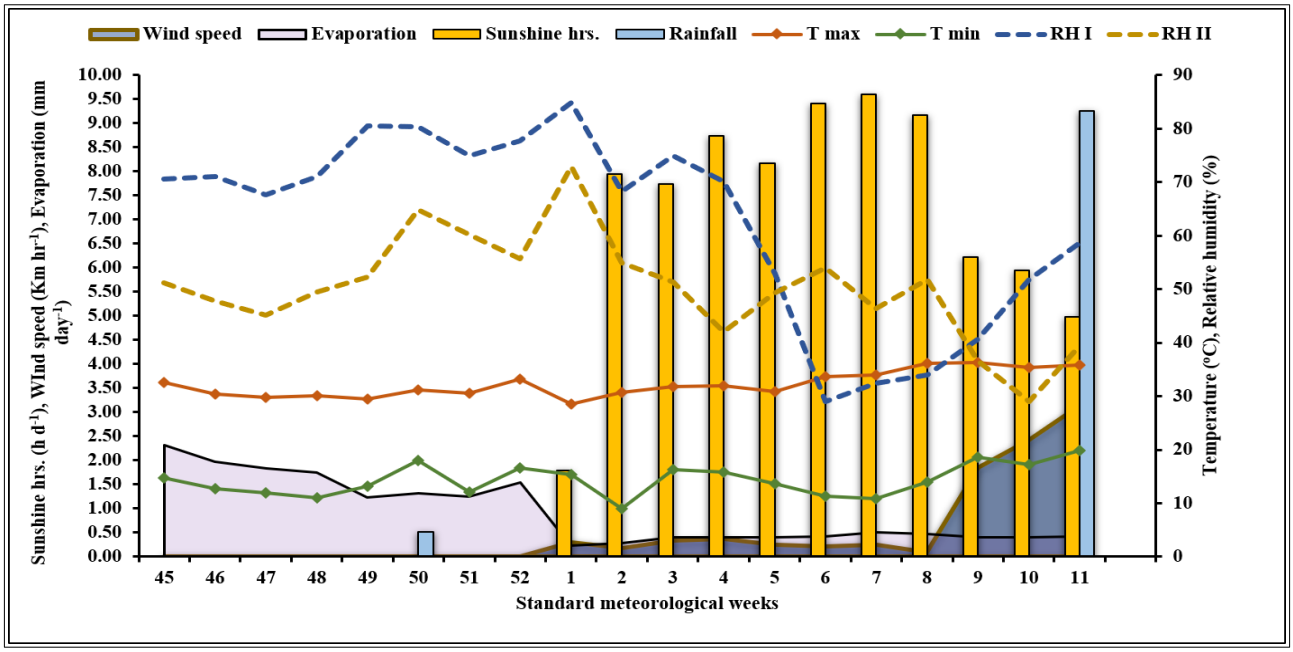


Fig. 1. Weekly meteorological data during the crop growth period at Agricultural Research Station, Adilabad.

Table 1. Agronomic details of the component crops

Crop	Variety	Duration (days)	Seed rate (kg ha^{-1})	Spacing (cm)
Mustard	NRCHB-101	110	6	45 × 20
Carrot	Private hybrid	130	6	45 × 5
Radish	Private hybrid	60	8	45 × 10
Beetroot	Private hybrid	100	10	45 × 10
Potato	Kufri pukhraj	120	3000	45 × 20

Observations

Total economic yield was recorded by summing the main crop/sole crop yield with inter crop yield in each treatment. For straight forward appraisal of individual crop productivity in terms of market profitability, the economic yield of each crop was converted to mustard equivalent yield (MEY) based on the minimum support price (MSP) of mustard for 2022–23 and the local market prices of vegetables, as follows: mustard, ₹54.5 kg^{-1}; radish, ₹13 kg^{-1}; carrot, ₹13 kg^{-1}; potato, ₹10 kg^{-1}; and beetroot, ₹12 kg^{-1}, as given in Eq. 1.

$$\text{MEY (crop a)} = \frac{\text{Yield (crop a)} \times \text{Price (a)}}{\text{Price of base crop}} \quad \text{Eq. (1)}$$

Where:

Yield (a) is the yield of individual crop (a) in kg harvest product ha^{-1},

Price (a) represents the market price of crop (a).

Oil content of mustard seed was estimated by nuclear magnetic resonance (NMR) analyser (27) and was expressed as percentage. Oil yield was calculated by multiplying the oil content (%) in each treatment with corresponding seed yield, as shown in Eq. 2.

$$\text{Oil yield (kg ha}^{-1}) = \frac{\text{Oil content (\%)} \times \text{Seed yield (kg ha}^{-1})}{100} \quad \text{Eq. (2)}$$

Economics

The economic parameters evaluated in the study included an inventory of all inputs with their corresponding prices. Gross returns (₹ ha^{-1}) were calculated based on the income obtained from the economic yield of component crops using prevailing market prices. Net returns (₹ ha^{-1}) were computed by subtracting the total cost of cultivation from the gross returns Eq. 3:

Net returns (₹ ha^{-1}) = Gross returns (₹ ha^{-1}) - Cost of cultivation (₹ ha^{-1}) Eq. (3)

In intercropping systems, gross and net returns were estimated by summing the returns obtained from both main and intercrops. The benefit–cost ratio was determined by dividing gross returns by the total cost of cultivation, as given in Eq. (4).

$$\text{B : C} = \frac{\text{Gross returns (₹ ha}^{-1})}{\text{Cost of cultivation (₹ ha}^{-1})} \quad \text{Eq. (4)}$$

Energetics

A complete inventory of all crop inputs (fertilisers, seeds, plant protection chemicals, fuels, human labour and machinery power) and outputs of both mustard and intercrops yield were recorded. Energy input in different treatments was calculated by multiplying the input with the corresponding energy coefficients and adding up all these (Table 2). The energy output was calculated by multiplying the total (mustard seed yield, root and tuber yield) yield with the corresponding energy coefficient. Net energy, energy use efficiency, energy productivity and specific energy was computed based on the Eq. 5–8.

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.15607

Net energy (MJ ha^{-1}) = Energy output (MJ ha^{-1}) - Energy intput (MJ ha^{-1}) Eq. (5)

$$\text{Energy use efficiency} = \frac{\text{Energy output (MJ ha}^{-1})}{\text{Energy input (MJ ha}^{-1})} \quad \text{Eq. (6)}$$

$$\text{Energy productivity} = \frac{\text{Total yield (kg ha}^{-1})}{\text{Energy input (MJ ha}^{-1})} \quad \text{Eq. (7)}$$

$$\text{Specific energy (MJ kg}^{-1}) = \frac{\text{Energy input (MJ ha}^{-1})}{\text{Total yield (kg ha}^{-1})} \quad \text{Eq. (8)}$$

Table 2. Energy coefficients of inputs and outputs used in study

Inputs	Energy equivalent
Men	1.96 MJ h^{-1}
Women	1.57 MJ h^{-1}
Tractor	64.80 MJ h^{-1}
Nitrogen	60.60 MJ kg^{-1}
Phosphorus	11.10 MJ kg^{-1}
Potassium	6.70 MJ kg^{-1}
Herbicide	288 MJ kg^{-1}
Insecticide	278 MJ kg^{-1}
Sprayer	23.8 MJ h^{-1}
Water	1.02 MJ m^3
Electricity	11.93 MJ kW h^{-1}
Diesel	56.3 MJ l^{-1}
Mustard seed	25 MJ kg^{-1}
Radish seed	0.8 MJ kg^{-1}
Carrot seed	79.45 MJ kg^{-1}
Beetroot seed	50 MJ kg^{-1}
Potato seed	3.6 MJ kg^{-1}
Outputs	
Mustard seed	22.72 MJ kg^{-1}
Mustard stalk	12.5 MJ kg^{-1}
Carrot yield	1.96 MJ kg^{-1}
Beetroot yield	17.1 MJ kg^{-1}
Radish yield	1.6 MJ kg^{-1}
Potato yield	3.6 MJ kg^{-1}

Statistical analysis

Recorded data were subjected to analysis of variance (ANOVA) appropriate for a RBD. Treatment means were compared using the *F*-test at the 5 % level of significance. Where significant differences existed, the least significant difference (LSD) was calculated. Statistical analysis was carried out using OPSTAT software.

3. Results and Discussion

Total economic yield and mustard equivalent yield

The total economic yield and MEY differed significantly among the sole and intercropping systems (Fig. 2). Among all the treatments, radish monocropping registered the highest total economic yield (24212 kg ha^{-1}). It was followed by monocropping of potato (21456 kg ha^{-1}), carrot (20513 kg ha^{-1}) and beetroot (20358 kg ha^{-1}), all of which were significantly superior to mustard monocropping and mustard-based intercropping systems. Monocropping of mustard recorded the lowest total economic yield (1556 kg ha^{-1}), owing to its comparatively lower biomass and economic produce. Among the intercropping systems, mustard with radish (3 : 3) obtained the highest total economic yield (13515 kg ha^{-1}), which was statistically at par with mustard with radish (2 : 2) (13456 kg ha^{-1}), but significantly superior to the remaining mustard-based intercropping systems.

A similar trend was observed in mustard equivalent yield where monocropping of radish provided significantly maximum mustard equivalent yield (5775 kg ha^{-1}). This was followed by monocropping of carrot (4893 kg ha^{-1}), beetroot (4482 kg ha^{-1}) and potato (3937 kg ha^{-1}). Among the intercropping systems, mustard with radish (3 : 3) recorded the highest MEY (3964 kg ha^{-1}), which was statistically at par with mustard with radish (2 : 2) (3933 kg ha^{-1}), but significantly superior to the other intercropping combinations. The mustard with carrot intercropping system noted comparatively higher MEY than mustard with beetroot and mustard with potato systems, indicating better economic advantage due to the higher market price and productivity of carrot. The lowest MEY among intercropping systems was observed in mustard with potato (2 : 2) (2646 kg ha^{-1}).

The superior performance of mustard intercropped with radish could be attributed to the greater compatibility of radish with mustard. Radish has a shorter crop duration and produces marketable roots within a relatively short period; therefore, its early harvest reduces the duration of interspecific competition with mustard. This temporal complementarity may have enabled mustard to utilise available resources more effectively during its later reproductive and seed-filling stages. In contrast, carrot, beetroot and potato remained in the field for longer periods, resulting in prolonged crop overlaps and a greater possibility of competition for available resources (28). Previous studies on mustard-based vegetable intercropping have also highlighted the importance of component crop productivity and intercropping efficiency in determining overall system performance (29). In addition, the 3 : 3 row configurations generally performed better than the 2 : 2 row ratios across crop combinations, suggesting improved and more efficient utilisation of growth resources under closer spatial arrangement (30). Appropriate row arrangements can influence resource sharing and interspecific interactions among component crops, thereby affecting overall productivity (24).

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.15607

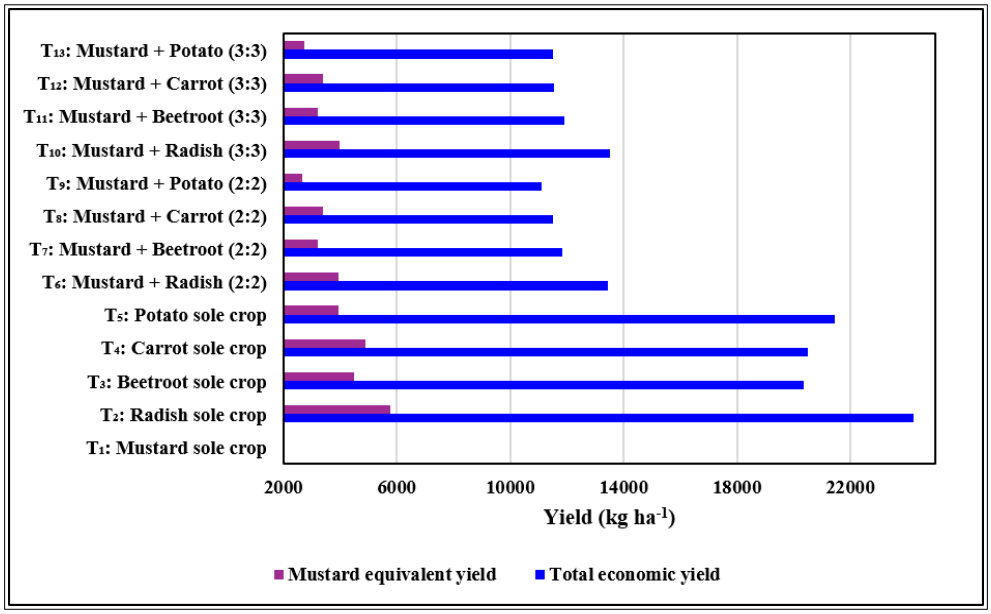


Fig. 2. Effect of mustard intercropping with root vegetables on yield.

Mustard oil content and oil yield

There was no significant influence of intercropping mustard with different root vegetables on oil content (Table 3). Numerically, the highest oil content was exhibited in mustard monocropping (37.0 %), followed by mustard with radish (3 : 3) (36.1 %), mustard with potato (3 : 3) (35.9 %) and mustard with beetroot (3 : 3) (35.8 %). The lowest oil content was observed in mustard with carrot (2 : 2) (34.2 %). The non-significant variation in oil content suggests that competition from the vegetable intercrops was insufficient to affect oil accumulation in mustard seeds. Oil content is largely a genetically governed trait therefore the adopted row arrangements possibly ensured adequate resource availability environment during reproductive growth and seed filling. Similar effects of intercropping and spatial arrangement on mustard oil quality have been reported earlier (30), while variations in oil related traits among *Brassica* species might not solely depend on crop compatibility and spatial arrangement (31).

Table 3. Effect of *Brassica juncea* (L.) Czern. intercropping with root vegetables on mustard oil content and oil yield

Treatments	Oil content (%)	Oil yield (kg ha^{-1})
T_1 - Mustard monocrop	37.0	575
T_6 - Mustard with radish (2 : 2)	35.0	333
T_7 - Mustard withbeetroot (2 : 2)	34.3	260
T_8 - Mustard withcarrot (2 : 2)	34.2	289
T_9 - Mustard withpotato (2 : 2)	34.5	258
T_{10} - Mustard with radish (3 : 3)	36.1	351
T_{11} - Mustard with beetroot (3 : 3)	35.8	275
T_{12} - Mustard withcarrot (3 : 3)	35.6	305
T_{13} - Mustard withpotato (3 : 3)	35.9	271
Sem ±	1.3	11
CD (*P* = 0.05)	NS	32

NS: non-significant.

In contrast, oil yield differed significantly due to variation in seed yield among treatments. Monocropping of mustard generated significantly higher mustard oil yield (575 kg ha^{-1}). Within the intercropping treatments, mustard with radish (3 : 3) produced the maximum oil yield (351 kg ha^{-1}) but remained statistically comparable to mustard with radish (2 : 2) (333 kg ha^{-1}) and mustard with carrot (3 : 3) (305 kg ha^{-1}). The lowest oil yield was recorded in mustard with potato (2 : 2) (258 kg ha^{-1}).The comparatively higher oil yield observed in mustard with radish intercropping system (3 : 3 or 2 : 2) may be attributed to better growth and yield performance of mustard under improved crop complementarity and resource utilisation. Similar findings were reported which observed that intercropping systems significantly influenced oil yield primarily through changes in seed yield rather than oil concentration (32, 33).

Economics

The economic performance of mustard-based root vegetable intercropping systems revealed significant variations in gross and net returns due to differences in cultivation costs (Table 4). The cost of cultivation varied significantly with ranging from ₹35920 ha^{-1} in mustard monocropping to ₹85992 ha^{-1} in potato monocropping. While in intercropping systems, mustard intercropped with potato (2 : 2) attained the highest cultivation cost (₹63492 ha^{-1}) followed by mustard with potato (3 : 3) (₹62292 ha^{-1}). In contrast, mustard with carrot (3 : 3) attained the lowest cultivation cost (₹50692 ha^{-1}) among intercropping treatments.

Monocropped radish produced the highest gross return amounting to ₹338968 ha^{-1}, the net return at ₹264526 ha^{-1} and a B : C ratio of 4.55, which was significantly greater than any other production treatment. This was followed by carrot monocropping, which registered gross returns of ₹266669 ha^{-1}, net returns of ₹193164 ha^{-1} and a B : C ratio of 3.63. Potato and beetroot in monoculture yielded higher gross and net

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.15607

returns than mustard monocropping, owing to their greater marketable yield and economic value. Whereas monocropping of mustard resulted in lowest gross returns (₹84802 ha^{-1}) and net returns (₹48882 ha^{-1}), with a comparatively lower B : C ratio of 2.36.

In case of economic returns of intercropping, radish intercropped in mustard at 3 : 3 ratio produced the highest gross returns (₹216033 ha^{-1}), net returns (₹160966 ha^{-1}) and B : C ratio (3.92), which was statistically comparable with 2 : 2 ratio (₹214353 ha^{-1}, ₹157986 ha^{-1} and 3.80, respectively). This was followed by carrot intercropped in mustard (3 : 3) with gross returns of ₹185620 ha^{-1}, net returns of ₹134927 ha^{-1} and a B : C of 3.66, followed closely by mustard with carrot intercropping (2 : 2). In contrast, mustard with potato intercropping systems at 3 : 3 and 2 : 2 ratio revealed comparatively lower profitability despite higher cultivation costs.

The higher economic profitability under vegetable intercropping attributed to better utilisation of space, rapid crop growth and higher marketable yield than sole cropping (34). Mustard with radish intercropping improved spatial arrangement in the 3 : 3 row ratios might have enhanced crop complementarity and minimised interspecific competition, thereby increasing overall system profitability (35, 36). Early marketable yield of radish, which provided substantial additional returns with comparatively lower cultivation costs. The comparable performance of the 2 : 2 and 3 : 3 row ratios indicate good compatibility between mustard and radish under both spatial arrangements. Similarly, it was observed that higher economic efficiency and better land use advantage in vegetable based intercropping systems (37, 38). In contrast, the lower profitability of mustard with potato systems may be due to the comparatively higher cultivation cost and input requirements of potato.

Energetics

Energy balance studies are important to make improvements that will lead to a more efficient and eco-friendly production system. In the study, energy parameters differed significantly among the sole and intercropping systems (Table 5). Energy input was highest in monocropping of potato (33536 MJ ha^{-1}), which was significantly superior to all other treatments. Among intercropping systems, mustard with potato (2 : 2) and mustard with potato (3 : 3) achieved comparatively higher energy inputs of 30309 and 29229 MJ ha^{-1}, respectively. In contrast, radish monocropping consumed the lowest energy input (19043 MJ ha^{-1}).

Table 4. Effect of *Brassica juncea* (L.) Czern. intercropping with root vegetables on economics

Treatments	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	Benefit-cost ratio
T_1 - Mustard monocrop	35920	84802	48882	2.36
T_2 - Radish monocrop	74442	338968	264526	4.55
T_3 - Beetroot monocrop	76867	244296	167429	3.18
T_4 - Carrot monocrop	73505	266669	193164	3.63
T_5 - Potato monocrop	85992	214560	128568	2.50
T_6 - Mustard with radish (2 : 2)	56367	214353	157986	3.80
T_7 - Mustard with beetroot (2 : 2)	54992	174379	119387	3.17
T_8 - Mustard with carrot (2 : 2)	51992	184539	132547	3.55
T_9 - Mustard with potato (2 : 2)	63492	144227	80735	2.27
T_{10} - Mustard with radish (3 : 3)	55067	216033	160966	3.92
T_{11} - Mustard with beetroot (3 : 3)	53792	175368	121576	3.26
T_{12} - Mustard with carrot (3 : 3)	50692	185620	134927	3.66
T_{13} - Mustard with potato (3 : 3)	62292	148733	86441	2.39
SEm ±	-	10482	6822	
CD (p = 0.05)	-	30924	20125	

Table 5. Energetics as influenced by *Brassica juncea* (L.) Czern. intercropping with root vegetables

Treatments	Input (MJ ha^{-1})	Output (MJ ha^{-1})	Net energy (MJ ha^{-1})	Energy use efficiency	Energy productivity (kg MJ^{-1})	Specific energy (MJ kg^{-1})
T_1 - Mustard monocrop	22420	84227	61807	3.76	0.07	14.41
T_2 - Radish monocrop	19043	38739	19696	2.03	1.27	0.79
T_3 - Beetroot monocrop	23236	348122	324886	14.98	0.88	1.14
T_4 - Carrot monocrop	23212	40205	16993	1.73	0.88	1.13
T_5 - Potato monocrop	33536	77242	43706	2.30	0.64	1.56
T_6 - Mustard with radish (2 : 2)	21960	69619	47659	3.17	0.61	1.63

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.15607

T_7 - Mustard with beetroot (2 : 2)	22407	230269	207862	10.28	0.53	1.89
T_8 - Mustard with carrot (2 : 2)	22496	64001	41505	2.84	0.51	1.96
T_9 - Mustard with potato (2 : 2)	30309	77484	47175	2.56	0.37	2.73
T_{10} - Mustard with radish (3 : 3)	22386	70490	48104	3.15	0.60	1.66
T_{11} - Mustard with beetroot (3 : 3)	22407	231266	208859	10.32	0.53	1.88
T_{12} - Mustard with carrot (3 : 3)	22622	64436	41814	2.85	0.51	1.96
T_{13} - Mustard with Potato (3 : 3)	29229	84227	54998	2.88	0.39	2.54
SEm ±	1051	5426	0.24	5220	0.007	0.381
CD (p = 0.05)	3102	16008	0.73	15399	0.020	1.125

Energy output varied markedly among treatments, with beetroot monocrop registered significantly maximum output energy (348122 MJ ha^{-1}). Among the intercropping treatments, mustard with beetroot (3 : 3) and mustard with beetroot (2 : 2) showed higher energy outputs of 231266 and 230269 MJ ha^{-1}, respectively. Consequently, monocropping of beetroot also reflected the highest energy use efficiency (14.98) and net energy (324886 MJ ha^{-1}), followed by mustard with beetroot systems. The lowest energy use efficiency was observed in carrot monocropping (1.73), while mustard monocropping exhibited the highest specific energy (14.41 MJ kg^{-1}) indicating greater energy requirement per unit biomass production.

Energy productivity was highest in monocropping of radish (1.27 kg MJ^{-1}), followed by carrot and beetroot (0.88 kg MJ^{-1}) reflecting better biomass production per unit energy input. Among the intercropping systems, mustard with radish (2 : 2) marked the highest energy productivity (0.61 kg MJ^{-1}), which was closely followed by mustard with radish (3 : 3) (0.60 kg MJ^{-1}). Lower specific energy values in radish and beetroot-based systems indicated more efficient conversion of input energy into biological output. Intercropping systems exhibited higher energy use efficiency and net energy due to greater biomass production and higher output energy relative to energy invested as compared to sole cropping system (39). Root vegetable crops generally produce substantial biological yield with efficient conversion of input energy into output energy (40). The exceptionally high energy output and energy-use efficiency of the mustard-beetroot intercropping systems may be attributed primarily to the high biological and economic yield of beetroot. Beetroot produces a substantial quantity of energy-rich roots (energy coefficient in Table 2), which contributed considerably to the total output energy of the system. The relatively high output energy obtained from beetroot, compared with the energy invested in cultivation, resulted in greater net energy and energy-use efficiency. On the other hand, mustard intercropping with radish in 3 : 3 and 2 : 2 reported higher energy productivity and less specific energy due to shorter crop duration, requiring a fewer energy intensive inputs and field operations than longer duration crops which produced higher conversion of energy into economic output (41).

4. Conclusion

The present investigation revealed that use of root vegetable crops in mustard-based intercropping systems was more effective compared to mustard monoculture farming in terms of productivity and use of resources. In comparison with all the other combinations studied, the combination of mustard grown in intercropping with radish using a row ratio of 3 : 3 and 2 : 2 proved to be the most suitable intercropping system with respect to mustard equivalent yield, oil yield, economics and energy efficiency in the agroclimatic conditions of Northern Telangana. These results must be further studied in long-term before recommendation.

Practical implications

The results are particularly relevant to farmers in Northern Telangana, where mustard is grown during the rabi season and diversification by intercropping with a short-duration crop such as radish can provide additional income from the same land area. Early maturity and marketable yield of radish offer earlier returns, while its compatibility with mustard can improve system productivity, profitability and energy-use efficiency. However, further multi-season and multi-location studies are needed to validate consistency and wider applicability.

Acknowledgements

The authors extend sincere thanks to the College of Agriculture and Agricultural Research Station, Adilabad for smooth conduct of the experiment. This work was funded under the postgraduate studies by the Prof. Jayashankar Telangana Agricultural University.

Authors' contributions

KR conducted the experiment and prepared the manuscript. CPK and SC helped in study formulation, supervised research and evaluated the manuscript. SA, GMKG and GMI helped in data analysis and manuscript drafting. BMR and SS assisted in data analysis and proof reading. All authors read and approved the final manuscript.

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.15607

Compliance with ethical standards

Conflict of interest

Authors do not have any conflict of interests to declare.

Ethical issues

None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Grammarly in order to rectify the grammar mistakes. After using this tool/service, the authors reviewed and edited the content as needed and takes full responsibility for the content of the publication.

References

1. Birthal PS. Towards sustainable transformation of agri-food system in India: challenges and policy imperatives. Agric Econ Res Rev. 2025;38(1):7–17. https://doi.org/10.1177/09713441251389677
2. Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, et al. Solutions for a cultivated planet. Nature. 2011;478(7369):337–42. https://doi.org/10.1038/nature10452
3. Bhattacharyya R, Ghosh BN, Mishra PK, Mandal B, Rao CS, Sarkar D, et al. Soil degradation in India: challenges and potential solutions. Sustainability. 2015;7(4):3528–70. https://doi.org/10.3390/su7043528
4. Lithourgidis AS, Dordas CA, Damalas CA, Vlachostergios DN. Annual intercrops: an alternative pathway for sustainable agriculture. Aust J Crop Sci. 2011;5(4):396–410.
5. ICAR-Directorate of Rapeseed-Mustard Research. Vision 2050. Bharatpur: ICAR-Directorate of Rapeseed-Mustard Research; 2015.
6. Kumar V, Sharma AK, Yogi RK, Singh VV. Rapeseed-mustard cultivation in India: national overview and regional insights with reference to Madhya Pradesh. J Oilseeds Brassica. 2025;16(2):149–57. https://doi.org/10.56093/job.v16i2.172304
7. United States Department of Agriculture. Oilseeds: world markets and trade. Washington, DC: United States Department of Agriculture; 2023.
8. Madhukar P, Rao PM, Srikanth T, Thirupathi I, Reddy KM, Karthik D, et al. Impact analysis of front-line demonstrations on mustard crop in northern zone of Telangana, India. Plant Arch. 2025;25(2):260912. https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-2.331
9. Rhaman MS, Awal MA, Shelley IJ. Interception and use of solar radiation in mustard/grass pea intercropping. Int J Plant Soil Sci. 2016;12(6):1–3. https://doi.org/10.9734/IJPSS/2016/27936
10. Brooker RW, Bennett AE, Cong WF, Daniell TJ, George TS, Hallett PD, et al. Improving intercropping: a synthesis of research in agronomy, plant physiology and ecology. New Phytol. 2015;206(1):107–17. https://doi.org/10.1111/nph.13132
11. Li C, Hoffland E, Kuyper TW, Yu Y, Zhang C, Li H, et al. Syndromes of production in intercropping impact yield gains. Nat Plants. 2020;6(6):653–60. https://doi.org/10.1038/s41477-020-0680-9
12. Martin-Guay MO, Paquette A, Dupras J, Rivest D. The new green revolution: sustainable intensification of agriculture by intercropping. Sci Total Environ. 2018;615:767–72. https://doi.org/10.1016/j.scitotenv.2017.10.024
13. Ramakrishna K, Kumari CP, Chauhan S, Prakash TR. Growth and yield attributes of mustard as influenced by mustard-based vegetable intercropping systems. Int J Environ Clim Change. 2023;13(10):3340–6. https://doi.org/10.9734/ijecc/2023/v13i103002
14. Singh RJ, Pande KK, Sachan VK, Singh NK, Sahu RP, Singh MP. Productivity, profitability and energy consumption of potato-based intercropping systems. Int J Veg Sci. 2016;22(2):190–9. https://doi.org/10.1080/19315260.2014.1003632
15. Shao Z, Hu S, Fan C, Meng Z, Yan X, Ji W, et al. Optimizing row ratio configurations for enhanced productivity and resource-use efficiency in maize-alfalfa intercropping. Plants. 2025;14(24):3846. https://doi.org/10.3390/plants14243846
16. Mucheru-Muna M, Pypers P, Mugendi D, Kung'u J, Mugwe J, Merckx R, et al. Staggered maize-legume intercrop arrangement robustly increases crop yields and economic returns in the highlands of Central Kenya. Field Crops Res. 2010;115(2):132–9. https://doi.org/10.1016/j.fcr.2009.10.013
17. Shyamsunder B, Menon DS, Walia DU, Prasanna T, Raju GS, Nawabpet P. Effect of intercropping wheat (*Triticum aestivum* L.) with mustard (*Brassica juncea*) on yield and economics under organic system of cultivation. Int J Environ Agric Biotechnol. 2024;9(2):218–23. https://doi.org/10.22161/ijeab.92.24
18. Pretty J, Benton TG, Bharucha ZP, Dicks LV, Flora CB, Godfray HC, et al. Global assessment of agricultural system redesign for sustainable intensification. Nat Sustain. 2018;1(8):441–6. https://doi.org/10.1038/s41893-018-0114-0
19. Mandal KG, Saha KP, Ghosh PK, Hati KM, Bandyopadhyay KK. Bioenergy and economic analysis of soybean-based crop production systems in central India. Biomass Bioenergy. 2002;23(5):337–45. https://doi.org/10.1016/S0961-9534(02)00058-2
20. Biswas S, Das R, Jana K, Puste A. Integrated nutrient management on oat+grasspea intercropping system: an evaluation of system productivity, economics, energetics and carbon footprint. Sci Rep. 2024;14(1):19414. https://doi.org/10.1038/s41598-024-66107-9
21. Piper CS. Soil and plant analysis. New York: International Science Publisher; 1966. p. 47–9.
22. Jackson ML. Soil chemical analysis. New Delhi: Prentice-Hall of India Private Limited; 1973. p. 400–3.
23. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 1934;37(1):29–38. https://doi.org/10.1097/00010694-193401000-00003
24. Subbiah BV, Asija GL. A rapid procedure for the estimation of available nitrogen in soils. Curr Sci. 1956;25(8):259–60.
25. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. Washington, DC: US Department of Agriculture; 1954. USDA Circular 939.
26. Muhr GR. Soil testing in India. New Delhi: US Agency for International Development, Mission to India; 1963.
27. Tiwari PN, Gambhir PN, Rajan TS. Rapid and nondestructive determination of seed oil by pulsed nuclear magnetic

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.15607

resonance technique. J Am Oil Chem Soc. 1974;51(3):104–9. https://doi.org/10.1007/BF00000023

28. Singh T, Rana KS, Satapathy BS. Productivity, compatibility and economics of mustard (*Brassica juncea*) and lentil (*Lens esculenta*) intercropping system as influenced by moisture conservation practices and fertility levels under rainfed conditions. Indian J Agric Sci. 2014;84(6):770–3. https://doi.org/10.56093/ijas.v84i6.41486

29. Ramakrishna K, Pragathi Kumari C, Chauhan S, Ram Prakash T, Inuganti K, Vijay Kumar S, et al. Evaluation of intercropping indices in mustard-based vegetable intercropping systems. Plant Arch. 2026;26(1):2208–12. https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.1.305

30. Tripathy S, Meena SL, Dhar S, Paul S, Singh S. Effect of row ratios and organic nutrient management on productivity and economics of Indian mustard (*Brassica juncea*) + chickpea (*Cicer arietinum*) intercropping system. Indian J Agric Sci. 2023;93(10):1067–72. https://doi.org/10.56093/ijas.v93i10.140083

31. Ramarao, Chandranath HT, Babalad HB, Hegde Y. Growth, yield and oil quality of mustard in chickpea (*Cicer arietinum*) and mustard (*Brassica juncea* L.) intercropping system under different row ratio in northern transition zone of Karnataka. Indian J Agric Res. 2020;54(3):322–8. https://doi.org/10.18805/IJARe.A-5453

32. Hosseinifarahi M, Abdipour M, Keladary A, Rashidi L. Evaluation of some morphological traits, essential oil content and land equivalent ratio in different intercropping patterns of mustard (*Brassica nigra* L.) with lavender (*Lavandula angustifolia* L.). Iran J Hortic Sci Technol. 2021;22(3):227–42.

33. Kaur M, Sardana V, Sharma P. Impact of intercropping of canola oilseed rape (*Brassica napus*) and Ethiopian mustard (*Brassica carinata*) with Indian rape (*Brassica rapa* var. toria) on productivity, economics and competitive indices. J Oilseeds Res. 2016;33(1):26–32. https://doi.org/10.56739/jor.v33i1.139035

34. Kumawat R, Shivran AC, Bijarnia A, Yadav BD, Choudhary HS. Yield, nutrient concentration, uptake and quality of mustard (*Brassica juncea*) and lentil (*Lens esculenta*) intercropping system influenced by different fertility levels. J Pharmacogn Phytochem. 2020;9:777–80.

35. Favacho FS, Lima JSS, Bezerra F, Silva JN, Barros AP. Productive and economic efficiency of carrot intercropped with cowpea-vegetable resulting from green manure and different spatial arrangements. Rev Cienc Agron. 2017;48:337–46. https://doi.org/10.5935/1806-6690.20170039

36. Kumar P, Siddiqui MZ, Prajapati SK, Singh S, Kumar A, Rawat DK. Study of the most suitable combination of intercropping systems of Indian mustard (*Brassica juncea* L.) with chickpea, lentil, linseed and field pea. Int J Environ Clim Change. 2023;13(11):3777–89. https://doi.org/10.9734/ijecc/2023/v13i113557

37. Choudhary SK, Singh RN, Upadhyay PK, Singh RK, Choudhary HR, Vijay P. Effect of vegetable intercrops and planting pattern of maize on growth, yield and economics of winter maize (*Zea mays* L.) in Eastern Uttar Pradesh. Environ Ecol. 2014;32(1):101–5.

38. Singh UK, Gangwar B, Srivastava H. Effect of mustard based intercropping systems on yield and profitability under organic management in Bundelkhand region. Indian J Ecol. 2023;50(3):627–30.

39. Meena LR, Kumar D, Meena SR, Kochewad SA, Meena AK. Energy budgeting of different cropping sequences in the Indian Upper Gangetic Plains. Indian J Agric Res. 2024;58(Special Issue):1053–62. https://doi.org/10.18805/IJARe.A-6320

40. Sahoo DC, Muralidharan P. Energy budgeting of different land management practices under common vegetable crops in the Nilgiris of South India. Indian J Soil Conserv. 2017;45(2):130–5.

41. Monshi MH, Mouri MH, Mim MR, Hossain S, Alom J, Hossain MS. Productivity and profitability analysis of cauliflower as sole and intercropping with red amaranth and radish leafy vegetable. Trop Agric Res Ext. 2023;26(4):303–17. https://doi.org/10.4038/tare.v26i4.5686

Additional information

Peer review: Publisher thanks the Sectional Editor and anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information: Available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy.

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting.

Copyright: © The Author(s). This is an open-access article distributed under the Creative Commons Attribution License CC BY 4.0.

Publisher information: Plant Science Today is published by Horizon e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.

https://doi.org/10.14719/pst.15607