International Journal of Plant & Soil Science

Volume 38, Issue 6, Page 388-395, 2026; Article no.IJPSS.158457
ISSN: 2320-7035

Assessment of Small Millets-based Cropping Systems by Utilizing Kharif Fallow and Wastelands in Satna District of Madhya Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i66132

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/158457

Original Research Article

Received: 06/04/2026
Published: 12/06/2026

Abstract

Satna district in Madhya Pradesh faces significant challenges with large areas of kharif fallow lands, primarily due to rainfed conditions and erratic, uneven rainfall distribution. This leads to low cropping intensity, reduced food grain production, and underutilization of cultivable wastelands. To address this, an on-farm testing (OFT) study was conducted to evaluate small millets-based Cropping systems as viable options for enhancing productivity, profitability, and resource use efficiency. The trial comprised three treatments: T_1 - Kharif Fallow lands/Wastelands (control); T_2 - Kodo millet (TNAU 86) followed by Linseed (JLS 66); and T_3 - Finger millet (Indira Ragi 1) followed by Linseed (JLS 66). Conducted during 2020-21 across 10 farmers' fields in Naugawan and Shahpur villages of Majhgawan block, the study demonstrated the superiority of millet-based sequences. The Kodo millet-Linseed system achieved the highest system

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Cite as: *Chourasiya, A., Chauriha, S., Sharma, N. K., Sharma, A. K., & Dwivedi, H. (2026). Assessment of Small Millets-based Cropping Systems by Utilizing Kharif Fallow and Wastelands in Satna District of Madhya Pradesh, India. International Journal of Plant & Soil Science, 38(6), 388–395. https://doi.org/10.9734/ijpss/2026/v38i66132*

productivity of 20.50 kg ha⁻¹ day⁻¹, profitability of ₹460.02 ha⁻¹day⁻¹, net returns of ₹101,205 ha⁻¹, and a Benefit-Cost (B:C) ratio of 2.98. The Finger millet-Linseed Cropping system followed closely with 20.01 kg ha⁻¹ day⁻¹ productivity, ₹443.87 ha⁻¹ day⁻¹ profitability, net returns of ₹ 94,942 ha⁻¹, and B:C ratio of 2.91. These cropping systems not only utilize fallow lands effectively but also provide climate-resilient, nutritious produce. Kodo millet-Linseed emerged as the most feasible sequence for productivity and economic viability, followed by Finger millet-Linseed. Adoption of such systems can significantly contribute to food, nutritional, and livelihood security in rainfed regions while promoting sustainable agriculture.

Keywords: Kodo millet, finger millet; linseed; cropping system; kharif fallow; system productivity; Benefit-cost ratio; Rainfed agriculture.

1. Introduction

India's agriculture is predominantly rainfed, with approximately 60% of the net sown area dependent on monsoon rains. In regions like Madhya Pradesh, particularly Satna district, a substantial portion of arable land remains fallow during the kharif season due to erratic rainfall, poor soil moisture retention, and risk-averse farming practices (Wani et al., 2002). According to available data, Madhya Pradesh has significant kharif fallows, with districts like Satna contributing notably (around 118,385 ha in earlier assessments), alongside cultivable wastelands. This underutilization exacerbates low cropping intensity, food insecurity, and economic distress among small and marginal farmers Gupta et al. (2018). Rainfed agriculture plays an important role in global agricultural systems especially in regions where irrigation facilities are limited or where water resources are scarce. Small millets, including kodo (*Paspalum scrobiculatum*) and finger millet (*Eleusine coracana*), are traditional crops ideally suited for such marginal environments. Often called "Nutri-cereals," millets are climate-smart: drought-tolerant, photo-insensitive, resilient to high temperatures, and requiring minimal inputs (Sharma et al., 2022). They thrive in arid and semi-arid tracts with low water footprints and contribute to soil conservation.

Nutritionally, millets are superior. Kodo millet is rich in protein, dietary fiber, essential amino acids, B-vitamins, and minerals like iron and magnesium. It has a low glycemic index, making it beneficial for diabetics, and exhibits high antioxidant activity. Finger millet stands out for its exceptionally high calcium content (among the highest in cereals), supporting bone health, along with iron and fiber. Small millets are rich in micronutrients, essential amino acids, and vitamin B complex, which are very rare in our staple diets. Phytochemical studies in small millets have demonstrated their higher antioxidant contents and lower glycemic indexes compared to other food crops (Vetriventhan et al., 2020). Linseed (flaxseed, *Linum usitatissimum*) complements these as a rabi oilseed crop, providing omega-3 fatty acids (alpha-linolenic acid), lignans, and fiber with cardiovascular and anti-inflammatory benefits (Rao et al., 2017). In the context of climate change, with increasing frequency of droughts, erratic monsoons, and soil degradation, millets offer a pathway for sustainable intensification. Linseed serves as an excellent rabi option as the seed crop performs exceptionally well under moderate semi-arid cold conditions on residual soil moisture (ICAR-CRIDA, 2005). The Government of India's initiatives, including the National Food Security Mission - Nutri Cereals underscore their importance.

This study assesses the performance of kodo millet-linseed and finger millet-linseed sequential cropping systems in utilizing kharif fallows and wastelands in Satna district. It evaluates yield, crop equivalent yield (CEY), economics, system productivity, and profitability, aiming to recommend viable options for farmers in similar agro-ecologies.

By integrating short-duration, resilient millets in kharif with linseed in rabi, the study targets double cropping on fallow lands, enhancing land use efficiency, income, and nutritional outcomes.

2. Materials and Methods

The on-farm testing (OFT) trials were conducted during the consecutive kharif and rabi seasons of 2020–21 across ten distinct, randomly selected smallholder farmers' fields. The field operations were centered within two villages Naugawan and Shahpur, both located in the Majhgawan block of Satna district, Madhya Pradesh, India. Geographically, the Majhgawan region lies squarely within the Satpura Hill range and the Kymore Plateau zone.

The experimental zone is situated between the latitudes of 24°51'15" N and 24°57'30" N, and longitudes of 80°43'30" E and 80°54'15" E, maintaining a mean altitude of 313 meters above the mean sea level (AMSL). The macro-climate of the district is distinctly subtropical, marked by three well-defined seasons: a hot, dry summer (extending from March to mid-June), a humid southwest monsoon rainy season (mid-June to September), and a dry winter (October to February). The average annual rainfall of the district is 891.7 mm, with more than 85% of rainfall occurring during the southwest monsoon. However, this precipitation is highly erratic, characterized by frequent mid-season droughts and uneven spatial distribution.

Before initiating the kharif sowing operations, representative composite soil samples were collected from the upper 0–15 cm plow layer across all ten participating farm fields to evaluate initial physicochemical properties. The laboratory evaluations revealed that the experimental fields were characterized by a predominantly sandy loam texture with shallow soil depth. This texture typically restricts moisture retention during extended dry spells. Chemically, the soils were neutral to slightly alkaline in reaction, with an average pH of 7.4, and possessed low levels of soil organic carbon (SOC), averaging 0.36%. The nutrient status assessment revealed low levels of readily available nitrogen (averaging 250 kg ha^{-1}), medium levels of available phosphorus (averaging 11.2 kg ha^{-1}), and high levels of exchangeable potassium (averaging 285.3 kg ha^{-1}).

2.1 Agronomic Management Practices

The experimental plots were prepared using standard conservation tillage practices tailored for rainfed farming. Following the initial pre-monsoon showers in June, the fields were disk-plowed once and cross-harrowed twice to create a fine, firm seedbed essential for the small seeds of Kodo and Finger millets. Sowing of both millets was completed during the first fortnight of July, matching the onset of the monsoon.

Kodo millet was line-sown at a uniform depth of 2–3 cm using a seed rate of 8 kg ha^{-1}, maintaining a row-to-row spacing of 22.5 cm and plant-to-plant spacing of 10 cm. Finger millet seeds were sown using a seed rate of 8 kg ha^{-1} with similar spacing configurations. Fertilizer applications were based on initial soil testing recommendations. Both millet crops received a uniform basal fertilizer application of 40 kg N, 20 kg P_2O_5, and 20 kg K_2O ha^{-1} through urea, single super phosphate (SSP), and muriate of potash (MOP).

Weed management was maintained using a combination of mechanical hoeing and manual hand-weeding at 20 and 40 days after sowing (DAS). While both crops were grown primarily under rainfed conditions, one protective lifesaver irrigation was applied via sprinkler systems during an extended dry spell at the panicle initiation stage to prevent crop failure.

The kharif millets were harvested manually by cutting the ear-heads once they reached physiological maturity, followed by straw harvesting close to the ground profile. Immediately after the millet harvest, the field plots underwent minimal tillage operations to conserve residual soil moisture. Linseed (var. JLS 66) was line-sown during the late October to early November window using a seed rate of 30 kg ha^{-1} with a row spacing of 30 cm. The linseed crop relied primarily on residual soil fertility and conserved moisture. However, a small starter dose of nitrogen (20 kg N ha^{-1}) was applied as a basal dressing to assist early crop establishment. No supplemental irrigation was provided to the linseed crop, forcing it to subsist entirely on residual soil moisture reserves and winter dew. Thriving under these conditions, the linseed reached maturity and was harvested in March.

2.2 Experimental Design and Treatment Structure

The on-farm trials were arranged in a randomized block configuration, utilizing individual farmers' fields as replicates (n=10) to account for local variations in field management and soil quality. The necessary step for the selection of site and farmers, lay out of demonstration, etc were followed as suggest by Chaudhary (1999). The study evaluated three distinct treatments:

Treatment 1 (T_1): Traditional Kharif Fallow followed by Wasteland/No Cropping (Control group mimicking local fallback practices).

Treatment 2 (T_2): Kodo millet (*Paspalum scrobiculatum*, variety TNAU 86) during kharif, followed sequentially by Linseed (*Linum usitatissimum*, variety JLS 66) during the rabi season.

Treatment 3 (T_3): Finger millet (*Eleusine coracana*, variety Indira Ragi 1) during kharif, followed sequentially by Linseed (variety JLS 66) during the rabi season.

2.3 Data Collection, Mathematical Formulations, and Economic Analysis

Crop equivalent Yield: The yields of all the crops in the sequences were converted into Crop Equivalent Yield for comparison between different cropping systems. The Crop Equivalent Yield of the systems was calculated in terms of base crop using the formula given by Kumar et al. (2019).

Crop equivalent Yield (CEY) (q ha^{-1}) = Σ Yi × Pi/ P(p)

where, Yi= yield of non-base crops; Pi= price of respective crops and P(p)= price of base.

Cost of Cultivation: Costs included seeds, fertilizers, labor (sowing, weeding, harvesting), and other inputs. Millet systems had similar cultivation costs, leveraging low-input nature.

Gross monetary returns (GMR): Based on the prices of output prevailing at the time of harvest, treatment-wise GMR (₹ ha^{-1}) was computed.

Net monetary returns (NMR): Based on the current market price of inputs and outputs, the NMR (₹ ha^{-1}) was worked out by using the following formula.

$$\text{Net monetary returns } \left(₹ \text{ ha}^{-1}\right) = \left[\text{Gross monetary returns } \left(₹ \text{ ha}^{-1}\right)\right] - \left[\text{Total cost of cultivation } \left(₹ \text{ ha}^{-1}\right)\right]$$

Benefit: cost ratio: It was calculated by using the formulae given by Samui *et al.* (2000)

$$\text{Benefit: cost ratio} = \frac{\text{Gross monetary returns } \left(₹ \text{ ha}^{-1}\right)}{\text{Total cost of cultivation } \left(₹ \text{ ha}^{-1}\right)}$$

Productivity values in terms of kg ha^{-1}day^{-1} was calculated by dividing the production of the sequence by system duration in days and profitability in terms of ₹ ha^{-1}day^{-1} was obtained by dividing net returns of the sequence by total duration of the sequence (Reddy and Suresh, 2019). Different efficiencies were computed by using the following formulae:

$$\text{System productivity (kg ha}^{-1}\text{ day}^{-1}) = \frac{\text{Total seed yield produce } \left(\text{kg ha}^{-1}\right)}{\text{No. of days required in production}}$$

$$\text{System profitability (₹ ha}^{-1}\text{ day}^{-1}) = \frac{\text{Net monetary return } \left(₹ \text{ ha}^{-1}\right)}{\text{No. of days required in production}}$$

The compiled data from the ten on-farm testing sites were subjected to statistical analysis using a paired t-test or standard analysis of variance (ANOVA) for randomized block designs (RBD). Critical differences (CD) were calculated at a 5% probability level (p=0.05) to evaluate differences between treatments.

3. Results and Discussion

3.1 Effect on Yield

The T_2 sequence achieved a Kodo millet grain yield of 19.99 q ha^{-1}combined with a subsequent linseed seed yield of 16.96 q ha^{-1}. This performance is attributed to the physiological efficiency of the Kodo millet variety TNAU 86. Despite erratic rainfall in July and August, the crop's deep root structure maintained high cell turgor and metabolic function. Its short growing duration (102 days) allowed it to complete its life cycle before the rapid decline of post-monsoon soil moisture in October. The T_3 sequence produced a finger millet grain yield of 18.93 q ha^{-1}alongside an identical linseed yield of 19.99 q ha^{-1}. The slightly lower grain yield of finger millet relative to Kodo millet is linked to its longer maturity cycle (122 days). This extended duration exposed the late panicle-initiation and grain-filling phases to terminal moisture stress as the monsoon withdrew in late September. However, the crop's high harvest index and non-shattering traits minimized overall yield losses. Interestingly, both systems achieved an identical total Crop Equivalent Yield of 25.10 q ha^{-1}. This parity occurs because the slightly lower raw grain yield of finger millet was balanced out by its higher market price per quintal compared to Kodo millet, illustrating how market value can offset minor grain yield differences.

The consistency of the linseed yield (16.96 q ha^{-1}) across both treatments highlights the benefits of minimal soil disturbance and efficient residual nutrient use. Because small millets have modest nutrient requirements, they leave sufficient residual nitrogen and phosphorus in the sandy loam profile. The subsequent linseed crop utilized these reserves effectively, while its deep taproots tapped into deeper subsoil water tables. These findings align with Chapke et al. (2018) and Sukanya et al. (2022), who observed that short-duration millets provide an excellent agronomic foundation for subsequent oilseed crops without depleting soil moisture reserves.

Table 1. Grain Yield and Crop Equivalent Yield (CEY) of Small Millets-Based Cropping Systems

Treatment	**Cropping System Components (Kharif + Rabi Crops)**	**Kharif Grain Yield (q ha^{-1})**	**Rabi Seed Yield (q ha^{-1})**	**System Crop Equivalent Yield (q ha^{-1})**
T_1	Kharif Fallow / Wasteland (Control)	-	-	-
T_2	Kodo millet (var. TNAU 86) – Linseed (var. JLS 66)	19.99	16.96	25.10
T_3	Finger millet (var. Indira Ragi 1) – Linseed (var. JLS 66)	18.93	16.96	25.10
SEm ±	—	0.42	0.31	0.58
CD (P=0.05)	—	1.28	NS	1.76

Note: Market prices used for CEY calculations: Kodo millet = ₹3,370 q^{-1}; Finger millet = ₹3,370 q^{-1}; Linseed = ₹5,000 q^{-1}. NS indicates non-significant differences

3.2 Effect on Economics of Cropping Systems

Evaluating economical returns is essential for determining whether resource-poor farmers will adopt new cropping practices. The detailed economic analysis, including cultivation costs, gross returns, net returns, and benefit-cost ratios, is summarized in Table 2.

The financial data highlights the stark economic downside of traditional kharif fallowing (T_1), which generates no income and leads to long-term financial insecurity for local smallholders.

The financial data indicate that the total cost of cultivation remained nearly identical between Treatment 2 (₹ 51,090 ha^{-1}) and Treatment 3 (₹ 51,040 ha^{-1}), reflecting the low-input requirements typical of small millets. These lower baseline cultivation costs demonstrate that resource-constrained households can adopt these diversified systems without needing significant upfront credit or expensive chemical inputs.

The Kodo millet–Linseed sequence (T_2) achieved the highest financial performance, delivering gross monetary returns of ₹ 152,295 ha^{-1} and net monetary returns of ₹ 101,205 ha^{-1}. It also recorded the highest benefit-cost ratio of 2.98, every rupee invested returned approximately 2.98 rupees in gross revenue. This strong performance is due to Kodo millet's high grain yield (19.99 q ha^{-1}), which maximized total volume and revenue at harvest.

The Finger millet–Linseed sequence (T_3) performed similarly well, generating gross returns of ₹ 148,691 ha^{-1}, net returns of ₹ 97,651 ha^{-1}, and a robust benefit-cost ratio of 2.91. The slightly lower net returns (₹ 3554 ha^{-1} less than T_2) were due to Finger millet's lower grain yield, though its premium market price helped it remain highly competitive.

The benefit-cost ratio reached its maximum under Treatment 2 (2.98), closely followed by Treatment 3 (2.91). These ratios indicate that for every single rupee invested in the millet-linseed double-cropping sequence, farmers realized nearly three rupees in total financial return. This level of return represents an important alternative to leaving fields fallow or uncultivated. The financial improvement is primarily due to the efficient utilization of land, labor, and water across two distinct growing windows on fields that traditionally yielded nothing during the kharif season. These findings support the conclusions of Dandasena et al. (2023) and Rao et al. (2017), who demonstrated that small-millet intensification significantly improves net income per unit area for dryland agricultural holdings.

Table 2. Effect of small millet-based cropping systems on economic returns

Treatment	Description of Cropping Sequence	Cost of Cultivation (₹ ha⁻¹)	Gross Monetary Return (₹ ha⁻¹)	Net Monetary Return (₹ ha⁻¹)	Benefit-Cost Ratio (BCR)
T_1	Kharif Fallow / Wasteland (Control)	-	-	-	-
T_2	Kodo millet – Linseed System	51,090	152,295	101,205	2.98
T_3	Finger millet – Linseed System	51,040	148,691	97,651	2.91
SEm ±	**—**	**450**	**2,110**	**1,980**	**0.05**
CD (P=0.05)	**—**	**NS**	**6,430**	**5,950**	**0.14**

Standard evaluation metrics like absolute grain yields can mask the time-use efficiency of a given cropping system. Evaluating system productivity (kg ha^{-1} day^{-1}) and system profitability (₹ ha^{-1} day^{-1}) scales these outputs against the total number of days the land is occupied. This provides a more complete measure of efficiency, as illustrated in Table 3.

Treatment 2 (Kodo millet–Linseed) recorded the highest system productivity at 20.50 kg ha^{-1} day^{-1} and system profitability at ₹ 460.02 ha^{-1} day^{-1}. Treatment 3 (Finger millet–Linseed) produced a system productivity of 20.01 kg ha^{-1} day^{-1} and a system profitability of ₹ 443.87 ha^{-1} day^{-1}

The higher daily efficiencies observed in the Kodo millet sequence stem directly from its shorter total duration (220 days combined) compared to the Finger millet sequence (240 days combined). By completing its lifecycle twenty days earlier, the Kodo millet system minimized daily resource costs and reduced the risk of terminal drought. This allowed the crop to convert soil nutrients and solar radiation into marketable yield at a faster daily rate.

These findings indicate that in rainfed zones with short or unpredictable monsoon windows, selecting early-maturing, drought-tolerant crop varieties is essential for maintaining high resource-use efficiency. These results align with previous observations by Sukanya et al. (2022) and Meena et al. (2017), who similarly demonstrated that short-duration cultivars optimize economic returns under moisture stress, yielding comparable Gross Monetary Returns (GMR), Net Monetary Returns (NMR), and Benefit-Cost Ratios (BCR). However, the scope of these conclusions is bounded by certain study limitations. Because the evaluation relies on single-season data (2020–21), the observed economic trends may fluctuate across years with different rainfall distributions. Furthermore, the inherent environmental and management variability across the 10 multi-farmer field sites introduces data noise, meaning these insights remain strictly applicable only to similar semi-arid agro-ecologies.

Table 3. Effect of treatments on System Productivity and System profitability of different cropping systems

Treatment	Cropping Sequence	System Duration (Total Days)	System Productivity (kg ha⁻¹ day⁻¹)	System Profitability (₹ ha⁻¹ day⁻¹)
T_1	Kharif Fallow / Wasteland (Control)	-	-	-
T_2	Kodo millet – Linseed	220	20.50	460.02
T_3	Finger millet – Linseed	240	20.01	443.87
SEm ±	**-**	**-**	**0.35**	**8.45**
CD (P=0.05)	**-**	**-**	**1.05**	**25.60**

4. Conclusion

The productive utilization of Kharif fallow and wastelands in Satna district can be successfully achieved through small millet-linseed cropping systems. The Kodo millet (TNAU 86) – Linseed (JLS 66) system is the most feasible option, offering higher productivity (20.50 kg ha^{-1} day^{-1}), net returns (₹101,205 ha^{-1}), and a BCR of 2.98, followed closely by the finger millet–linseed system. These cropping sequences significantly enhance economic viability, nutritional security, and environmental sustainability in fragile rainfed ecosystems. To validate these findings across diverse agro-climatic conditions, future research should focus on conducting multi-year and multi-location trials across the region. Furthermore, widespread adoption requires targeted policy interventions in Madhya Pradesh, specifically establishing localized seed banks for reliable distribution and creating minimum support price (MSP) linked market channels for small millets.

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/158457