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Optimization of Mulching Practices for Enhanced Productivity of Linseed under Ber-Based Agri-Horti System in Budelkhand region

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Abstract

*Water scarcity and soil degradation are major challenges to sustainable agricultural productivity in the semi-arid Bundelkhand region of central India. Mulching has emerged as an effective agronomic intervention for conserving soil moisture, suppressing weed growth, and improving overall crop productivity; however, comprehensive information regarding the comparative efficiency of various mulching materials on linseed (*Linum usitatissimum *L.) within an ber-based agri-horti system remains limited. A field experiment was conducted to study the effect of different types of mulch on linseed under ber-based agri-horti system at Forestry Research Farm of Banda University of Agriculture and Technology, Banda, Uttar Pradesh, during the* rabi *season. The experiment was conducted in a Randomized Block Design with nine treatments, which are replicated thrice. Control (T_0), Paddy straw (T_1), Wheat straw (T_2), Kans grass (T_3), Doob grass (T_4), lemon grass (T_5), White polythene (T_6), Black polythene (T_7), and Mustard straw (T_8), each applied at 5 tons per hectare. The linseed variety "Buat-4" was sown as an intercrop in a ber (*Ziziphus mauritiana *L.). The orchard was established under the CEDA Project with a spacing of 6 m × 6 m. Black polythene mulch (T_7) significantly performed superior over all other treatments. The lowest yield (10.6 q/ha) was obtained with the application of mulch 0 tons/ha, and the highest yield (26.5 q/ha) was obtained with the application of black polythene mulch. Economically, mulch is the most effective and economically viable option for enhancing linseed productivity within a ber-based agri-horti system in the Bundelkhand region, offering evidence-based guidance for developing water-smart agroforestry interventions in water-limited semi-arid environments.*

Keywords: Agri-horti system, Bundelkhand, Mulch, Growth, Ber, Linseed, Soil moisture conservation, yield

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Introduction

Bundelkhand, situated in the central portion of the Indian subcontinent, encompasses a geographical expanse of approximately 70,000 km^2 and is shared between the states of Uttar Pradesh and Madhya Pradesh. The region is characterized by semi-arid to sub-humid climatic conditions, with mean annual rainfall ranging between 800 and 900 mm, predominantly concentrated in the monsoon season. Temperatures exhibit extreme seasonal fluctuations, peaking at approximately 48°C during summer and descending to near-freezing (1°C) in winter. The landscape comprises undulating terrain, rocky outcrops, and dissected plains interspersed with shallow, highly eroded soils that suffer from poor water-holding capacity and limited groundwater recharge.

Mulching and moisture conservation practices are especially important in the Bundelkhand region due to its unique and challenging agro-climatic conditions, which frequently suffer from recurrent droughts and erratic rainfall. This region belongs to the arid and semi-arid, with limited water resources, so mulching is a very effective practice in this region to conserve moisture and enhance crop productivity. Improving soil moisture retention is a key focus in agricultural production, particularly in India, where water resource limited and controlled. A significant factor driving efforts to reduce water usage in farming is the growing population, which increases demand for water in urban areas. Since urban water consumption remains relatively fixed but continues to rise, agricultural water availability is continually shrinking. To tackle these challenges, farmers are exploring innovative techniques to improve soil moisture levels. One effective method is mulching, a practice that involves covering the soil with a protective layer to minimize surface evaporation. Additionally, mulch suppresses weed growth, which helps optimize water use efficiency. Incorporating agricultural by-products as mulch offers a sustainable approach, reducing water consumption while providing additional benefits for soil health and crop production (Khose *et al.* 2023).

Linseed (*Linum usitatissimum* L.) is an important self-pollinated oilseed and fiber crop grown in the *rabi* season. This crop belongs to the family Linaceae and is the only cultivated species of the genus *Linum* (2n = 30). The crop originated in the Mediterranean region and has been cultivated since ancient times for its oil-rich seeds and fibre. In India, it is commonly known as Alsi, Jawas, or Agasi. Linseed is rich in nutrients, containing 35-47% oil, 11-32% protein, 50- 60% linolenic acid, 5-6% fibre, and omega-3 fatty acids. Due to its high nutritional and therapeutic value, linseed plays a significant role in human health and industrial applications because they have unique property found linen compound on it. Generally, flax fibre is valued for its strength, absorbency, breathability, and UV protection properties (Akin *et al*, 2000; Salmon-Minotte and Frank, 2005).

Globally, linseed ranks among the major oilseed crops, with India contributing significantly to world production. Within India, Madhya Pradesh is the leading producer, followed by Chhattisgarh, Uttar Pradesh, and Maharashtra. Linseed oil is widely used in food, feed, pharmaceutical, and industrial products such as paints, varnishes, soaps, and fibre-based goods.

Agroforestry is a sustainable approach to land management that integrates woody perennials, crops, and/or livestock on the same land, either simultaneously or over time. This system is more dynamic, diverse, and functionally complex than traditional monocultures of trees or crops. While agroforestry may seem innovative, it has actually been practiced in India for thousands of years (Puri and Nair, 2004).

The Agri-horti system integrates annual or perennial crops with fruit-bearing trees on the same land, enhancing productivity through the efficient use of natural resources. This approach has been recognized as the most beneficial among six evaluated agroforestry methods. By deliberately planting fruit trees alongside other crops, farmers can maximize yield per unit of land, especially during the early growth stages of the trees. This system creates a symbiotic relationship between fruit trees and crops, leading to improved land utilization and overall agricultural efficiency.

Ber (*Ziziphus mauritiana* L.), having chromosome number 2n = 48, a member of the Rhamnaceae family, is a widely cultivated and naturally occurring fruit species. Among its varieties, *Zizyphus jujube* and *Zizyphus mauritiana* are the most common. Often called the King of Arid Zone Fruits and popularly known as the Poor man's apple (Nidhi *et al.* 2019). This hardy plant thrives in both wild and cultivated environments across warm arid and semi-arid regions, reaching an altitude of up to 1500 meters above sea level. Originating in Central Asia, particularly India and China, ber adapts to diverse climatic conditions, with optimal growth temperatures ranging from 49^0C to 50^0C. Additionally, it flourishes even in poor-quality soil with pH levels as high as 9.0, making it well-suited for arid and semi-arid landscapes.

It is essential to understand how mulching practices influence crop growth, yield, and resource utilization for optimizing water management and enhancing productivity. However, limited information is available regarding the effect of different mulching practices on linseed under agri-horti systems. Therefore, the present study was undertaken to evaluate the impact of various mulching types on the growth and yield performance of linseed under a ber-based agri-horti system in the semi-arid conditions of the Bundelkhand region. The findings of this study will be beneficial in creating awareness among farmers about efficient mulching practices, helping them conserve soil moisture, improve crop productivity, and ultimately enhance their income and livelihood security in the Bundelkhand region.

Materials and Methods

Experimental site

The experiment was carried out at the forestry instructional farm, Banda University of Agriculture and Technology, Banda (U.P.), which is situated in the Bundelkhand region of Banda district. Geographically, the experimental site falls under the agro- climatic zone VIII (Central Plateaus and Hills Region) and is located on 25^0 N latitude 80^0 E longitudes and an altitude of 387 meters above mean sea level. The climate of the site is semi-arid, characterized by hot, dry summers, and cold winters, which are broadly representative of the Bundelkhand agro-ecological context.

Experimental design and treatment

The experiment was conducted in a Randomized Block Design (RBD) with 9 treatments, which were replicated thrice. These treatments were different types of mulching, that is, (T_1) Paddy (*Oryza sativa*) straw, (T_2) Wheat (*Triticum aestivum*) straw, (T_3) Kans (*Saccharum spontaneum*) grass, (T_4) Doob (*Cynodon dactylon*) grass, (T_5) Lemon (*Cymbopogon spp.*) grass, (T_6) White polythene, (T_7) Black polythene, (T_8) Mustard (*Brassica spp.*) straw. Ber (planted under the CEDA project) was established at a spacing of 6 m × 6 m. The linseed variety "Buat-4" was sown as an intercrop using a seed drill at a row × plant spacing of 30 cm × 10 cm. Fertilizers were applied at recommended doses of N:P:K:S at the ratio of 80:40:40:40 kg ha^{-1}. The different types of mulch were applied after 15 days of sowing at the rate of 5 tons/ha. Observations on growth and yield attributes were recorded at 30 days after sowing (DAS), 60 DAS, and at final harvest. Parameters recorded included Plant Height (cm), Number of branches per plant, 50% DAS of Flowering, Dry Weight per plant (g), Days to maturity, Number of capsules per plant, Number of seeds per capsule, Test Weight (g), Seed Yield (q ha^{-1}), Straw Yield (q ha^{-1}), and Biological yield (q ha^{-1}) were measured. Economic analysis was performed to estimate the cost of cultivation, gross return, net return, and benefit- cost (B: C) ratio under each treatment.

Results and discussion

Plant Height (cm)

Mulching treatments exerted a significant influence on the plant height of linseed at all stages of crop growth (Table 1). The tallest plants observed at harvest (65.5 cm) were recorded under treatment T_7 (Black Polythene Mulch), while the shortest (58.4 cm) were noted in the control plot without mulch (T_0). This significant variation underscores the role of mulching in promoting plant growth. The enhanced performance of T_7 can be attributed to the favorable soil micro environment created by black polythene mulch, which reduces surface evaporation, regulates soil temperature, and improves moisture retention and nutrient availability. Additionally,

Table 1: Growth and yield response of Linseed to different types of mulches under ber-based agri-horti system

Treatments	Plant height (cm) 30 DAS	60 DAS	At harvest	No. of branches at harvest	50% flowering DAS	Dry weight at harvest (g/plant)	Days to Maturity	Capsules per plant	Seeds per capsule	Test weight (g)	Seed yield (qha^{-1})	Straw yield (qha^{-1})	Biological yield (qha^{-1})
T_0 Control	7.7	26.9	58.4	4.2	52.0	6.4	112	36	7.1	5.4	5.2	5.4	10.6
T_1 Paddy straw	8.5	28.4	60.1	4.9	47.3	6.6	120	40	9.3	5.9	7.3	7.3	14.6
T_2 Wheat straw	8.1	28.5	63.6	4.4	45.0	6.6	119	39	8.2	6.2	6.9	6.9	13.8
T_3 Kansgrass	8.6	29.9	63.0	6.1	41.3	6.9	119	37	8	5.7	5.7	7.3	13
T_4 Doob grass	7.8	28.8	62.4	5.4	46.3	7.0	122	37	9.0	6.0	5.5	7.4	12.9
T_5 Lemongrass	8.3	29.5	59.8	6.5	43.0	7.3	118	41	9.2	6.1	6.5	6.8	13.3
T_6 White polythene	9.5	30.1	65.0	4.9	39.0	6.5	115	35	9.1	6.0	11.9	12.4	24.3
T_7 Black polythene	10.0	30.8	65.5	6.6	37.3	7.4	111	42	9.5	6.3	13.3	12.9	26.2
T_8 Mustardstraw	8.3	28.9	60.9	6.3	43.7	6.9	120	38	9.4	5.6	6.2	6.6	12.8
SEm ±	0.3	1.0	1.8	0.2	1.4	0.3	3	1	0.3	0.2	0.3	0.06	0.11
C.D (5%)	0.8	3.0	5.4	0.6	4.1	0.8	10	4	1.0	0.7	1.0	0.19	0.32

mulching accelerates organic matter mineralization and the release of essential nutrients such as nitrogen.

Number of Branches per Plant

The number of branches per plant exhibited considerable treatment-dependent variation (Table 1). The highest branch count at harvest was observed under treatment T_7 (Black Polythene Mulch), with 6.6 branches per plant, followed by T_5 (Lemon grass) with 6.5 branches. The lowest count was recorded in the control treatment T_0 (No Mulch), with 4.2 branches per plant. The increase in branching under T_7 can be attributed to improved soil moisture and moderated temperature conditions, which enhance vegetative growth and nutrient assimilation. Mulching effectively reduces plant water stress and sustains cytokinin activity in the shoot meristem, thereby promoting axillary bud development and lateral branching. These observations are consistent with previous findings. Shirisha *et al*. (2023) reported a significant rise in lentil branching under mulched plots due to improved soil moisture, while Bahadur *et al*. (2018) found that polyethylene mulch enhanced soil temperature and nutrient uptake, stimulating vegetative branching in leguminous crops.

Days to 50% Flowering

The flowering in linseed was notably influenced by the different mulch treatments (Table 1). The longest duration to reach 50% flowering was recorded under treatment T_0 (Control), with 52 days, while the earliest flowering occurred in the T_7 (Black polythene) treatment at 37.3 days. The delayed flowering observed in mulched treatments such as T_0 and T_1 is likely due to an extended vegetative phase supported by poor moisture and nutrient availability. Mulching enhances nitrogen availability, which promotes vigorous vegetative growth and delays the synthesis of floral-inducing hormones. These results are consistent with findings by Zhang *et al*. (2011), who reported delayed flowering in lentil under mulched conditions, attributing it to sustained vegetative development.

Dry Weight (g/plant)

Dry matter accumulation in linseed plants serves as a key indicator of biomass production. In the present study (Table 1), the highest dry weight at harvest (7.4 g/plant) was recorded under treatment T_7 (Black Polythene Mulch), while the lowest (6.4 g/plant) occurred in the control (T_0: No Mulch). The superior performance of T_7 is attributed to consistent moisture availability and improved root zone aeration, which together enhance root metabolism and nutrient absorption. Mulching also enhances leaf area and chlorophyll content under favorable conditions, which contribute to higher photosynthetic activity, thereby boosting biomass accumulation. These findings are corroborated by Layek *et al*. (2020) reported increased dry matter in lentil under organic mulch, attributed to accelerated microbial decomposition and nutrient release.

Days to Maturity

Linseed plants under treatment T_4 (Doob grass) exhibited the longest maturity duration of 122 days, while the earliest maturity was recorded in the treatment T_7 (Black polythene) at 111 days (Table 1). The extended crop duration observed under mulched conditions can be attributed to reduced water stress and enhanced nutrient uptake, which collectively support prolonged growth and assimilate translocation. This prolonged period likely contributes to improved grain filling, resulting in enhanced seed weight and quality. Kumar *et al.* (2021) found that sustained vegetative vigor and canopy retention under mulching delayed maturity in lentil.

Capsules per Plant

The number of capsules per plant serves as a crucial determinant of yield potential in linseed, and the results demonstrated a significant enhancement under different mulching treatments (Table 1). The highest capsule count at harvest was recorded in treatment T_7 (Black Polythene Mulch) with 42 capsules per plant, closely followed by T_5 (Lemon grass) at 41. In the treatment T_0 (No Mulch), the lowest number of capsules was registered, with 36 per plant. The increased capsule formation under mulched conditions can be attributed to improved accumulation and translocation of photosynthesis, driven by superior soil moisture retention, reduced root-zone competition, and enhanced nutrient availability, particularly phosphorus, which plays a key role in reproductive development. Mulching also supports a favorable microclimate for effective pollination and fertilization, further boosting pod set. These findings align with previous studies. Karupakula *et al.* (2011) noted that mulching enhanced pod formation in lentils by maintaining optimal soil temperature and reducing water loss.

Seeds per Capsule

The number of capsules per plant indicates reproductive potential, and the seeds per capsule provide insights into fertilization efficiency and assimilate distribution. In the present study (Table 1), the highest number of seeds per capsule (9.5) was observed in T_7 (Black polythene), while the lowest value (7.1) was recorded under the control treatment T_0 (No Mulch). Although T_7 (Black Polythene), slightly higher seeds per capsule may be attributed to reduced intra-plant competition, allowing more efficient nutrient allocation to each developing pod.

Test Weight (g)

Test weight, a key indicator of grain density and quality, was found to be significantly influenced by different mulch practices (Table 1). The highest test weight was recorded in treatment T_7 (Black Polythene Mulch) at 6.3 g, followed by T_2 (Wheat straw) at 6.2 g. The control treatment T_0 (No Mulch) registered the lowest value at 5.4 g. The improved test weight observed under mulched conditions is attributed to an extended grain filling period and uninterrupted assimilate translocation, facilitated by reduced water and temperature stress. Polythene mulch supports consistent root uptake of potassium and calcium, critical elements for grain development and hardness. These findings are supported by Praharaj *et al*. (2020), who reported increased 100-seed weight in lentil due to prolonged seed filling under black and white mulching. Similarly, Singh *et al*. (2009) found that mulching improved lentil grain weight through better micronutrient availability, particularly zinc and boron.

Seed Yield (qha^{-1})

Seed yield represents the integrated outcome of a plant's physiological, morphological, and reproductive attributes. In the present study (Table 1), the highest seed yield (13.3 qha^{-1}) was obtained under treatment T_7 (Black Polythene Mulch), followed by T_6 (White polythene) at 11.9 qha^{-1}. The control treatment T0 (No Mulch) recorded the lowest yield, with 5.2 qha^{-1}. The superior performance of T_7 can be attributed to a synergistic effect of enhanced branching, increased capsule formation, greater test weight, and extended maturity duration. Mulching contributes to improved soil nutrient availability, minimized evaporation losses, and healthier root development. It synchronized flowering and consistent pod filling under mulched conditions, promoting uniform seed development and higher overall productivity.

Straw Yield (qha^{-1})

Straw yield plays a vital role in enhancing the economic value, industrial fiber, and biofuel potential of linseed cultivation. In the present study (Table 1), the highest straw yield (12.9 qha^{-1}) was recorded under treatment T_7 (Black Polythene Mulch), while the lowest (5.5 qha^{-1}) was noted in the control treatment T_0 (No Mulch). The increased straw yield in mulched plots can be attributed to vigorous vegetative growth, thicker stem formation, and delayed senescence facilitated by consistent moisture availability. Mulching supports cell wall development and prolongs photosynthetic activity, thereby encouraging biomass allocation toward non-grain plant components. These results align with previous studies, McIntyre *et al.* (2000) found that mulched plots produced higher aboveground biomass owing to reduced water stress and more efficient nutrient cycling.

Biological Yield (qha^{-1})

Biological yield, which encompasses the total aboveground biomass, was highest under treatment T_7 (Black Polythene Mulch) at 26.5 qha^{-1}, followed by T_6 (White polythene) at 24.3 qha^{-1}. The lowest biological yield was recorded in the control plot T_0 (No Mulch), at 10.6 qha^{-1}(Table 1). The increased productivity in mulched treatments can be attributed to improved vegetative growth (including plant height and branching), greater reproductive output (pods and seeds), and favorable physiological responses (such as dry matter accumulation and extended maturity). These results align with the findings Similarly, Amini and Alami-Milani *et al.* (2013) observed that plastic mulch increased lentil productivity by prolonging active photosynthesis and delaying leaf senescence.

Growth parameters of ber:

Statistically non-significant differences were observed in all recorded growth parameters of ber, tree height, collar diameter, canopy spread, number of branches, average fruit weight, and fruit yield per plant across the nine mulching treatments (Table 2). This outcome is consistent with the relatively short duration of linseed cultivation (approximately 122 days), which is insufficient to produce measurable changes in the growth trajectory of perennial ber trees that have been established over several seasons.

Economic Analysis

Economic evaluation of linseed production under different mulching treatments revealed marked differences in returns (Table 3). The maximum gross return (Rs. 1,02,633/ha) and net return (Rs. 69,726/ha) were both recorded under T_7 (black polythene mulch), in contrast to the minimum gross return (Rs. 53,890.93/ha) and net return (Rs. 30,879.93/ha) registered under the (T_0)control treatment. The highest benefit-cost ratio of 2.12 was obtained under T_7, indicating that for every rupee invested, farmers earned a net return of Rs. 2.12. White polythene (T_6) recorded the second-highest B:C ratio of 1.99, indicating that even low-cost locally available mulching materials substantially improve economic viability.

Conclusion

The present investigation provides evidence that mulching substantially enhances the growth, yield, and economic performance of linseed intercropped under a ber-based agri-horti system in the semi-arid Bundelkhand region. Among all treatments evaluated, black polythene mulch (T_7) applied at 5 tons per hectare consistently, the treatment produced the highest seed yield (13.3 q/ha), and biological yield (26.20 q/ha), and the most

Table 2: Growth parameters of ber at various crop growth stages in the ber-based agri-horti system

Treatments	Tree Height (m)	Collar Diameter (cm)	Canopy Spread N-S (m)	Canopy Spread E-W (m)	No. of Branches/ Tree	Avg. Fruit Weight (g)	Fruit Yield/ Plant (kg)
T_0 Control	2.9	8.9	4.7	4.4	14	15.3	10.9
T_1 Paddy straw	3.4	8.6	3.9	3.9	17	13.2	13.2
T_2 Wheat straw	3.8	9.6	3.1	3.4	14	13.4	8.8
T_3 Kans grass	3.7	9.0	3.3	2.9	12	15.6	9.0
T_4 Doob grass	3.8	8.0	3.4	3.2	11	15.0	11.2
T_5 Lemon grass	3.6	9.5	3.5	3.6	10	12.7	10.6
T_6 White polythene	3.9	11.9	4.4	4.3	11	15.4	10.7
T_7 Black polythene	3.9	10.7	3.7	3.2	11	13.8	11.0
T_8 Mustard straw	3.9	10.1	3.2	3.5	10	14.4	9.60
SEm ±	0.1	0.4	0.2	0.2	1.0	0.7	0.50
C.D (5%)	0.4	1.2	0.5	0.6	2.0	2.2	1.50

Table 3: Economics of linseed as influenced by different types of mulches under ber-based agri-horti system

Treatments	Seed Yield (qha^{-1})	Cost of cultivation (Rs. ha^{-1})	Gross Return (Rs. ha^{-1})	Net return (Rs. ha^{-1})	B:C Ratio
T_0 Control	5.2	23,011	53,890	30,879	1.34
T_1 Paddy straw	7.3	28,107	69,558	41,451	1.47
T_2 Wheat straw	6.9	28,107	67,817	39,710	1.41
T_3 Kans grass	5.7	25,407	60,854	35,447	1.39
T_4 Doob grass	5.5	25,407	60,273	34,866	1.37
T_5 Lemon grass	6.5	25,407	65,496	40,089	1.58
T_6 White polythene	11.9	31,807	95,089	63,282	1.99
T_7 Black polythene	13.3	32,907	10,2,633	69,726	2.12
T_8 Mustard straw	6.2	25,867	63,755	37,888	1.46

favorable benefit–cost ratio (2.12). These outcomes are attributable to the unique thermo-regulatory and moisture-conserving properties of black polythene.

Organic mulches, particularly lemon grass (T_5) and paddy straw (T_1), also demonstrated meaningful improvements over the control in terms of vegetative growth, branching, yield attributes, and economic returns, and represent practical and low-cost alternatives for resource-constrained smallholder farmers in the region. Importantly, none of the mulching treatments adversely affected the growth and productivity of ber trees, confirming the agronomic compatibility of intensive mulching practices with the ber-based agri-horti system.

In view of these findings, it is recommended that farmers in the Bundelkhand region maximize linseed productivity and profitability within integrated agri-horti systems-based farming.

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