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Performance of Field Pea (*Pisum sativum* L.) under Organic Mulches in the Hilly Region of Arunachal Pradesh, North-Eastern India

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Authors' contributions

This work was carried out in collaboration among all authors. Author OS conceptualized the study, performed the methodology, did investigation, formal analysis, data curation, wrote and prepared the original draft of the manuscript, did data visualization. Author SL performed the methodology, did investigation, validation, wrote, reviewed and edited the manuscript. Author SKM did formal analysis, validation, wrote, reviewed and edited the manuscript. Author BK did investigation, searched for resources, wrote, reviewed and edited the manuscript. Author SS did investigation, data curation, wrote, reviewed and edited the manuscript. All authors read and approved the final manuscript.

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Abstract

Moisture stress during the rabi season keeps much of the rice-fallow area of North-Eastern India uncropped and limits pulse production. A field experiment was conducted from October 2023 to February 2024 at the Agriculture Research Farm of Rajiv Gandhi University, Rono Hills, Doimukh, Arunachal Pradesh, India, to evaluate organic mulches for field pea (*Pisum sativum* L.) grown under organic management. Seven treatments (an unmulched control and dry leaves, rice straw, rice husk, water hyacinth, fern and weed residue, each applied at 5 t ha-^{1}) were laid out in a randomized block design with three replications. The local landrace 'Makhyatmubi' was sown at 30 × 10 cm after seed treatment with a microbial consortium, and vermicompost (1.5 t ha^{-1}) and rock phosphate (12.5 kg ha^{-1}) were applied after sowing. Fern mulch retained the most moisture in the 0–10 cm soil layer (28.51%, 48.88% and 30.90% at flowering, pod formation and harvest, respectively) and gave the highest root volume (30.50 cm^{3}) at pod formation, together with the highest total nodule number (199.0 and 156.5 plant^{-1}) and effective nodule number (169.0 and 109.0 plant-1) at flowering and pod formation, respectively. Fern mulch recorded the highest seed yield (1380 kg ha^{-1}, 86.5% above the control) and stover yield (5530 kg ha^{-1}), although seed yield was statistically at par with rice husk, water hyacinth and weed residue, and stover yield with rice straw, water hyacinth and weed residue. Fern mulch also gave the highest gross returns (₹83,010 ha^{-1}), the highest net returns (₹54,422 ha-^{1}, significantly greater than all other treatments) and the highest benefit–cost ratio (1.90). The superior performance of fern is probably related to its dense, continuous surface cover and soft tissue which decomposes more readily than rice straw or rice husk and may have conserved moisture and improved the root-zone environment better. Fern is therefore a promising, low-cost organic mulch for field pea production in the hilly region of Arunachal Pradesh and subject to validation, in similar rainfed, acidic rice-fallow hill agro-ecosystems of North-Eastern India.

Keywords: Organic mulch; fern; field pea; nodulation; root volume; soil moisture; North-Eastern India.

1. Introduction

Pulses are a major source of dietary protein in the global food-grain system (Singh, 2017; Swetha *et al.*, 2022; Parida *et al.*, 2023). Despite favourable soil and agro-climatic conditions, North-Eastern India faces a pulse deficit of about 82%, and its average pulse productivity of about 848 kg ha^{-1} is only marginally below the national average of 885 kg ha^{-1} recorded in 2020–21 (Directorate of Pulses Development, 2022; Dhivya *et al.*, 2020; Marwein & Ray, 2021; Shirisha *et al.*, 2023). The shortfall therefore mainly reflects the large supply deficit arising from the limited area under pulses, rather than a large yield gap, and the region has considerable scope to narrow it by bringing rice-fallows under a *rabi* pulse.

Field pea (*Pisum sativum* L.) is an important *rabi* pulse that provides a plant-based alternative to animal protein (Powers & Thavarajah, 2019). It is a cool-season legume that is sensitive to high temperature (Parihar *et al.*, 2025), which makes the cool, dry winter of the hills well suited to it. North-Eastern India receives an average annual rainfall of more than 2,000 mm, well above the national average of 1,194 mm, yet crop production is constrained by moisture stress after the monsoon. More than 80% of the area remains fallow after rice (Ray *et al.*, 2019), because inadequate irrigation and unsuitable soil and water conservation practices cause severe water scarcity in the *rabi* season (Ray *et al.*, 2019; Shirisha *et al.*, 2023). At the national level, about 11.7 million ha of rice-fallow, roughly 82% of it in eastern India, remain uncropped in winter largely because soil moisture declines rapidly after the monsoon and short-duration pulses, including field pea are among the options for using this land (Kumar *et al.*, 2025; Geethika *et al.*, 2024).

Producing more food with less water requires higher crop water productivity (Jyothi *et al.*, 2022; Mukesh *et al.*, 2024; Mukesh *et al.*, 2025; Sharma *et al.*, 2025). Conservation practices such as mulching conserve soil moisture, build soil organic carbon, improve soil structure and microbial activity, and improve resource-use efficiency (Praharaj *et al.*, 2025). Mulching reduces surface evaporation, increases the infiltration and retention of rainfall (Kader *et al.*, 2017; El-Beltagi *et al.*, 2022). Recent syntheses likewise indicate that organic mulching raises soil organic matter, water-holding capacity and keeps moisture in the root zone for longer (Demo & Bogale, 2024), and bio-mulches applied at 5 t ha^{-1} increased root-zone moisture in garden pea in the mid hills of Meghalaya (Emilia *et al.*, 2025). Organic mulches can raise yield, water-use efficiency and profitability while suppressing weeds and improving the physical, chemical and biological properties of soil (Marwein & Ray, 2019; Parida *et al.*, 2023). Such benefits have been reported for rajma, garden pea, lentil and potato crops in the hills of Meghalaya (Marwein & Ray, 2019; Parida *et al.*, 2023; Shirisha *et al.*, 2023; Devi *et al.*, 2023), but information on field pea under locally available organic mulches in Arunachal Pradesh is scarce.

We therefore evaluated six locally available organic mulches against an unmulched control for their effects on soil moisture, root growth, nodulation, yield attributes, yield and economics of organically grown field pea in the hilly region of Arunachal Pradesh to identify the most suitable mulch for the *rabi* season. These materials, particularly fern, which is abundantly available in the hilly environment are locally accessible organic wastes which may make their use economically and environmentally viable.

2. Materials and Methods

2.1 Study Site and Weather

A field experiment was conducted during the *rabi* season, from October 2023 to February 2024, at the Agriculture Research Farm of Rajiv Gandhi University, Rono Hills, Doimukh, Papum Pare district, Arunachal Pradesh, India, 27°08′N latitude, 93°46′E longitude and altitude of 350 m above sea level. The climate of the area is humid subtropical (wet and humid), with a long-term mean annual rainfall of about 3,200 mm for the district, most of it received during May–October (Central Ground Water Board [CGWB], 2013); the seasonal rainfall of 273 mm recorded during the crop season was therefore only about 9% of the annual mean. Monthly weather

during the crop season is given in Table 1. Total rainfall was 273 mm, of which 165 mm fell in October and only 40 mm from November to January. Mean monthly maximum and minimum temperatures ranged from 20.3 to 27.0 °C and from 10.0 to 19.0 °C, respectively, and relative humidity decreased from 80% in October to 67% in February.

2.2 Soil, Experimental Design and Treatments

The soil was a sandy clay loam, strongly acidic (pH 4.76), with 1.09% organic carbon and 156.80, 17.61 and 350.11 kg ha^{-1} of available N, P_2O_5 and K_2O, respectively. The experiment was laid out in a randomised block design (RBD) with seven treatments and three replications. The gross plot size was 14 × 12.5 m^2. The treatments were an unmulched control and six organic mulches (Table 2), each applied at 5 t ha^{-1}. Water hyacinth and fern were chopped and sun-dried for 2–3 days before being spread over the plots, following the organic-mulching approach used in earlier trials in the region (Marwein & Ray, 2019; Parida *et al.*, 2023).

Table 1. Monthly weather during the crop season (*rabi*, 2023–24)

Month	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Total rainfall (mm)
October	27.0	19.0	80	165
November	22.3	15.0	77	15
December	21.5	13.5	77	20
January	20.3	10.0	69	5
February	21.2	13.0	67	68
Mean / total	22.5	14.1	74	273

Source: NASA POWER

Table 2. Treatment details

Code	Treatment	Rate (t ha^{-1})	Preparation before application
T_0	Control (no mulch)	–	–
T_1	Dry leaves	5	–
T_2	Rice straw	5	–
T_3	Rice husk	5	–
T_4	Water hyacinth	5	Chopped and sun-dried for 2–3 days
T_5	Fern	5	Chopped and sun-dried for 2–3 days
T_6	Weed residue	5	–

2.3 Crop Management

The treatments were randomly allocated to plots within each of the three blocks. Seeds of the local landrace 'Makhyatmubi', obtained from Manipur, were treated with a microbial consortium comprising phosphorus-solubilising bacteria (PSB), an N-fixer, a potassium-solubilising bacterium (KSP), a cellulose decomposer and an indole acetic acid (IAA) producer, so as to meet the recommended phosphorus dose of field pea, and the phosphorus requirement was supplemented through organic manures applied in equal proportions on a P-content basis. The seeds were sown at a spacing of 30 × 10 cm on 24th October 2023. After sowing, vermicompost (1.5 t ha^{-1}) and rock phosphate (12.5 kg ha^{-1}) were applied to hasten germination and the respective mulch was spread evenly over each plot at 5 t ha^{-1}. The crop was harvested on 26th February 2024.

2.4 Observations Recorded

Soil moisture was determined at flowering, pod formation and harvest (on 20th December 2023, 9th January 2024 and 26th February 2024, respectively). Soil samples were collected from each plot with a soil auger at 0–10, 10–20, 20–30 and 30–40 cm depths, placed in brown paper bags, and oven-dried at 105 °C for 24 h to constant weight. Moisture content was calculated on a dry-weight basis as:

$$\text{Soil moisture content (\%)} = [(\text{Fresh weight} - \text{Dry weight}) / \text{Dry weight}] \times 100 \quad (1)$$

Root parameters were measured at flowering and pod formation on a composite sample of three randomly chosen plants from each plot, and the mean values were used for analysis. Root volume (cm3) was measured by water displacement: a 100 ml measuring cylinder was filled to 60 ml with water, the gently blotted roots were immersed, and the rise in water level was noted. Root fresh and dry weights (g) were recorded, and total and effective nodules per plant were counted manually, and effective nodules were identified by cutting them open and observing their internal colour. All three sampled plants per plot (nine plants per treatment) were examined for the presence of nodules. Branches per plant (primary and secondary branches combined) and 100-seed weight (weight of 100 randomly drawn seeds, in g, determined on an electronic balance) were recorded at harvest from three randomly chosen plants per plot and averaged. Seed yield and stover yield were recorded on a whole-plot basis and expressed in kg ha^{-1}.

2.5 Economic Analysis

Gross returns (₹ ha-1) were calculated by multiplying seed yield by the market price of seed (₹ 60 kg^{-1}):

$$\text{Gross returns} = \text{Seed yield (kg ha-1)} \times \text{Price of seed (₹ kg}^{-1}\text{)} \quad (2)$$

Net returns (₹ ha-1) were obtained by subtracting the cost of cultivation of each treatment from the gross returns (the cost of cultivation was computed treatment-wise from the actual inputs used, namely ploughing, harrowing, seed, sowing, mulch material together with its collection, chopping, drying, transport and spreading, microbial consortium, rock phosphate vermicompost, handweeding, irrigation and harvesting; see Table 7 in Section 3.5)

$$\text{Net returns} = \text{Gross returns} - \text{Cost of cultivation} \quad (3)$$

The benefit–cost ratio (B:C) was calculated as net returns per rupee invested:

$$\text{B:C ratio} = \text{Net returns} / \text{Cost of cultivation} \quad (4)$$

2.6 Statistical Analysis

The data were analysed using a randomised complete block design (Gomez & Gomez, 1984) using OPSTATS. The significance of treatment effects was tested by the *F*-test at $P \leq 0.05$, and the critical difference (CD) was calculated where the *F*-test was significant. Treatment means differing by less than the CD are described as statistically at par.

3. Results and Discussion

3.1 Soil Moisture

Mulching significantly affected soil moisture only in the 0–10 cm layer; differences at 10–20, 20–30 and 30–40 cm were non-significant, so only the surface layer is presented (Fig. 1). Fern mulch (T_5) retained the highest moisture at flowering (28.51%), pod formation (48.88%) and harvest (30.90%), compared with 18.17%, 39.57% and 19.15%, respectively, in the unmulched control. Moisture was higher at pod formation than at the other two stages in all treatments. Flowering-stage sampling on 20th December 2023 came after a dry spell (only 40 mm of rain from November to January), whereas pod-formation sampling on 9th January 2024 followed the 68 mm of rain received in February (Table 1), which probably recharged the surface layer; moisture at harvest on 26th February 2024 fell again as the crop and evaporation depleted the profile.

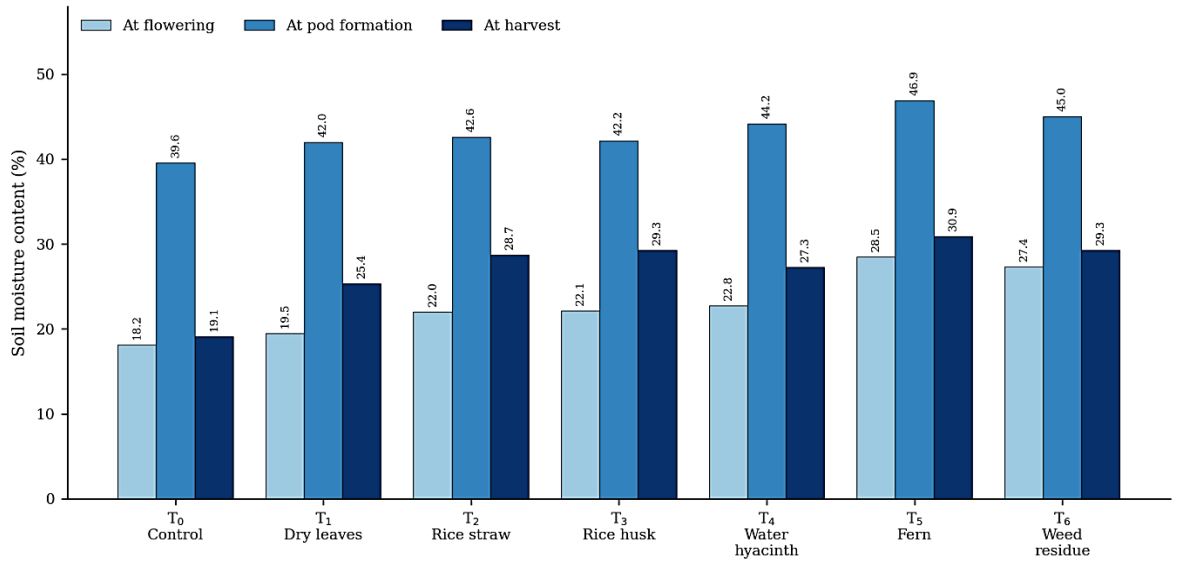


Fig. 1. Soil moisture content (%) in the 0–10 cm layer under different organic mulches at flowering, pod formation and harvest of field pea. Differences among treatments were significant ($P \leq 0.05$) at this depth. Values above the bars are means of three replications; SE(m)±: [flowering, pod formation, harvest]; CD ($P \leq 0.05$):

Because only 40 mm of rain fell from November to January (Table 1), stored soil moisture was probably the main determinant of crop performance, and the surface mulches would have acted mainly by reducing evaporation from the topsoil. Mulching is known to conserve more soil moisture than bare soil (Sinkevičienė *et al.*, 2009; Rezaei Pour *et al.*, 2018; El-Beltagi *et al.*, 2022), and organic mulches can store water for many days and extend the interval between irrigations (Kader *et al.*, 2017). The advantage of fern over the other materials may be due to a more continuous surface cover, although cover and soil temperature were not measured in this study. Fern fronds, once chopped and dried, form a dense, fine-textured mat that decomposes more readily than rice straw or rice husk, which have higher C:N ratios and decompose slowly, so fern may have combined better surface cover and water retention with a faster return of nutrients to the root zone; mulch thickness, decomposition rate, nutrient content and water-holding capacity were not measured here, and these explanations remain to be tested. Higher soil moisture supports a larger canopy and greater photosynthetic capacity, and thereby a higher seed yield (Bu *et al.*, 2013; Li *et al.*, 2013; Siczek *et al.*, 2015).

3.2 Root Parameters

Root volume did not differ significantly among treatments at flowering but did at pod formation (Table 3). At pod formation, fern mulch produced the highest root volume (30.50 cm^3, 110% above the control), which was at par with rice straw, rice husk, water hyacinth and weed residue and significantly higher than the control and dry leaves. At flowering, fern mulch gave the significantly highest root fresh weight (2.08 g), whereas root dry weight (0.45 g) was at par with all other mulches and higher than the control. At pod formation, fern mulch recorded the highest root fresh weight (6.20 g, at par with weed residue and rice husk) and root dry weight (2.06 g, at par with rice husk and significantly higher than all other treatments). Representative root systems at the two stages are shown in Fig. 2.

Table 3. Effect of organic mulches on root parameters of field pea

Treatment	Flowering			Pod formation		
	Root volume (cm^3)	Fresh weight (g)	Dry weight (g)	Root volume (cm^3)	Fresh weight (g)	Dry weight (g)
T_0	14.00	0.06	0.00	14.50	1.17	0.10
T_1	16.25	0.98	0.36	21.00	2.21	0.52
T_2	17.00	1.36	0.40	25.00	2.29	0.35
T_3	17.95	1.50	0.37	27.50	4.94	1.36
T_4	19.00	1.50	0.38	27.00	4.01	0.70
T_5	**19.70**	**2.08**	**0.45**	**30.50**	**6.20**	**2.06**
T_6	18.40	1.44	0.39	23.50	6.03	1.05
SE(m)±	1.94	0.01	0.04	2.72	0.40	0.32
CD ($P \leq 0.05$)	NS	0.05	0.12	8.48	1.26	0.99

T_0, Control; T_1, Dry leaves; T_2, Rice straw; T_3, Rice husk; T_4, Water hyacinth; T_5, Fern; T_6, Weed residue. SE(m)±, standard error of the mean; CD, critical difference at $P \leq 0.05$; NS, non-significant. The highest value in each column is in bold

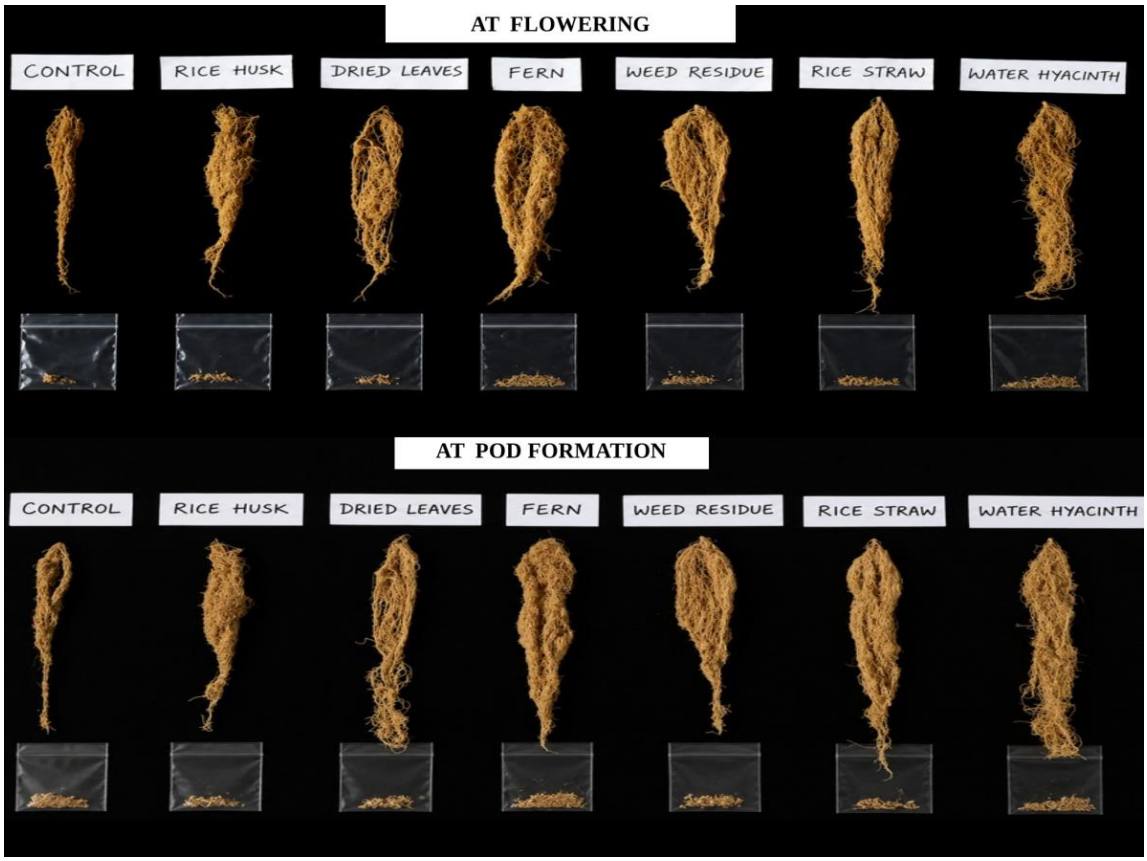


Fig. 2. Root systems of field pea at flowering and pod formation under different organic mulches (treatments identified by the mulch names on the labels)

These responses are consistent with the moisture and temperature moderation provided by organic mulches, which favour root proliferation and root colonisation by beneficial microorganisms (Derkowska *et al.*, 2008; Korir *et al.*, 2017). Organic mulching alters fine-root traits, enzyme activities and rhizosphere microbial communities (Sun *et al.*, 2021) and improves root health and

nutrient supply (El-Beltagi *et al.*, 2022). The weak root development in the control, which had the lowest soil moisture at all stages, supports the role of moisture availability in root growth. Fern may also have a high capacity to hold moisture and organic matter, but its decomposition and nutrient release were not measured here.

3.3 Nodule Characteristics

No nodules were found on any of the nine plants examined per treatment (three per plot) in the control and dry-leaf plots at either stage (Table 4). Fern mulch had the significantly highest total nodule number at flowering (199.0 plant^{-1}) and pod formation (156.5 plant^{-1}) and the highest effective nodule number at pod formation (109.0 plant^{-1}). Effective nodules at flowering (169.0 plant^{-1}) were at par with water hyacinth (156.5 plant^{-1}). Nodulation under rice husk was much lower than under the other mulches (50.0 and 25.0 plant^{-1} total nodules at the two stages).

Table 4. Effect of organic mulches on nodule characteristics of field pea

Treatment	Flowering		Pod formation	
	Total nodules (plant^{-1})	Effective nodules (plant^{-1})	Total nodules (plant^{-1})	Effective nodules (plant^{-1})
T_0	0.00	0.00	0.00	0.00
T_1	0.00	0.00	0.00	0.00
T_2	143.00	136.50	52.00	34.00
T_3	50.00	47.00	25.00	7.50
T_4	169.50	156.50	114.50	75.00
T_5	**199.00**	**169.00**	**156.50**	**109.00**
T_6	155.00	127.00	112.50	92.00
SE(m)±	8.79	6.90	5.63	4.45
CD ($P \leq 0.05$)	27.41	21.49	17.56	13.87

T_0, Control; T_1, Dry leaves; T_2, Rice straw; T_3, Rice husk; T_4, Water hyacinth; T_5, Fern; T_6, Weed residue. SE(m)±, standard error of the mean; CD, critical difference at $P \leq 0.05$; NS, non-significant. The highest value in each column is in bold

Nodule initiation depends on early root-hair development and is sensitive to stress that can delay or inhibit nodulation (Nuc & Olejnik, 2025). Organic inputs improve soil conditions for rhizobial activity in legumes (Joshi *et al.*, 2016), and mulching regulates soil temperature and water content, which can improve nodulation (Siczek *et al.*, 2015). Fern mulch may have created a favourable root-zone environment for the seed-applied consortium, including the N-fixer and IAA producer, which promote root-hair formation and nodulation. The absence of nodules in the control and dry-leaf plots suggests that nodule initiation was constrained under the driest surface conditions, but rhizobial populations and soil temperature were not measured, and this interpretation needs to be tested. Rice husk gave low nodulation yet a seed yield at par with fern (Section 3.4), so nodulation was evidently not the only driver of yield in this trial, in which all plots also received vermicompost and rock phosphate.

3.4 Yield Attributes and Yield

Fern mulch recorded the highest number of branches per plant (71.77), 100-seed weight (73.90 g), seed yield (1380 kg ha^{-1}) and stover yield (5530 kg ha^{-1}) (Table 5). These values were not always significantly different from those of other mulches: branch number was at par with rice husk; 100-seed weight with water hyacinth and weed residue; seed yield with rice husk, water hyacinth and weed residue; and stover yield with rice straw, water hyacinth and weed residue. Fern mulch increased seed yield by 86.5% and stover yield by 91.3% over the unmulched control. It was significantly better than the control and dry leaves for all four traits, and significantly better than rice straw for branches per plant, 100-seed weight and seed yield.

Table 5. Effect of organic mulches on yield attributes and yield of field pea

Treatment	Branches (plant^{-1})	100-seed weight (g)	Seed yield (kg ha^{-1})	Seed yield increase over control (%)	Stover yield (kg ha^{-1})
T_0	30.66	56.37	740	–	2890
T_1	34.96	56.80	990	33.8	3340
T_2	50.02	59.23	1020	37.8	5280
T_3	60.62	62.70	1200	62.2	4540
T_4	47.65	67.20	1160	56.8	5240
T_5	**71.77**	**73.90**	**1380**	**86.5**	**5530**
T_6	40.95	67.20	1200	62.2	5070
SE(m)±	3.67	2.94	100	–	310
CD ($P \leq 0.05$)	11.44	9.15	310	–	980

T_0, Control; T_1, Dry leaves; T_2, Rice straw; T_3, Rice husk; T_4, Water hyacinth; T_5, Fern; T_6, Weed residue. SE(m)±, standard error of the mean; CD, critical difference at $P \leq 0.05$; NS, non-significant. The highest value in each column is in bold. The SE(m)± and CD for seed and stover yield are expressed in kg ha^{-1}

The yield advantage of the mulched plots is consistent with their greater soil moisture (Section 3.1), larger root systems (Section 3.2) and, for fern, greater nodulation (Section 3.3). Organic mulching has been shown to conserve soil moisture and to increase seed and stover yields in comparison with unmulched conditions (Zamir *et al.*, 2013; Tao *et al.*, 2015; Marwein & Ray, 2019). Greater

moisture retention and organic matter inputs from the mulch may also have prolonged the availability of nutrients (Shashikanth & Thimmegowda, 2022; Devi *et al.*, 2023). Because the same landrace and the same inputs were used in all plots, the differences in yield can be attributed to the mulch treatments.

3.5 Economics

The cost of cultivation was approximately the same for the control, dry leaves, water hyacinth, fern and weed residue (₹28,588 ha^{-1}) and was higher for rice straw (₹32,588 ha^{-1}) and rice husk (₹33,337 ha^{-1}) (Table 6), indicating that the locally available materials (dry leaves, water hyacinth, fern and weed residue) added little or no extra cost beyond the labour for collection, chopping, drying and spreading. Fern mulch gave the highest gross returns (₹83,010 ha^{-1}), which were at par with rice husk, water hyacinth and weed residue and significantly higher than those of the control, dry leaves and rice straw. Net returns under fern (₹54,422 ha^{-1}) were significantly higher than under every other treatment, and its B:C ratio (1.90) was the highest, compared with 0.56 in the control. Because fern did not raise the cost of cultivation over the control, its economic advantage came entirely from the higher seed yield. Rice straw and rice husk entailed higher costs without outperforming fern. Similar economic benefits of mulching through higher yield have been reported by Gopinath and Mina (2011), Vanlauwe *et al.* (2015), Gaire *et al.* (2013), Ram *et al.* (2016) and Yadav *et al.* (2019).

Table 6. Effect of organic mulches on the economics of field pea

Treatment	Gross returns (₹ ha^{-1})	Cost of cultivation (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio
T_0	44,505	28,588	15,917	0.56
T_1	59,362	28,588	30,774	1.08
T_2	61,410	32,588	28,822	0.88
T_3	72,076	33,338	38,738	1.16
T_4	69,800	28,588	41,213	1.44
T_5	**83,010**	28,588	**54,422**	**1.90**
T_6	72,257	28,588	43,670	1.53
SE(m)±	6,577	–	2,211	–
CD ($P \leq 0.05$)	20,490	–	6,890	–

Cost of cultivation was computed from the actual input costs (Table 7), net returns = gross returns − cost of cultivation, and B:C ratio = net returns / cost of cultivation. T_0, Control; T_1, Dry leaves; T_2, Rice straw; T_3, Rice husk; T_4, Water hyacinth; T_5, Fern; T_6, Weed residue. SE(m)±, standard error of the mean; CD, critical difference at $P \leq 0.05$; NS, non-significant. The highest gross returns, net returns and B:C ratio are in bold

Table 7. Cost of cultivation (₹ ha^{-1}) of field pea under organic mulches

Cost component	T_0	T_1	T_2	T_3	T_4	T_5	T_6
Ploughing	1200	1200	1200	1200	1200	1200	1200
Harrowing	1200	1200	1200	1200	1200	1200	1200
Seed	7500	7500	7500	7500	7500	7500	7500
Sowing	1000	1000	1000	1000	1000	1000	1000
Mulch material (collection, chopping, drying, transport)	-	-	4000	4750	-	-	-
Microbial consortium	500	500	500	500	500	500	500
Rock phosphate	188	188	188	188	188	188	188
Vermicompost	12000	12000	12000	12000	12000	12000	12000
Handweeding	1000	1000	1000	1000	1000	1000	1000
Irrigation	2000	2000	2000	2000	2000	2000	2000
Harvesting	2000	2000	2000	2000	2000	2000	2000
Total cost of cultivation	28,588	28,588	32,588	33,338	28,588	28,588	28,588

T_0, Control; T_1, Dry leaves; T_2, Rice straw; T_3, Rice husk; T_4, Water hyacinth; T_5, Fern; T_6, Weed residue

4. Conclusion

Among the organic mulches tested, fern showed the best overall performance in the hilly region of Arunachal Pradesh. It retained the most moisture in the surface soil, gave the highest root volume, root biomass and nodule number, and produced the highest seed yield (1380 kg ha^{-1}, 86.5% above the unmulched control). Seed yield under fern was statistically at par with rice husk, water hyacinth and weed residue, but fern gave significantly higher net returns than every other treatment and the highest B:C ratio (1.90) at no additional cost of cultivation. Fern mulch can therefore be recommended for organically grown field pea in the *rabi* season, with weed residue and water hyacinth as alternatives where fern is scarce. Because rice-fallows with post-monsoon moisture stress and acidic soils are widespread across North-Eastern India and the wider Eastern Himalayan region, and fern and other biomass are readily available there, the practice is likely to be relevant to comparable rainfed hill agro-ecosystems, subject to validation under local conditions. These findings come from a single season and location, and soil temperature, weed dynamics and mulch decomposition were not measured; multi-season and multi-location trials are needed to confirm these findings.

5. Limitations

The study was conducted at one location during a single rabi season, limiting the extent to which its findings can be generalised. Soil temperature, mulch cover, mulch decomposition, nutrient release, rhizobial populations and weed dynamics were not measured, so the mechanisms underlying the observed treatment differences remain uncertain. Additional experiments across seasons and locations are needed to assess the consistency of the agronomic and economic responses.

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Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. ChatGPT, Claude and Perplexity were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the 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.

References

Bu, L. D., Liu, J. L., Zhu, L., Luo, S. S., Chen, X. P., Li, S. Q., Hill, R. L., & Zhao, Y. (2013). The effects of mulching on maize growth, yield and water use in a semi-arid region. *Agricultural Water Management, 123*, 71–78. https://doi.org/10.1016/j.agwat.2013.03.015

Central Ground Water Board. (2013). *Ground water information booklet: Papum Pare District, Arunachal Pradesh* (Technical Report Series D). Ministry of Water Resources, Government of India.

Demo, A. H., & Asefa Bogale, G. (2024). Enhancing crop yield and conserving soil moisture through mulching practices in dryland agriculture. *Frontiers in Agronomy, 6*, Article 1361697. https://doi.org/10.3389/fagro.2024.1361697

Derkowska, E., Sas-Paszt, L., Sumorok, B., Szwonek, E., & Głuszek, S. (2008). The influence of mycorrhization and organic mulches on mycorrhizal frequency in apple and strawberry roots. *Journal of Fruit and Ornamental Plant Research, 16*, 227–242. https://www.inhort.pl/files/journal_pdf/journal_2008/full21%202008.pdf

Devi, T. I., Ray, L. I. P., Swetha, K., Jyothi, K. S., Ram, V., & Swami, S. (2023). Performance of potato with organic mulches in Meghalaya. *Indian Journal of Hill Farming, 36*(1), 153–159. https://doi.org/10.56678/iahf-2023.36.01.19

Dhivya, R. S., Ray, L. I. P., & Behera, U. K. (2020). Organic amendments on soil nutrient balance under mid hills of Meghalaya. *e-planet, 18*(1), 29–38. https://e-planet.co.in/images/Publication/vol-18-1/e-Planet_vol_18_1.pdf

Directorate of Pulses Development. (2022). *Annual report 2021–22*. Ministry of Agriculture & Farmers Welfare, Government of India. https://dpd.gov.in/Annual%20Report%20%282021-22%29.pdf

El-Beltagi, H. S., Basit, A., Mohamed, H. I., Ali, I., Ullah, S., Kamel, E. A. R., Shalaby, T. A., Ramadan, K. M. A., Alkhateeb, A. A., & Ghazzawy, H. S. (2022). Mulching as a sustainable water and soil saving practice in agriculture: A review. *Agronomy, 12*(8), Article 1881. https://doi.org/10.3390/agronomy12081881

Emilia, Ray, L. I. P., Mishra, G. P., & Das, J. (2025). Bio-mulching for conservation of in-situ soil moisture under mid hills of Meghalaya. *Journal of Soil and Water Conservation, 23*(3), 240–249. https://doi.org/10.5958/2455-7145.2024.00029.2

Gaire, R., Dahal, K. R., & Amgain, L. P. (2013). Effect of different mulching materials on weed dynamics and yield of direct seeded rice in Chitwan, Nepal. *Agronomy Journal of Nepal, 3*, 73–81. https://doi.org/10.3126/ajn.v3i0.9008

Geethika, J. D., Subramanian, E., Gurusamy, A., Arunachalam, P., Saliha, B. B., & Kumar, A. S. (2024). Sustainable rice fallow crop production challenges and opportunities: An overview. *Current Agriculture Research Journal, 12*(2). https://doi.org/10.12944/CARJ.12.2.04

Gomez, K. A., & Gomez, A. A. (1984). *Statistical procedures for agricultural research* (2nd ed.). John Wiley & Sons. https://www.wiley.com/en-gb/statistical-procedures-for-agricultural-research-2nd-edition-p-9780471870920

Gopinath, K. A., & Mina, B. L. (2011). Effect of organic manures on agronomic and economic performance of garden pea (*Pisum sativum*) and on soil properties. *The Indian Journal of Agricultural Sciences, 81*(3), 236–239. https://doi.org/10.56093/ijas.v81i3.4526

Joshi, D., Gediya, K. M., Patel, J. S., Birari, M. M., & Gupta, S. (2016). Effect of organic manures on growth and yield of summer cowpea [*Vigna unguiculata* (L.) Walp.] under middle Gujarat conditions. *Agricultural Science Digest, 36*(2), 134–137. https://doi.org/10.18805/asd.v0iof.9624

Jyothi, K. S., Ray, L. I. P., Swetha, K., Devi, T. I., Singh, A. K., Swami, S., & Pandey, P. K. (2022). Maize cultivars performance and estimation of effective rainfall during rainy season under mid hills of Meghalaya. *Indian Journal of Hill Farming, 35*(2), 184–191. https://doi.org/10.56678/iahf-2022.35.02.27

Kader, M. A., Senge, M., Mojid, M. A., & Ito, K. (2017). Recent advances in mulching materials and methods for modifying soil environment. *Soil and Tillage Research, 168*, 155–166. https://doi.org/10.1016/j.still.2017.01.001

Korir, H., Mungai, N. W., Thuita, M., Hamba, Y., & Masso, C. (2017). Co-inoculation effect of rhizobia and plant growth promoting rhizobacteria on common bean growth in a low phosphorus soil. *Frontiers in Plant Science, 8*, Article 141. https://doi.org/10.3389/fpls.2017.00141

Kumar, R., Das, A., Mondal, S., Upadhyay, P. K., Bhatt, B. P., Mishra, J. S., Singh, A. K., Choudhary, J. S., Kumar, S., Sundaram, P. K., Biswas, A. K., Rathore, S. S., Singh, R. K., Parameswari, P., Singh, D. K., Kumar, S., Ahmad, A., Saurabh, K., Shubha, K., ... Chaudhari, S. K. (2025). Greening rice-fallow areas: Integrating pulses and oilseeds for sustainable cropping in eastern India. *Frontiers in Sustainable Food Systems, 9*, Article 1502759. https://doi.org/10.3389/fsufs.2025.1502759

Li, S. X., Wang, Z. H., Li, S. Q., Gao, Y. J., & Tian, X. H. (2013). Effect of plastic sheet mulch, wheat straw mulch, and maize growth on water loss by evaporation in dryland areas of China. *Agricultural Water Management, 116*, 39–49. https://doi.org/10.1016/j.agwat.2012.10.004

Marwein, Y., & Ray, L. I. P. (2019). Performance of rajma (*Phaseolus vulgaris*) cultivars under organic mulches in Meghalayan Plateau of North Eastern India. *Legume Research – An International Journal, 42*(1), 114–118. https://doi.org/10.18805/LR-3827

Marwein, Y., & Ray, L. I. P. (2021). Variation of bio-physico edaphic parameters under organic mulch grown with French bean (*Phaseolus vulgaris* L.). *Indian Journal of Hill Farming, 34*(1), 154–160.

Mukesh, Yumnam, S., Laishram, P., Kumar, H., Senjam, P., Singh, L. N. K., Gopimohan, N., & Jat, J. K. (2024). Genetic basis of yield variation in spring mung bean (*Vigna radiata* L.): A correlation and path analysis study. *International Journal of Bio-resource and Stress Management, 15*(12), 1–7. https://doi.org/10.23910/1.2024.5749

Mukesh, Yumnam, S., Laishram, P., Sarika, K., Meetei, C. C., & Choudhary, S. L. (2025). Unravelling genetic relationships in spring mung bean genotypes using morphological and molecular markers under the foothill condition of Manipur. *Plant Science Today, 12*(4). https://doi.org/10.14719/pst.9126

Nuc, K., & Olejnik, P. (2025). Molecular mechanisms underlying root nodule formation and activity. *Agronomy, 15*(7), Article 1552. https://doi.org/10.3390/agronomy15071552

Parida, P. K., Ray, L. I. P., & Shirisha, K. (2023). Effect of organic mulches on yield, water productivity and economy of garden pea cultivars. *International Journal of Environment and Climate Change, 13*(8), 1773–1783. https://doi.org/10.9734/ijecc/2023/v13i82131

Parihar, A. K., Hazra, K. K., Lamichaney, A., Bohra, A., Singh, A. K., Mishra, R. K., Chandra, A., Singh, U., & Dixit, G. P. (2025). High-temperature sensitivity of plant pigments and their significance in breeding for heat-tolerant field pea (*Pisum sativum* L.). *Journal of Plant Growth Regulation, 44*(10), 5946–5961. https://doi.org/10.1007/s00344-025-11806-4

Powers, S. E., & Thavarajah, D. (2019). Checking agriculture's pulse: Field pea (*Pisum sativum* L.), sustainability, and phosphorus use efficiency. *Frontiers in Plant Science, 10*, Article 1489. https://doi.org/10.3389/fpls.2019.01489

Praharaj, S., Lal, B., Gouda, H. S., Pandey, A. K., Acharya, S., & Kumari, A. (2025). Conservation agriculture for sustainable food system: Current insights and emerging perspectives. *Regional Sustainability, 6*(5), Article 100264. https://doi.org/10.1016/j.regsus.2025.100264

Ram, H., Singh, G., & Aggarwal, N. (2016). Effect of irrigation, straw mulching and weed control on growth, water use efficiency and productivity of summer mungbean. *Legume Research – An International Journal, 39*(2), 284–288. https://doi.org/10.18805/lr.v39i2.9533

Ray, L. I. P., Bora, P. K., Singh, A. K., Singh, R., & Feroze, S. M. (2019). Dry and wet spell rainfall probabilities in planning rice based cropping system of Meghalaya. *Journal of Agrometeorology, 21*(Special issue), 8–17.

Rezaei Pour, Z., Vaezi, A. R., & Baba Akbari, M. (2018). Investigating the effect of wheat straw mulch on soil water retension in rainfed condition. *Iranian Journal of Soil and Water Research, 49*(5), 955–964. https://doi.org/10.22059/ijswr.2018.219065.667560

Sharma, R., Rallapalli, S., & Magner, J. (2025). Optimizing water-efficient agriculture: Evaluating the sustainability of soil management and irrigation synergies using fuzzy extent analysis. *Scientific Reports, 15*, Article 29382. https://doi.org/10.1038/s41598-025-15426-6

Shashikanth, Murukannappa, & Thimmegowda, M. N. (2022). Growth and yield of maize (*Zea mays*) influenced by organic mulching in rainfed Alfisols of Southern Karnataka. *The Pharma Innovation Journal, 11*(5), 484–488. https://www.thepharmajournal.com/archives/2022/vol11issue5/PartF/11-4-379-347.pdf

Shirisha, K., Ray, L. I. P., Parida, P. K., Singh, A. K., & Singh, N. J. (2023). Organic mulching effects on water productivity, soil temperature, growth and yield of lentil varieties. *International Journal of Bio-resource and Stress Management, 14*(8), 1099–1107. https://doi.org/10.23910/1.2023.3556c

Siczek, A., Horn, R., Lipiec, J., Usowicz, B., & Łukowski, M. (2015). Effects of soil deformation and surface mulching on soil physical properties and soybean response related to weather conditions. *Soil and Tillage Research, 153*, 175–184. https://doi.org/10.1016/j.still.2015.06.006

Singh, N. (2017). Pulses: An overview. *Journal of Food Science and Technology, 54*(4), 853–857. https://doi.org/10.1007/s13197-017-2537-4

Sinkevičienė, A., Jodaugienė, D., Pupalienė, R., & Urbonienė, M. (2009). The influence of organic mulches on soil properties and crop yield. *Agronomy Research, 7*(Special issue 1), 485–491. https://agronomy.emu.ee/vol07Spec1/p7sI53.pdf

Sun, X., Ye, Y., Liao, J., Tang, Y., Wang, D., & Guan, Q. (2021). Organic mulching alters the composition, but not the diversity, of rhizosphere bacterial and fungal communities. *Applied Soil Ecology, 168*, Article 104167. https://doi.org/10.1016/j.apsoil.2021.104167

Swetha, K., Ray, L. I. P., Jyothi, K. S., Devi, T. I., Singh, A. K., & Singh, N. J. (2022). Development of water production function for garden pea (*Pisum sativum* L.) under mid hills of Meghalaya. *Indian Journal of Hill Farming, 35*(2), 209–217. https://doi.org/10.56678/iahf-2022.35.02.30

Tao, Z., Li, C., Li, J., Ding, Z., Xu, J., Sun, X., & Zhao, M. (2015). Tillage and straw mulching impacts on grain yield and water use efficiency of spring maize in Northern Huang–Huai–Hai Valley. *The Crop Journal, 3*(5), 445–450. https://doi.org/10.1016/j.cj.2015.08.001

Vanlauwe, B., Descheemaeker, K., Giller, K. E., Huising, J., Merckx, R., Nziguheba, G., Wendt, J., & Zingore, S. (2015). Integrated soil fertility management in sub-Saharan Africa: Unravelling local adaptation. *SOIL, 1*(1), 491–508. https://doi.org/10.5194/soil-1-491-2015

Yadav, G. S., Das, A., Lal, R., Babu, S., Datta, M., Meena, R. S., & Singh, R. (2019). Impact of no-till and mulching on soil carbon sequestration under rice (*Oryza sativa* L.)–rapeseed (*Brassica campestris* L. var. rapeseed) cropping system in hilly agro-ecosystem of the Eastern Himalayas, India. *Agriculture, Ecosystems & Environment, 275*, 81–92. https://doi.org/10.1016/j.agee.2019.02.001

Zamir, M. S. I., Javeed, H. M. R., Ahmed, W., Ahmed, A. U. H., Sarwar, N., Shehzad, M., Sarwar, M. A., & Iqbal, S. (2013). Effect of tillage and organic mulches on growth, yield and quality of autumn planted maize (*Zea mays* L.) and soil physical properties. *Cercetări Agronomice în Moldova, 46*(2), 17–26. https://doi.org/10.2478/v10298-012-0080-z

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