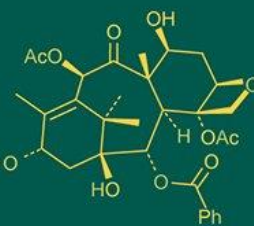
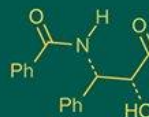
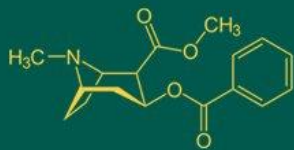


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# Eco-physiological and economic assessment of polyethylene mulching in king chilli (*Capsicum chinense* Jacq.) in the hill ecosystems of the Eastern Himalayas

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## Abstract

In the rainfed hill ecosystems of North East India, the production of King Chilli (*Capsicum chinense* Jacq.) a crop of immense economic and cultural significance is increasingly threatened by climatic variability, specifically erratic rainfall distribution and soil moisture stress. To develop a resilient agronomic protocol, a two-year field investigation was conducted during 2021-2022 and 2022-2023 in the Chandel district of Manipur. The study evaluated the efficacy of distinct soil surface modifications using synthetic mulches on crop physiology, soil hydrothermal regimes, and economic viability. The experiment utilized a Randomized Block Design (RBD) with three treatments: Silver Polyethylene Mulch (M1), Black Polyethylene Mulch (M2), and a non-mulched Control (Mno) representing traditional farmers' practice. Agro-physiological data revealed that surface covering significantly altered the crop microclimate. The Black Polyethylene Mulch (M2) treatment emerged as the superior intervention, recording the maximum plant height (49.58 cm) and significantly advancing 50% flowering time to 21.18 days, compared to 24.22 days in the control. Yield attributes were profoundly impacted; plants under M2 produced the highest fruit count (755.32 fruits/plant) and fruit weight (4.54 g), resulting in a productivity leap over the control, which recorded only 579.31 fruits/plant. Furthermore, M2 demonstrated superior thermal efficiency, maintaining soil temperatures 4.8-5.3 °C higher than the control at a 5 cm depth during peak solar radiation. These findings suggest that black plastic mulching is a potent, low-cost climate-smart technology for enhancing King Chilli productivity and tribal farm incomes in the Eastern Himalayas.

**Keywords:** *Capsicum chinense*, hydrothermal regimes, protected cultivation, weed dynamics, hill agriculture

## 1. Introduction

The Eastern Himalayan region, particularly the state of Manipur, is a biodiversity hotspot known for its unique germplasm of Solanaceous crops. Among these, King Chilli (*Capsicum chinense* Jacq.), locally known as *U-Morok* and globally recognized as one of the hottest chillies (*Bhut Jolokia*), holds a premier position. For centuries, this crop has been intrinsically linked to the socio-economic fabric of the tribal communities in the Chandel district, consumed as both a fresh culinary staple and a dried cash crop. However, the traditional cultivation of King Chilli is fraught with agronomic challenges. The crop is largely grown under rainfed conditions in hill slopes where water management is critical. *Capsicum chinense* is highly sensitive to hydrological fluctuations; it possesses a shallow root system that succumbs easily to both waterlogging during the heavy monsoons and moisture deficit during the post-monsoon winter months. King chilli, being an energy rich crop require proper manuring and balanced fertilizers along with sufficient moisture level for higher yield and quality produce (Prasad *et al* 2009) <sup>[1]</sup>. Chili is sensitive to water stress, young chili seedlings cannot withstand earlier water stress while older plants can withstand deflects or excess of soil moisture (Ashrafuzzaman *et al.*, 2011) <sup>[1]</sup>.

The district of Chandel has recently experienced highly erratic rainfall patterns, exacerbating these abiotic stresses. During the critical crop establishment phase (February to June), water deficit frequently limits physiological growth, while subsequent heavy rains can lead to root-

zone asphyxiation. Furthermore, the "traditional practice" followed by local farmers involves manual weeding and exposed soil cultivation. This method is labour-intensive and inefficient, as exposed soil rapidly loses moisture through evaporation and facilitates aggressive weed proliferation, which competes for nutrients and light. The convergence of these factors results in a significant yield gap, where the local demand for King Chilli far exceeds the production capacity. To bridge this gap, modern agronomic interventions are required. Mulching the practice of covering the soil surface has been globally identified as a robust tool for soil microclimate modification. Mulching is the general practice of covering the soil around plants to make conditions more favourable for growth, development and efficient crop production (Nagalakshmi *et al.*, 2002) [7]. The theoretical basis of mulching lies in its ability to decouple the soil surface from the atmosphere, thereby reducing evaporation, moderating soil temperature, and obstructing solar radiation required for weed germination. Specifically, black polyethylene mulches are renowned for their ability to increase soil temperature through thermal absorption and conduction, a property vital for winter cropping seasons. Conversely, organic mulches like straw are typically associated with soil cooling. Despite the global validation of mulching technologies, specific research on their impact on *Capsicum chinense* within the specific agro-climatic zone of Chandel is sparse. Most existing studies

focus on generic vegetable crops in plain areas, leaving a knowledge gap regarding the physiological response of King Chilli in hill ecosystems. This study aims to fill that void by systematically evaluating the impact of silver and black polyethylene mulches on soil hydrothermal properties, vegetative growth, reproductive phenology, and economic returns. The objective is to validate a scalable, "climate-smart" technology that can be seamlessly adopted by the tribal farmers of the region.

## 2. Materials and Methods

### 2.1 Geoclimatic Description of the Study Site

The field experiment was conducted over two consecutive cropping cycles (2021-2022 and 2022-2023) in selected farmer fields under the supervision of Krishi Vigyan Kendra (KVK), Chandel. The district is located in the south-eastern part of Manipur, bordering Myanmar, within the coordinates 23.49°-24.28° N latitude and 94.09°-94.31° E longitude. The total geographical area of the district is 3,313 km<sup>2</sup>. The region is characterized by a sub-tropical climate. Weather data recorded during the trial period indicated significant variability. The rainfall pattern was erratic, with peak precipitation occurring in July (~250 mm) and scanty rainfall during the winter months (December-January), creating distinct periods of moisture excess and deficit (Figure 1).

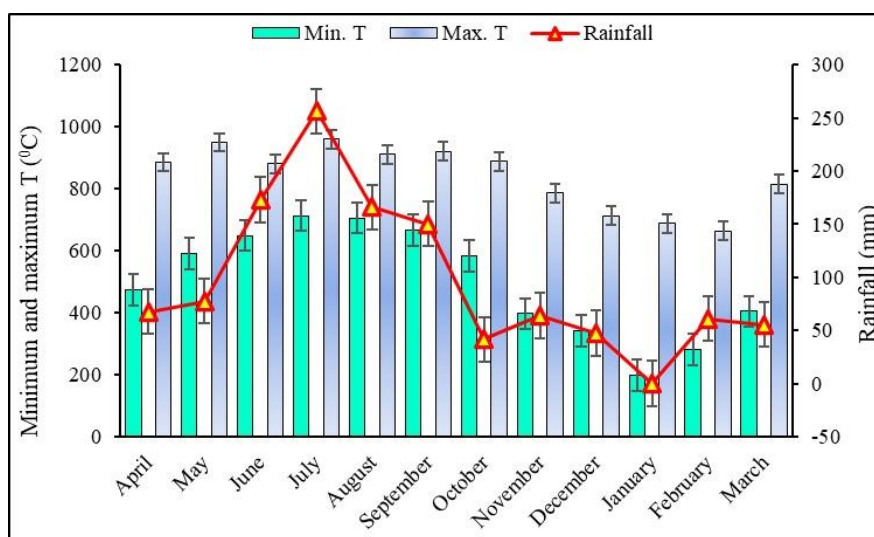


Fig 1: Average maximum and minimum temperature and rainfall (mm)

### 2.2 Experimental Design and Treatments:

The trial was laid out in a Randomized Block Design (RBD) to minimize spatial heterogeneity. The experiment comprised three treatments:

- **T<sub>1</sub> (Mno):** Control/Farmers' Practice. This involved traditional open-field cultivation with no mulch application and manual weeding.
- **T<sub>2</sub> (M1):** Silver Polyethylene Mulch. A reflective mulch sheet intended to repel aphids and conserve moisture.
- **T<sub>3</sub> (M2):** Black Polyethylene Mulch. A 30-micron thick sheet used for weed suppression and soil thermal enhancement.

### 2.3 Agronomic Practices

Land preparation involved deep ploughing followed by harrowing to bring the soil to a fine tilth. Raised beds were

prepared to facilitate drainage, crucial for mitigating waterlogging risks. For the mulched treatments, the polyethylene sheets were laid flat over the beds, and edges were anchored with soil to prevent wind displacement. Circular holes were perforated at specific spacing for transplanting the seedlings. All other agronomic practices, including nutrient management and plant protection, were standardized across all treatments to ensure that observed differences were solely attributable to the mulching factor.

### 2.4 Data Collection and Instrumentation:

- **Vegetative Parameters:** Plant height (cm) and number of primary/secondary branches were recorded at 30, 45, 60, and 90 Days After Transplanting (DAT) using a meter scale and visual counting from five randomly tagged plants per plot.

- **Reproductive Phenology:** The number of days taken for the first flower initiation and 50% flowering were recorded to assess crop maturity duration.
- **Yield Attributes:** Fruit length (cm) and diameter (cm) were measured using digital vernier calipers. Fruit weight (g) was recorded using a precision electronic balance. The total yield per plant was calculated by summing the harvest over multiple pickings.
- **Soil Temperature:** Soil thermal regimes were monitored using soil thermometers placed at depths of 5 cm and 10 cm. Readings were taken at various intervals throughout the day (morning to late afternoon) to map the diurnal temperature curve.
- **Socio-Economic Survey:** To assess adoptability, a survey of participating farmers was conducted, evaluating parameters such as family size, scientific orientation, and attitude towards technology using structured schedules.

## 2.5 Statistical Analysis

The biological data obtained were subjected to Analysis of Variance (ANOVA) for RBD. The standard error of mean (SEM $\pm$ ) and Critical Difference (CD) at 5% probability were

calculated to compare treatment means. Benefit-Cost (B:C) ratio was calculated using the formula: Gross Return/Total Cost of Cultivation.

## 3. Results and Discussion

### 3.1 Socio-Economic Profile of the Farming Community

Successful technology transfer relies on understanding the human demographic. The survey results indicated that 69% of the respondents belonged to medium-sized families (5-9 members), with the majority (89%) living in nuclear family setups<sup>26</sup>. These findings align with Jha *et al.* (2019) <sup>[5]</sup>, reflecting the changing social structure in tribal areas. Ideally, 62% of farmers displayed a "favourable" attitude towards King Chilli cultivation and a "moderate" level of scientific orientation. However, the gap in technical know-how was evident, as 87% had only a "medium" level of adoption of improved practices. These findings are in accordance with the findings of Jha (2012) <sup>[4]</sup> and Boruah *et al.*, (2015) <sup>[2]</sup>. This data validates the necessity of the current study as a demonstration tool to bridge the "lab-to-land" gap.

### 3.2 Effect of Mulching on Vegetative Growth Dynamics

**Table 1:** Comparison of plant height (cm) and primary branches at 45 days, 60 days and 90 days after transplanting

| Treatment | Plant Height (cm) |        |        |        | Primary branches |        |        |        |
|-----------|-------------------|--------|--------|--------|------------------|--------|--------|--------|
|           | 30 DAT            | 45 DAT | 60 DAT | 90 DAT | 30 DAT           | 45 DAT | 60 DAT | 90 DAT |
| Mno       | 25.94             | 32.45  | 36.25  | 42.5   | 1.68             | 4.1    | 7.11   | 10.42  |
| M1        | 29.41             | 36.25  | 39.29  | 47.29  | 2.62             | 6.55   | 9.98   | 14.12  |
| M2        | 32.45             | 36.85  | 42.28  | 49.58  | 2.25             | 6.11   | 8.57   | 13.15  |
| Min       | 25.94             | 32.45  | 36.25  | 42.50  | 1.68             | 4.10   | 7.11   | 10.42  |
| Max       | 32.45             | 36.85  | 42.28  | 49.58  | 2.62             | 6.55   | 9.98   | 14.12  |
| Avg       | 29.27             | 35.18  | 39.27  | 46.46  | 2.18             | 5.59   | 8.55   | 12.56  |
| SD        | 2.66              | 1.95   | 2.46   | 2.95   | 0.39             | 1.07   | 1.17   | 1.57   |
| CV        | 9.09              | 5.54   | 6.27   | 6.35   | 17.71            | 19.09  | 13.70  | 12.47  |
| SE        | 1.54              | 1.12   | 1.42   | 1.70   | 0.22             | 0.62   | 0.68   | 0.90   |

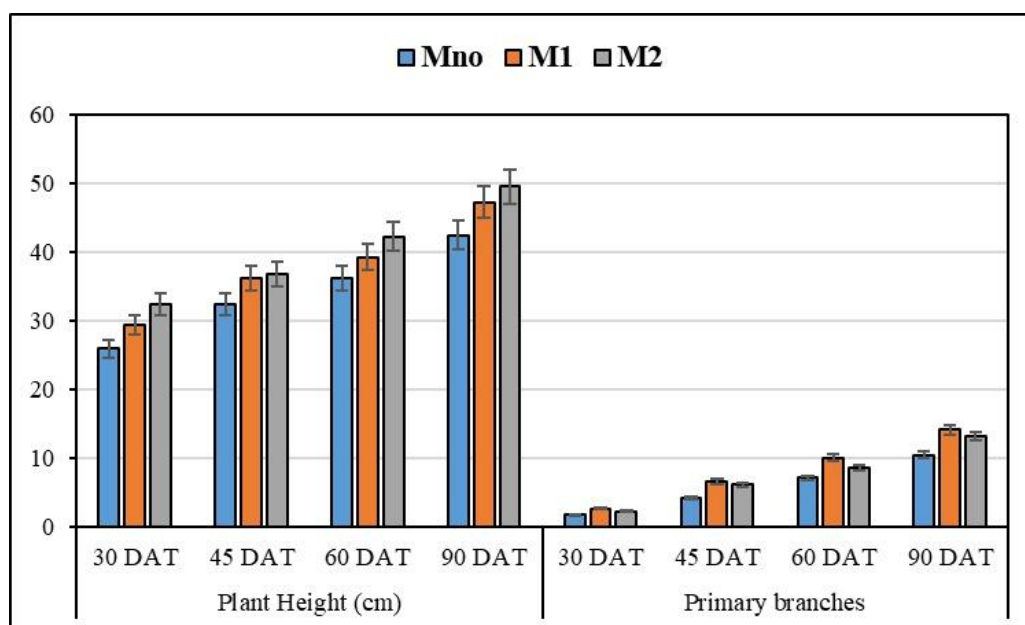


**Fig 2:** Comparison of plant height and primary branches

The application of polyethylene mulches induced a significant positive response in the vegetative architecture of the plants.

- **Plant Height:** As presented in Table 1, the Black Mulch (M2) treatment consistently recorded superior

plant height across all observation intervals. At 90 DAT, plants under M2 reached a mean height of 49.58 cm, significantly taller than the 42.50 cm observed in the Control (Mno). The Silver Mulch (M1) performed immediately, recording 47.29 cm. The increased plant

height in mulched plants was possibly due to moisture conservation, higher soil temperature, weed control, and increased mineral nutrient uptake. Changes in the plant height of chilli have been observed with different mulches and plastic mulch found to increase plant height than other mulches as also reported by Shinde *et al*, (1999) <sup>[12]</sup>.

- **Branching:** The number of primary and secondary branches—key determinants of the plant's photosynthetic canopy—followed a similar trend. M2 recorded the highest number of primary branches (13.15) at 90 DAT, compared to just 10.42 in the control.

### Discussion on Growth parameters:

The enhanced vegetative growth under black mulch can be attributed to the "mulch effect," which conserves soil moisture and minimizes nutrient leaching. As noted by Patil and Bansod (1972) <sup>[10]</sup>, black polyethylene creates a favourable microclimate that enhances microbial activity and nitrogen mineralization, making more nutrients available for uptake.

### 3.3 Impact on Reproductive Phenology earliness in flowering is a critical trait for market economics, allowing farmers to capture early-season premium prices

**Table 2:** Comparison of secondary branches, flowering initiation and time taken for 50% flowering after different DAT

| Treatment | Secondary branches |        |        | Flowering initiation<br>(From DAT) | Days taken to 50%<br>flowering |
|-----------|--------------------|--------|--------|------------------------------------|--------------------------------|
|           | 45 DAT             | 60 DAT | 90 DAT |                                    |                                |
| Mno       | 5.61               | 12.32  | 17.11  | 17.21                              | 24.22                          |
| M1        | 7.89               | 16.21  | 19.89  | 15.18                              | 21.57                          |
| M2        | 9.18               | 18.21  | 21.57  | 14.14                              | 21.18                          |
| Min       | 5.61               | 12.32  | 17.11  | 14.14                              | 21.18                          |
| Max       | 9.18               | 18.21  | 21.57  | 17.21                              | 24.22                          |
| Avg       | 7.56               | 15.58  | 19.52  | 15.51                              | 22.32                          |
| SD        | 1.48               | 2.45   | 1.84   | 1.27                               | 1.35                           |
| CV        | 19.52              | 15.70  | 9.42   | 8.22                               | 6.05                           |
| SE        | 0.85               | 1.41   | 1.06   | 0.74                               | 0.78                           |

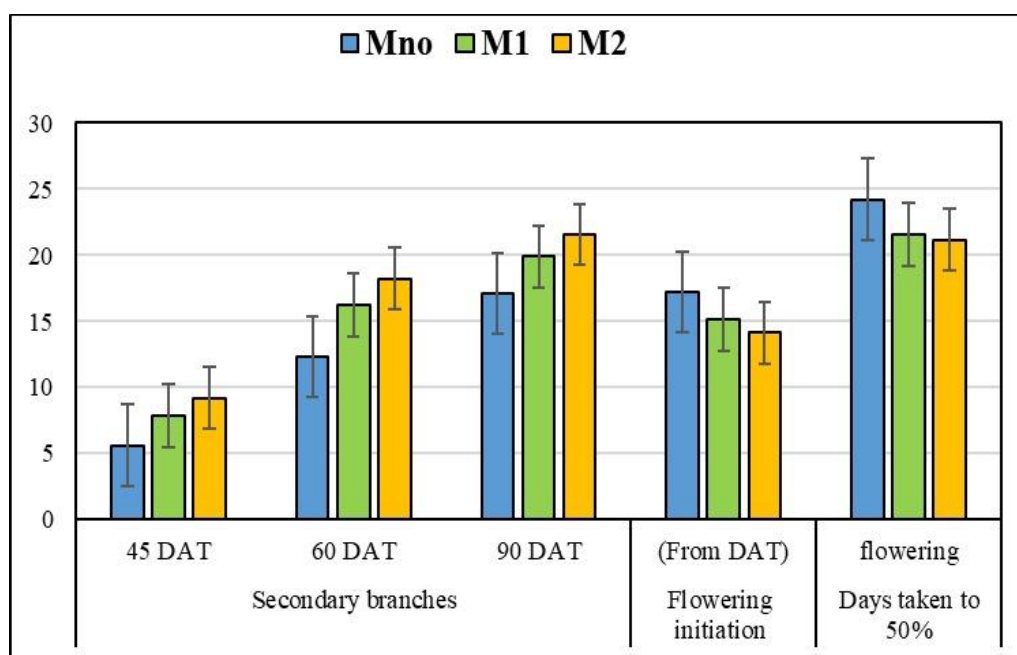


**Fig 3:** Comparison of secondary branches, flowering initiation and days taken for 50% flowering

- **Flowering Initiation:** The study observed that black mulch significantly advanced the reproductive phase. Floral initiation occurred earliest in M2 (14.14 DAT), whereas the control plants delayed initiation until 17.21 DAT.
- **50% Flowering:** Similarly, the time taken to achieve 50% flowering was reduced to 21.18 days in M2, compared to 24.22 days in the control.

The first flowering was observed in the plant under black mulch (14.14 DAT) and the longest duration was seen in case of control plot (17.21 DAT). Also, the plants under black mulch took 21.18 days to achieve 50% flowering as against 24.22 DAT in case of farmers' plots.

This acceleration in phenology is likely driven by the higher soil temperatures maintained under the black mulch, which stimulates root metabolic activity and hormonal signalling for faster development, a phenomenon corroborated by Dhesi *et al*. (1964) <sup>[3]</sup>.

### Effect on secondary branches and flowering initiation

As can be seen from the Figure 3, in the case of secondary branches per plant, it was observed that the maximum number of secondary branches per plant in black plastic mulch (9.18, 18.21, 21.57) and minimum secondary branches in no mulch condition (5.61, 12.32, 17.11) at 30, 60 and 90 DAT respectively.

### 3.4 Yield Attributes and Total Productivity

**Table 3:** Observations on average fruit length, diameter and weight

| Treatment | Fruit length (cm) | Fruit Diameters (cm) | Average weight of fruit (g) |
|-----------|-------------------|----------------------|-----------------------------|
| Mno       | 7.54              | 0.81                 | 3.69                        |
| M1        | 8.25              | 0.87                 | 4.38                        |
| M2        | 8.77              | 0.86                 | 4.54                        |
| Min       | 7.54              | 0.81                 | 3.69                        |
| Max       | 8.77              | 0.87                 | 4.54                        |
| Avg       | 8.19              | 0.85                 | 4.20                        |
| SD        | 0.50              | 0.03                 | 0.37                        |
| CV        | 6.16              | 3.10                 | 8.77                        |
| SE        | 0.29              | 0.02                 | 0.21                        |

**Table 4:** Observations on average fruit/plant, fruit yield/plant and fruit yield/plot

| Treatment | Number of fruits plant <sup>-1</sup> | Fruit yield plant <sup>-1</sup> | Fruit yield plot <sup>-1</sup> |
|-----------|--------------------------------------|---------------------------------|--------------------------------|
| Mno       | 139.34                               | 579.31                          | 8.79                           |
| M1        | 145.23                               | 665.28                          | 10.87                          |
| M2        | 155.68                               | 755.32                          | 11.28                          |
| Min       | 139.34                               | 579.31                          | 8.79                           |
| Max       | 155.68                               | 755.32                          | 11.28                          |
| Avg       | 146.75                               | 666.64                          | 10.31                          |
| SD        | 6.76                                 | 71.86                           | 1.09                           |
| CV        | 4.60                                 | 10.78                           | 10.57                          |
| SE        | 3.90                                 | 41.49                           | 0.63                           |

The ultimate measure of agronomic success is yield. The data indicates that mulching had a transformative effect on the economic output of King Chilli.

- **Fruit Metrics:** Plants grown under black mulch produced significantly heavier and larger fruits. The average fruit weight in M2 was 4.54 g, whereas control fruits weighed only 3.69 g. Fruit length also increased from 7.54 cm (Control) to 8.77 cm (M2). This is in tune with the findings of Neupane *et al* (2021) <sup>[9]</sup>.

- **Yield Volume:** The most striking difference was observed in the number of fruits per plant. M2 recorded an average of 755.32 fruits/plant, a massive increase over the 579.31 fruits/plant in the control. The results were in accordance with Narayan *et al* (2017) <sup>[8]</sup> who reported recorded highest number of fruits with maximum fruit weight and total fruit yield in case of black plastic mulch (double coated) in chilli.

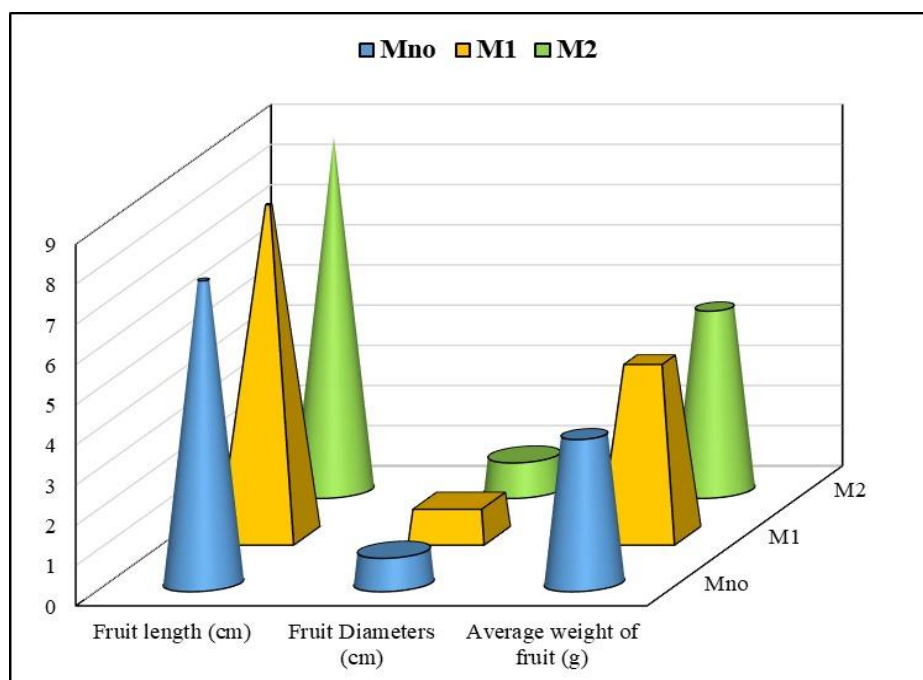


**Fig 4:** Comparison of average fruit length, diameter and weight

#### Effect on fruit yield & quality

Among mulching treatments, as seen in figure 4, black plastic mulch recorded average number of fruits/plant (755.32) with 579.31 fruits/plant observed in no mulch

condition. Also, the weight of fruit in mulched plants was recorded to be 4.54 g as compared to 3.69 g in no mulch plants. The results are in close harmony with the result reported by (Singh *et al*, 2005) <sup>[13]</sup> in tomato. The increase in

the fruit yield of mulched plot was probably associated with the conservation of soil moisture and improved microclimate in both beneath and above the soil surface. The suitable condition enhanced the plant growth and development and produced increased fruit bearing nodes compared to the control. Similar finding was reported by Ashrafuzzaman *et al.*, (2011) <sup>[1]</sup> in chilli. The amiable conditions are supposed to have enhanced the plant growth and development and produced increased fruit bearing nodes compared to the control. The increase in the number of fruits per plant of mulched plot (Figure 5) was probably associated with the conservation of moisture and improved microclimate both beneath and above the soil surface. Quite similarly, Nagalakshmi *et al* (2002) <sup>[7]</sup> reported the maximum number of fruits per plant (97.67), length of fresh fruit (6.93 cm) and circumference of fruit (3.57 cm) with the application of black plastic mulch compared to organic and no mulch (control). These researchers observed that plants under polyethylene mulch produce larger fruit and have higher fruit yield per plant because of the better plant growth that due to favourable hydro-thermal regime of soil and complete weed free environment.

The amiable condition enhanced the plant growth and development and produced increased fruit bearing nodes compared to the control. Keeping in consideration the relationship between the soil moisture content and fruit number, it was clear that fruit number had a strong relation with soil moisture content. Hence, mulching produced higher fruit yield per plant and fruit yield per hectare than for the control, indicating that the mulch had positive effect in generating increased fruit yield.

- The observed results were in accordance with those reported by Narayan *et al* (2017) <sup>[8]</sup> who also recorded

highest number of fruits with maximum fruit weight and total fruit yield in case of black plastic mulch (double coated) in chilli. Similar findings were also reported by Kanak *et al.* 2025 <sup>[6]</sup>.

**Discussion on Yield:** The substantial yield increase (approx. 30% over control) in mulched plots is linked to two primary factors:

1. **Weed Suppression:** Black mulch serves as an opaque barrier to solar radiation, effectively arresting weed germination. This eliminates weed-crop competition for nutrients and light.
2. **Moisture Conservation:** By preventing surface evaporation, the mulch ensures that the shallow root system of the chilli plant has continuous access to moisture, which is critical for fruit setting and preventing blossom drop.

### 3.5 Soil Hydrothermal Regimes:

The study confirmed the thermodynamic properties of black polyethylene.

- **Thermal Regulation:** Soil temperature recordings at 5 cm depth revealed that M2 maintained temperatures 4.8 °C to 5.3 °C higher than the control plots during the peak afternoon hours (3:30 PM).
- **Diurnal Trends:** Temperatures gradually increased from early morning, peaking in the afternoon. The mulch acted as a "one-way valve," allowing radiation to heat the soil while preventing the escape of long-wave thermal radiation, creating a greenhouse effect within the soil profile. This thermal boosting is vital during the cooler months of the crop cycle.



**Fig 5:** The performance of king chilli plants in field conditions

### Effect on soil temperature

The average soil temperature at 5 to 10 cm depth was different due to the effect of mulch. Soil temperature varied significantly with mulch, time of the day and the depth of soil. Soil temperature was less in the early morning and gradually increased until it peaked at 3:30 pm in all the fields and then decreased gradually. The soil temperature under mulch was higher than that of the control plots for all the times as was also reported by Yasmin *et al*, (2020) <sup>[14]</sup>. The maximum difference in temperatures between mulched and control plots was 4.8 to 5.3 °C at 5 cm soil depth at 3:30 pm. In general, soil temperature was higher at 5 cm than at 10 cm depth. The polythene mulch seemingly allowed part of the radiation to pass through it but acted as barrier against outgoing thermal radiation.

### 4. Conclusion and Recommendations

The findings of this two-year investigation provide conclusive evidence that the adoption of black polyethylene mulching is a viable, high-impact strategy for King Chilli growers in the Chandel district. The intervention addresses the core constraints of the region: erratic rainfall, moisture deficit, and weed drudgery.

### Key Conclusions

1. **Superior Growth:** Black mulch (M2) significantly enhances vegetative vigor and advances flowering by approximately 3 days.
2. **Yield Maximization:** It increases fruit yield by maintaining optimal soil moisture and temperature regimes.

3. **Weed Management:** It acts as an effective, chemical-free weed control measure.

### Recommendation

It is recommended that extension agencies and KVKs prioritize the demonstration of black polyethylene mulching technology to tribal farmers. Future policy should focus on subsidizing mulching materials to accelerate adoption, thereby ensuring sustainable farm incomes and food security in the hill ecosystems of Manipur.

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