FASE FRONTIERS OF AGRICULTURAL SCIENCE AND ENGINEERING

CHINESE ACADEMY OF ENGINEERING 中国工程院 Engineering Transactions of CAE

RESEARCH ARTICLE

2026 / Volume 13 / Issue 1 / 25648

Biodegradable and non-biodegradable plastic mulches enhance chili production in Sri Lankan wet zone agriculture

Nipuna THENNAKOON[1], Sidath WICKRAMA[1], Nalin MADHURANGA[1], Chandima JAYASUNDARA[2], Achini DIAS[3,4], Meththa GIMHANI[3,4], Mojith ARIYARATNA (✉)[1], Anurudda KARUNARATHNA[2], Surani CHATHURIKA[3,5], Martine GRAF[4], Michaela REAY[6], David CHADWICK[4], Davey JONES[4]

1 Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya 20400, Sri Lanka.
2 Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya, Peradeniya 20400, Sri Lanka.
3 Sri Lanka Institute of Nanotechnology, Nanotechnology and Science Park, Mahenwatta, Pitipana, Homagama 10206, Sri Lanka.
4 School of Environmental and Natural Sciences, Bangor University, Bangor, Gwynedd, LL57 2UW, United Kingdom.
5 Department of Urban Bioresources, Faculty of Urban and Aquatic Bioresources, University of Sri Jayewardenepura, Nugegoda 10115, Sri Lanka.
6 Organic Geochemistry Unit, School of Chemistry, University of Bristol, Bristol BS8 1TS, United Kingdom.

KEYWORDS

Plasticulture, soil fertility, sustainable agriculture, water conservation, yield

HIGHLIGHTS

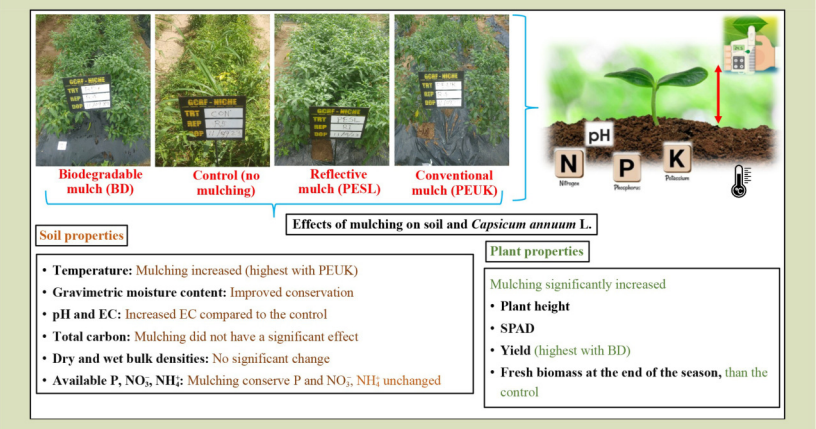
- All plastic mulches promoted soil moisture retention compared to the unmulched control.
- Non-biodegradable mulch gave the highest soil temperature and the control was the lowest.
- Mulching conserved soil P and NO_3^-, but had little effect on NH_4^+.
- Mulching did not affect soil pH but increased soil EC relative to the control.
- Biodegradable mulch performed comparably to non-biodegradable plastic mulches by improving biomass yield.

Received December 31, 2024;
Accepted June 16, 2025.

Correspondence: mojith@agri.pdn.ac.lk

Special Issue: Agricultural Plastic's Application and Problems

GRAPHICAL ABSTRACT



ABSTRACT

Plastic film mulching (PFM) enhances plant growth and productivity by modifying soil properties. In Sri Lanka, the adoption of PFM is gradually rising, especially for high-value crops. However, its influence on soil remains a topic of significant scrutiny, especially in environmentally delicate locations such as the wet zone (WZ) of Sri Lanka. This research examines how different PFMs affect soil physicochemical properties and plant performance in chili production within the WZ. Chili (*Capsicum annuum* cv. MICH HY-1) was cultivated under a non-biodegradable low-density polyethylene (LDPE) mulch (PEUK), a reflective LDPE mulch, a PLA-PBAT biodegradable mulch (BD) and no

mulch film application for one growing season. Soil physicochemical properties (pH, EC, moisture, nutrients and temperature), plant height and leaf chlorophyll content (SPAD) were measured monthly. The fresh biomass of roots, leaves, stems and remaining fruits was measured at the end of the season. This study demonstrated that mulching effectively conserved soil NO_3^- and available P while having no significant impact on NH_4^+ levels. Mulching increased gravimetric moisture content (GMC) and soil temperature compared to the control, with PEUK achieving the highest soil temperature (36.3 ± 0.71 °C). Mulching did not influence soil pH, but the control consistently had the lowest EC (17.6 ± 1.54 μS·cm^{-1}). Mulching significantly improved plant height (PEUK of 70.2 ± 1.7 cm), SPAD (PEUK of 65.6 ± 1.4), yield (BD of 1230 ± 84 g) and fresh biomass relative to the control (height of 58.8 ± 2.3 cm, SPAD of 49.7 ± 1.5 and yield of 736 ± 59 g). Overall, the findings demonstrate that biodegradable mulch performed similarly to non-biodegradable plastic mulches in improving both soil properties and crop yield, indicating it could be a sustainable alternative for chili production in wet tropical regions.

© The Author(s) 2025. Published by Higher Education Press. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0)

1 Introduction

Chilies (*Capsicum annuum* and *C. frutescens*), grown for the a hot-tasting tropical fruit, belongs to the Solanaceae family[1]. As a crucial agricultural commodity, chili is important for the economy in Sri Lanka, contributing to both domestic consumption and export revenues[2]. In 2023, *Yala* (April to September) and *Maha* (October to March) growing seasons, Sri Lanka produced a total of 67.4 Mt of green chili from a total of 12100 ha[3]. The country exports various chili-based products, including dried chili, chili powder and other processed products, to markets such as India, the Middle East and Europe. Chili production supports the livelihoods of smallholder farmers, especially in rural areas, due to the high demand for the crop. Also, chili is an essential ingredient in Sri Lankan cuisine, which drives local consumption[4].

However, chili farmers in Sri Lanka face multiple agronomic challenges that limit productivity, including water scarcity, nutrient management inefficiencies, weed competition, and pest and disease pressure[2]. Erratic rainfall patterns, exacerbated by climate change, disrupt production cycles, leading to reduced productivity[5]. Additionally, price volatility in fertilizer markets can significantly affect chili prices, resulting in income uncertainty for farmers. These challenges emphasize the need for effective water conservation strategies, weed control and efficient fertilizer management practices to maintain high yields and stable incomes[2,5]. To address these challenges, many farmers have adopted plastic film mulching (PFM) for chili production[2].

PFM has been shown to enhance plant growth and productivity by reducing evaporation, regulating soil temperature, and improving water use efficiency[6–8]. Also, it supports sustainable practices by promoting plant development, accelerating fruit ripening and improving crop quality[9]. Specifically, UV-treated silver-on-black low-density polyethylene (LDPE) mulch has demonstrated efficacy in increasing chili growth and yield while reducing weed infestations and fertilizer dependency[2]. This UV-treated silver-on-black polyethylene mulch is widely used in Sri Lanka because of the higher market availability and cheaper than other mulch types (i.e., biodegradable and black-only non-biodegradable LDPE mulch). It differs from non-biodegradable mulch because a silver top coat is treated with UV inhibitors to prevent mulch degradation and act as a pest repellent by reflecting light[2]. Plastic film mulching has been reported to increase crop yields by 20%–50% in maize production, by improving soil hydrothermal conditions and tilth[10–12]. In chili production, it optimizes soil health and crop growth by elevating topsoil temperatures, which accelerates early plant development, particularly in cooler climates[13–15]. Also, PFM reduces soil compaction, enhancing root penetration and

nutrient use efficiency[16,17]. For example, in maize production, PFM has been shown to enhance inorganic N availability, decrease N leaching and improve N use efficiency, leading to improved germination, N uptake and higher grain yields[18,19]. Additionally, PFMs mitigate soil erosion by protecting the soil surface, preserving valuable topsoil and preventing long-term land degradation[20,21].

LDPE mulches remain dominant in global agriculture due to their mechanical resilience, predictable performance across climates and economic accessibility, particularly for smallholder farmers[9,12]. Their impermeability effectively minimizes water loss and stabilizes soil temperatures, fostering early crop establishment in variable climates[22,23]. However, long-term LDPE use risks soil degradation through microplastic accumulation and reduced microbial diversity, exacerbating environmental burdens in ecologically sensitive regions[24,25]. Conversely, biodegradable films can mitigate plastic pollution by degrading to carbon dioxide, water and microbial biomass, aligning with circular economy principles[26,27]. However, their adoption is hindered by higher costs, inconsistent degradation rates under tropical humidity and reduced tensile strength, which may compromise weed suppression and durability in high-rainfall systems[8,9]. While biodegradable mulches often require tailored formulations to match the thermal efficiency of LDPE, their capacity to balance agronomic performance with environmental sustainability is considerable, positioning them as critical for tropical regions that prioritize both soil health and long-term productivity.

PFM adoption in Sri Lanka's tropical agriculture is in a transitional phase, with farmers slowly incorporating this technology into their agronomic practices[28]. However, in certain regions, the practice of using raised beds covered with PFM has become standard for producing high-value crops, such as chili, squash and eggplant[2,28]. Despite the growing use of PFM in wet tropical regions, significant knowledge gaps exist regarding optimal PFM selection and application, particularly in Sri Lanka's WZ. Field-based research is therefore needed to evaluate both non-biodegradable and biodegradable PFMs, considering their agronomic benefits and potential environmental impact.

This study, therefore, aimed to assess how these different types of mulching materials influence soil physical and chemical properties, crop growth, and crop productivity in a real-world field setting. To our knowledge, this is the first study in Sri Lanka to compare the agronomic performance and soil physical and chemical properties of chili production using three different types of PFMs, including a biodegradable mulch, a non-biodegradable black mulch, and a reflective non-biodegradable mulch film. We hypothesized that (1) different PFM types would differentially modify soil properties based on their physical characteristics (with non-biodegradable black LDPE maximizing soil warming, reflective LDPE mulch optimizing light distribution and biodegradable mulch providing comparable benefits), and (2) these modifications would lead to enhanced crop performance metrics compared to bare soil through improved growing conditions. By evaluating the performance of these mulches in the WZ and red-yellow podzolic soil conditions, we aimed to provide valuable insights into their potential for enhancing sustainable farming practices in similar climates and soil conditions.

2 Materials and methods

2.1 Site selection

The study was conducted at the Meewathura Field Research Station (7°25′ N 80°59′ E), situated in Peradeniya (Agro Climatic Zone-WM), within the Kandy District of the Central Province, Sri Lanka. The field is located at an elevation of 500 masl and is characterized by a sandy clay-loam texture, and the soil unit is a red-yellow podzolic soil (Rhodudults and Tropudults) under the Sri Lankan classification system, which corresponds to Entisols in the USDA soil classification[29–31]. These soils are known for being acidic, with pH values typically ranging between 4.5 and 5.5, requiring specific management practices for agricultural productivity. The regional climatic conditions include an annual temperature range from a minimum of 18 °C to a maximum of 33 °C and a total annual rainfall ranging from 1400 to 3300 mm[32]. The research was conducted over 7 months, encompassing both the dry and wet periods from the end of August 2023 to mid-March 2024. The weather parameters of the site during the research period are given in Fig. 1. This extended period allowed for the observation of crop performance under varying seasonal conditions. The field area was specifically selected due to its suitability for the research objectives, and as it had no prior history of plant fertility management applications or plastic incorporation, ensuring a controlled environment for assessing treatment impacts.

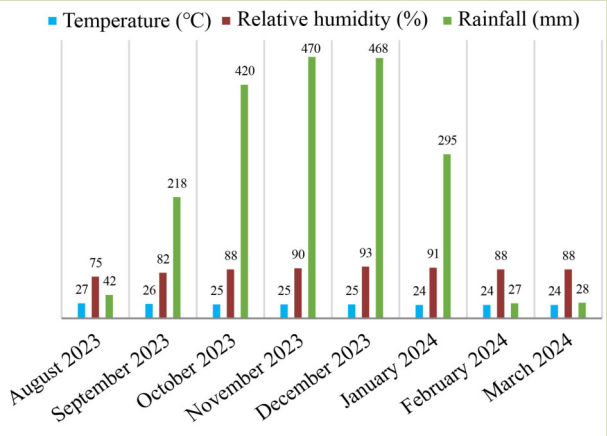


Fig. 1 Weather parameters of the research site during the experimental period.

2.2 Experimental design

The experimental site was prepared by thoroughly weeding the area and plowing the soil to a depth of 15 cm, and seedbeds were prepared after rotavating the soil. The experimental design was a randomized complete block design with four replicates for each treatment, resulting in a total of 16 plots, which were arranged into a 4 × 4 grid (Fig. 2). Each plot measured 1 m × 4 m. The total land area was 108 m^2. The plots were arranged as furrows with ridges spaced 50 cm apart. A sprinkler system with six sprinklers was established for the irrigation. The PFMs were manually installed over the respective plots, 1 day before the transplanting date of chili seedlings, with the edges buried in the soil to ensure they remained securely in place throughout the study.

The study incorporated three types of PFMs as treatments: (1) non-biodegradable mulch, a black low-density polyethylene (LDPE) film with a thickness of 30 μm (GroMax Industries Ltd., UK), from here on referred to as PEUK; (2) reflective mulch, a black and silver LDPE film with a thickness of 30 μm (Heyleys Agriculture Holdings Ltd., Colombo, Sri Lanka), from here on referred to as PESL. Silver LDPE mulch is made by co-extruding a black layer with a silver-pigmented or metallic-coated film. The silver side reflects more light and absorbs less heat, but its durability is reduced due to UV degradation. The final PFM treatment was (3) biodegradable mulch, composed of a 15:85 weight ratio blend of polylactic acid (PLA) and polybutylene adipate-*co*-terephthalate (PBAT), with a thickness of 15 μm (GroMax Industries Ltd., Hadleigh, UK), from here on referred to as biodegradable mulch (BD). An unmulched control treatment (CON) consisting of bare soil was included for comparison.

Chili (*C. annuum* cv. MICH HY-1 hybrid) seeds, which were treated with Captan 50% WP (7 $g \cdot m^{-2}$) to avoid damping off, were put into the nursery on 13 August 2023. All agronomic practices followed the recommendations given by the Department of Agriculture, Sri Lanka. After a 4-week nursery

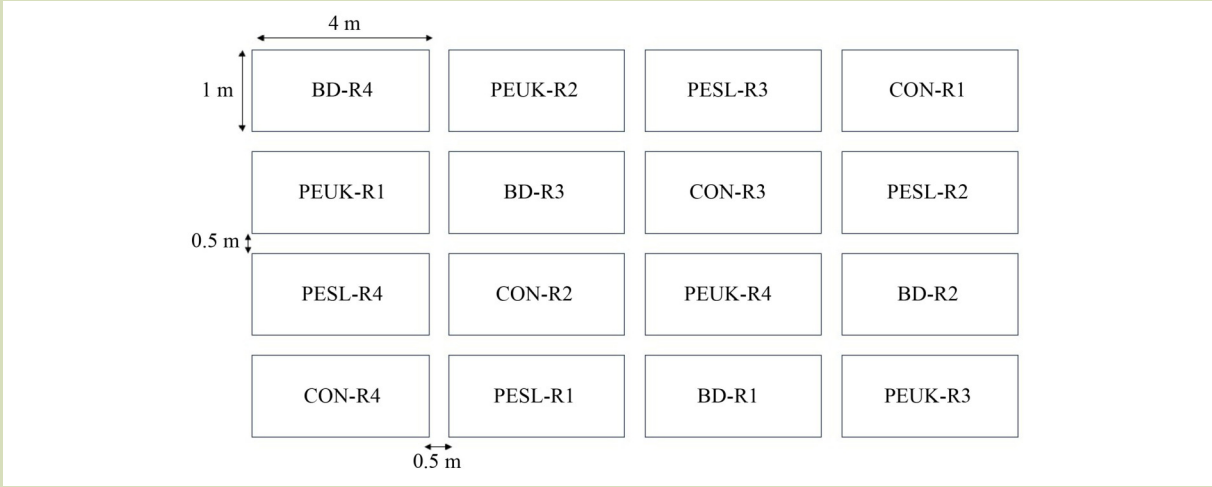


Fig. 2 Field layout showing the complete randomized treatment plots. CON-R, no mulching-replicate; BD-R, biodegradable mulch-replicate; PESL, reflective mulch-replicate; PEUK, non-biodegradable mulch-replicate.

period, chili seedlings were planted in the field on 10 September 2023. Spacing of 60 cm between rows and 45 cm between plants was used in two parallel rows per plot, with each row containing nine seedlings, resulting in a total of 18 plants per plot[33]. Fertilizer application was meticulously planned, starting with a basal dose of 100 kg·ha^{-1} of triple super phosphate (TSP) and 50 kg·ha^{-1} of muriate of potash (MOP)[33]. After planting, all agronomic practices were performed in the same manner for all plots to minimize any effect of management practices on the results. Plots were fertilized again at 2 weeks after planting (WAP) with 100 kg·ha^{-1} of urea, at 4 WAP with 125 kg·ha^{-1} of urea, at the flowering stage (8 WAP) with 125 kg·ha^{-1} of urea and 50 kg·ha^{-1} of MOP, and at 12 and 16 WAP with 125 kg·ha^{-1} of urea was applied as a support to the nutritional needs of the plants[33]. Chili was cultivated during the *Maha* season, and irrigation was conducted in 2-day intervals throughout the growing season, according to the requirement, considering the rainfall in the area, to maintain the optimal soil moisture condition for plant growth. Irrigation practices were similar to the local farmers in the WZ, Sri Lanka. Manual weeding was done after planting with the top-dressing application to reduce competition from unwanted plants and to avoid pest and disease occurrence. Pest control was done using Imidacloprid 200 kg·m^{-3} SL, Fenobucarb 500 kg·m^{-3} electrical conductivity (EC) and Profenophos 500 kg·m^{-3} EC according to necessity. Plants were harvested manually 90 days after planting, once the chili pods turned dark green.

2.3 Measuring soil and plant parameters

From the start of the experiment, soil gravimetric moisture content (GMC) and temperature were measured at three locations per plot at 10 cm depth, at monthly intervals using an in-house moisture-temperature meter, which was created and calibrated using the oven drying method and soil thermometer, specifically for this experiment. At the start and end of the season, soil wet and dry bulk densities were measured using the core method[34].

Every 4 weeks, soil samples were collected from 0 to 20 cm depth using a stainless-steel soil corer. Three random samples were taken within a 15-cm radius from the plant base in each plot and homogenized for pH, EC, and nutrient analysis. Soil pH and EC were measured using a 1:2.5 w/v ratio of fresh soil to distilled water extraction method. From each sample, 10 g of soil was homogenized with 25 mL of distilled water by shaking for 30 min and allowing it to settle for 10 min. EC and pH were measured using a calibrated pH and EC meter (Eutech WC PC 650, Eutech instruments Pte Ltd., 7 Gul Circle, Singapore) with standard electrodes.

Available soil phosphorus, ammonium and nitrate were measured as nutrient parameters. P was analyzed in a 1:5 w/v ratio of air-dried soil to 0.5 mol·L^{-1} $NaHCO_3$ extract, following a modified ammonium molybdate colorimetric method[35]. Inorganic nitrogen was extracted in a 1:5 w/v fresh soil to 0.5 mol·L^{-1} KCl extract. NH_4^+ was measured colorimetrically via the salicylic acid method[36] and NO_3^- was analyzed using the vanadium chloride method[37].

Crop height was measured at monthly intervals on six randomly selected plants per plot, from the plant base to the tip of the longest shoot when fully elongated using a measuring tape. Leaf chlorophyll content was also assessed at monthly intervals using a SPAD chlorophyll meter (SPAD-502 PLUS, Konica Minolta, Tokyo, Japan) on six randomly selected plants per plot. Plants were harvested every 2 weeks, a total of six times throughout the season. Six plants per plot were randomly selected, and the fresh weight of chilies was recorded. At the end of the experiment (13 March 2024), the previously selected six plants were uprooted and cleaned from each plot. Leaves, stems and remaining fruits were shredded separately, the roots were washed from the soil and fresh biomass was recorded for all parts.

2.4 Statistical analysis

All data was tested for outliers using Dixon's Q-Test. Descriptive statistics were used to attain standard errors. Plant (leaves, stem, remaining fruits and stem fresh biomass) and soil (total C, wet and dry bulk density) measurements at the end of the season and harvest data were analyzed using one-way analysis of variance (ANOVA), and the mean separation was performed using Duncan's New Multiple Range Test. To assess treatment differences in time series measurements (nutrients, pH and EC for soil) and (SPAD and plant height for plants), mixed-effect models (repeated measures ANOVA) were applied, and LSD means separation was done. All analyses were performed using SAS statistical software, University Edition, and the interpretations were made at $\alpha = 0.05$.

3 Results

3.1 Soil chemical parameters

Overall, available soil P, NH_4^+ and NO_3^- revealed temporal effects and differences between the different mulching treatments ($p < 0.05$). At 4 WAP, the PESL treatment (18.3 ± 3.4 mg·kg^{-1}) had the highest P concentration, while the BD (8.4 ± 1.0 mg·kg^{-1}) treatment had the lowest ($p < 0.05$, Fig. 3(a)). By 8 WAP, P levels increased in PESL (20.2 ± 0.4 mg·kg^{-1}) and remained the highest compared to BD (12.1 ± 1.3 mg·kg^{-1}) and PEUK (9.7 ± 0.4 mg·kg^{-1}) as the lowest. At 12 WAP, BD treatment had the highest P concentration (20.6 ± 4.5 mg·kg^{-1}), while PESL (12.3 ± 1.7 mg·kg^{-1}) had the lowest concentration ($p < 0.05$). There were no significant differences between the four treatments at 16 WAP. At 20 WAP, BD and PEUK had the highest available P (8.9 ± 0.77 and 8.8 ± 0.74 mg·kg^{-1}, respectively) while the CON and PESL had the lowest (6.7 ± 0.72 and 6.5 ± 0.27 mg·kg^{-1}), respectively ($p < 0.05$, Fig. 3(a)). At 24 WAP, the highest available P concentration was in the BD treatment (8.2 ± 0.76 mg·kg^{-1}) and the lowest P concentration was in the CON and PESL treatments (6.3 ± 0.53 and 5.7 ± 0.12 mg·kg^{-1}) ($p < 0.05$, Fig. 3(a)). From 16 WAP to 24 WAP, P concentrations decreased across the four treatments. Overall, the PESL treatment had the highest P concentration at 4 and 8 WAP, while BD had the highest values at 12, 20 and 24 WAP. The CON had the lowest concentration at 8.20 mg·kg^{-1} and 24 WAP when compared to other treatments, resulting in lower available P retention in WZ chili fields.

For soil ammonium at 4 WAP, the BD treatment had the highest concentration and the PEUK treatment the lowest ($p < 0.05$, Fig. 3(b)). By 8 WAP, NH_4^+ levels dropped sharply across the four treatments, with PESL having the highest concentration (6.6 ± 2.5 mg·kg^{-1}) and CON was the lowest (3.7 ± 0.1 mg·kg^{-1}). By 12 WAP, NH_4^+ concentrations had increased for all treatments, but there were no significant differences between treatments. By 16 WAP, NH_4^+ concentrations had decreased across all treatments, having the

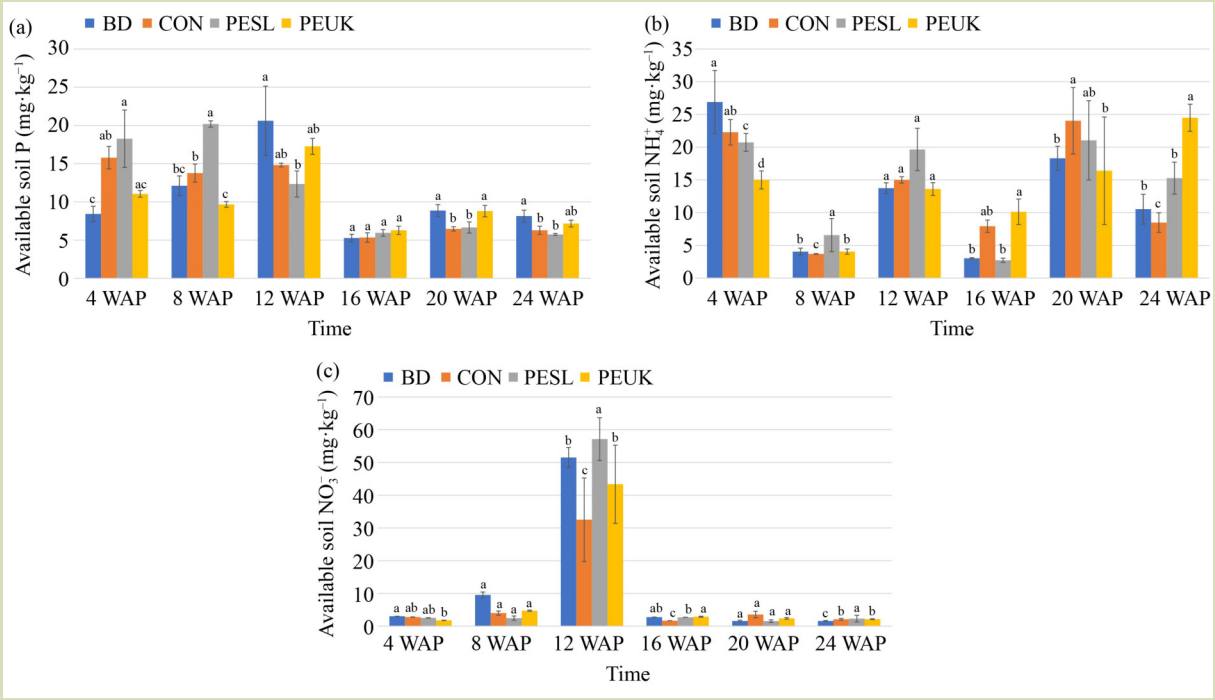


Fig. 3 (a) Available soil P, (b) available soil NH_4^+, and (c) available soil NO_3^- measured at different time points under four treatments. CON, no mulching; BD, biodegradable mulch; PESL, reflective mulch; PEUK, non-biodegradable mulch; and WAP, weeks after planting. Values are means ± standard error of the mean (SEM), lowercase letters on the error bars indicate significant differences between four treatments ($n = 4$) ($p < 0.05$).

lowest available NH_4^+ concentration in PESL and BD (2.7 ± 0.3 mg·kg^{-1} and 3.0 ± 0.1 mg·kg^{-1}, respectively) compared to others (p < 0.05, Fig. 3(b)). By 20 WAP, NH_4^+ concentrations had increased, with the CON treatment having the highest value (24.0 ± 5.1 mg·kg^{-1}), and PEUK and BD the lowest (16.4 ± 8.2 mg·kg^{-1} and 18.3 ± 1.8 mg·kg^{-1}, respectively). At 24 WAP, PEUK was the highest NH_4^+ concentration (24.5 ± 2.1 mg·kg^{-1}) and CON was the lowest (8.5 ± 1.5 mg·kg^{-1}) (p < 0.05, Fig. 3(b)). The BD treatment had the highest NH_4^+ concentration at 4 WAP and PESL peaked at 16 WAP and CON at 20 WAP. NH_4^+ concentrations fluctuated across the study period, with sharp declines observed at 8 and 16 WAP, followed by increases at later stages, where PEUK had the highest concentration at 24 WAP. There was no clear indication of the effect of mulching on available soil NH_4^+.

For soil NO_3^-, at 4 WAP, the BD treatment had the highest concentration and PEUK the lowest (p < 0.05, Fig. 3(c)). By 8 WAP, NO_3^- concentrations were not significantly different between treatments. At 12 WAP, the PESL treatment had the highest NO_3^- concentration (57.1 ± 6.5 mg·kg^{-1}) and CON the lowest (32.5 ± 12.7 mg·kg^{-1}). At 16 WAP, NO_3^- concentrations had dropped significantly, with the PEUK treatment having the highest concentration (2.9 ± 0.2 mg·kg^{-1}) and CON the lowest (1.7 ± 0.01 mg·kg^{-1}). At 20 WAP, NO_3^- concentrations were similar among the four treatments. At 24 WAP, the PESL treatment had the highest NO_3^- concentration (2.3 ± 1.0 mg·kg^{-1}) and BD the lowest (1.6 ± 0.1 mg·kg^{-1}) (p < 0.05, Fig. 3(c)). Overall, the BD had the highest NO_3^- concentration at 4 WAP and PESL peaked at 12 and 24 WAP. NO_3^- concentrations had declined sharply by 16 WAP and remained low, with PEUK having the highest concentration at 16 WAP. The CON treatment consistently had lower NO_3^- concentrations at most time points, indicating that mulching resulted in a higher soil NO_3^- conservation.

For soil pH, 4 and 8 WAP values were similar across treatments. By 12 WAP, the BD treatment had the highest pH (6.10 ± 0.10) compared to others (p < 0.05, Fig. 4(a)). After 16 WAP, pH values dropped significantly and remained lower until the end of the season. By 16 WAP, there were no significant differences between the four treatments. At 20 WAP, the highest pH was observed in the PESL treatment (5.1 ± 0.13) and CON had lowest (4.7 ± 0.07) (p < 0.05, Fig. 4(a)). By 24 WAP, pH values had stabilized without significant differences between treatments, ranging between 5.0 ± 0.07 (BD) and 5.1 ± 0.11 (PESL). Therefore, mulching did not have a significant effect on soil pH.

For soil EC, at 4 WAP, the BD treatment had the highest value (136.2 ± 29.8 μS·cm^{-1}) and CON had the lowest (67.7 ± 8.6 μS·cm^{-1}) (p < 0.05, Fig. 4(b)). By 8 WAP, EC had decreased across the four treatments with the CON treatment having the lowest value (17.6 ± 1.5 μS·cm^{-1}) compared to the other treatments. At 12 WAP, EC remained low, with the lowest value of 20.8 ± 1.8 μS·cm^{-1} in the CON treatment and the highest value of 41.8 ± 9.0 μS·cm^{-1} in the BD treatment (p < 0.05, Fig. 4(b)). After 16 WAP, EC increased again, with no significant difference between the four treatments at 16 and 20 WAP. By 24 WAP, the PEUK treatment had the highest EC

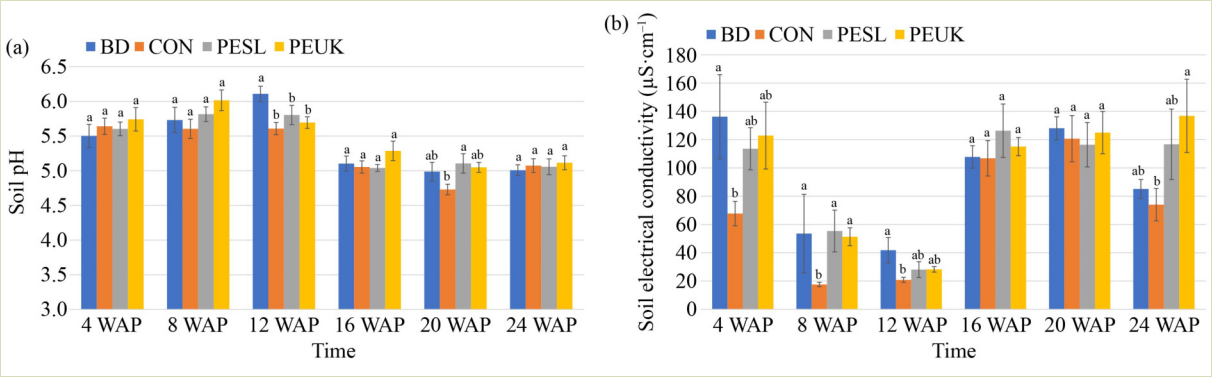


Fig. 4 (a) Soil pH and (b) soil EC measured at different time points under four treatments. CON, no mulching; BD, biodegradable mulch; PESL, reflective mulch; PEUK, non-biodegradable mulch; and WAP, weeks after planting. Values are means ± SEM, lowercase letters on the error bars indicate significant differences between four treatments (n = 4) (p < 0.05).

(136.8 ± 25.9 μS·cm^{-1}) and CON the lowest value (74.0 ± 11.5 μS·cm^{-1}) ($p < 0.05$, Fig. 4(b)). Finally, the CON treatment consistently had the lowest values over the time points compared to other treatments, so mulching had a significant impact on soil EC.

For GMC at 4 WAP, there were no significant differences between the treatments. By 8 WAP, the BD treatment had the highest GMC (23.6% ± 3.75%) compared to others ($p < 0.05$, Fig. 5(a)). At 12 WAP, soil GMC was similar across the four treatments. By 16 WAP, soil GMC had dropped in all treatments, with the BD treatment having the highest value (11.5% ± 0.8%) and CON the lowest (9.3% ± 0.4%). At 20 WAP, soil GMC had increased in all the treatments but there were no significant differences between treatments. By 24 WAP, the PEUK treatment had the highest soil GMC (18.1% ± 1.4%) and CON the lowest (10.5% ± 0.6%) ($p < 0.05$, Fig. 5(a)). The CON treatment consistently had the lowest soil GMC at multiple time points, including 8, 16 and 24 WAP, which indicates that mulching helped conserve soil moisture.

For soil temperature at 4 WAP, values were similar across the treatments, ranging from 30.3 ± 0.5 °C (CON) to 30.7 ± 0.3 °C (PEUK) and there no significant differences at 8 WAP. By 12 WAP, temperatures had decreased across the four treatments, with PEUK having the highest (29.7 ± 0.3 °C) and CON the lowest (28.7 ± 0.3 °C) ($p < 0.05$, Fig. 5(b)). By 16 WAP, soil temperature had increased again, with the BD and PEUK treatments having the highest (30.6 ± 0.7 °C and 30.4 ± 0.4 °C, respectively) and CON the lowest (28.8 ± 0.2 °C) ($p < 0.05$, Fig. 5(b)). At 20 WAP, temperatures were similar between the treatments, and at 24 WAP, soil temperatures varied with PEUK and PESL having the highest temperatures of 33.3 ± 0.1 °C and 33.2 ± 0.2 °C respectively, and the BD and CON the lowest (32.5 ± 0.2 °C and 32.5 ± 0.2 °C, respectively) ($p < 0.05$, Fig. 5(b)). Overall, soil temperature varied over time and between treatments, with PEUK consistently having the highest values at 12, 16 and 24 WAP. In contrast, CON consistently had the lowest temperatures at these times.

3.2 Plant measurements

Plant height revealed significant temporal effects and differences between the treatments throughout the study period ($p < 0.05$). At 4 WAP, the BD (25.7 ± 1.2 cm) and PESL (25.1 ± 1.0 cm) treatments had the tallest plants, and PEUK the shortest (21.8 ± 1.1 cm). By 8 WAP, PESL (51.1 ± 1.3 cm), PEUK (48.9 ± 1.1 cm) and BD (47.7 ± 1.5 cm) treatments had taller plants compared to the CON treatment, which had the lowest (41.2 ± 1.5 cm) ($p < 0.05$, Fig. 6(a)). At 12 WAP, PEUK (55.7 ± 1.7 cm), PESL (55.8 ± 1.6 cm) and BD (53.4 ± 1.8 cm) had the tallest plants compared to the CON treatment (48.0 ± 1.8 cm). By 16 WAP, PEUK had the tallest plants (60.8 ± 1.9 cm), followed by PESL (59.3 ± 1.9 cm) and BD (59.3 ± 1.8 cm), and CON had the shortest (52.0 ± 1.7 cm). At 20 WAP, the PEUK treatment still had the tallest plants (64.1 ± 1.6 cm), followed closely by PESL (62.8 ± 2.3 cm) and BD (61.8 ± 1.7 cm), and the CON treatment remained the lowest (56.0 ± 1.8 cm). By 24 WAP, PEUK maintained the tallest plant height (70.2 ± 1.7 cm), followed by PESL (65.8 ± 2.0 cm) and

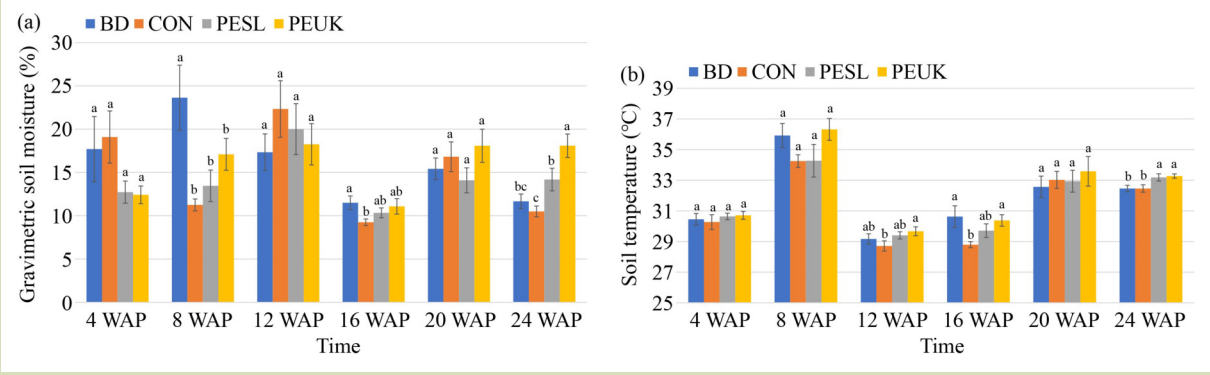


Fig. 5 (a) Soil GMC and (b) temperature measured at different time points under four treatments. CON, no mulching; BD, biodegradable mulch; PESL, reflective mulch; PEUK, non-biodegradable mulch; and WAP, weeks after planting. Values are means ± SEM, lowercase letters on the error bars indicate significant differences between four treatments ($n = 4$) ($p < 0.05$).

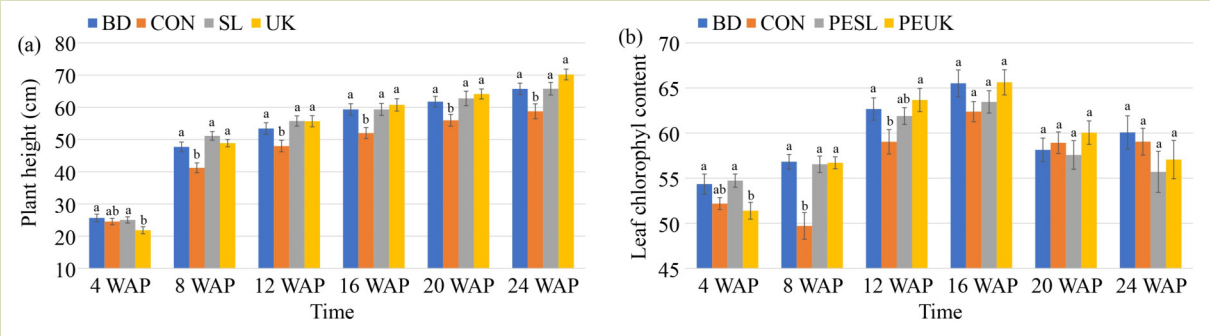


Fig. 6 (a) Plant height and (b) SPAD measured at different time points under four treatments. CON, no mulching; BD, biodegradable mulch; PESL, reflective mulch; PEUK, non-biodegradable mulch; and WAP, weeks after planting. Values are means ± SEM, lowercase letters on the error bars indicate significant differences between four treatments (n = 4) (p < 0.05).

BD (65.7 ± 1.8 cm), and the CON treatment had the shortest plants (58.8 ± 2.3 cm) (p < 0.05, Fig. 6(a)).

Leaf chlorophyll content (SPAD) also revealed differences between the treatments and time points (p < 0.05). At 4 WAP, the PESL (54.7 ± 0.7) and BD (54.3 ± 1.1) treatments had the highest SPAD values, and PEUK the lowest (51.4 ± 0.9) (p < 0.05, Fig. 6(b)). By 8 WAP, the BD (56.8 ± 0.8), PEUK (56.7 ± 0.7) and PESL (56.5 ± 0.9) treatments had the highest SPAD values compared to the CON treatment, which had the lowest (49.7 ± 1.5). At 12 WAP, PEUK had the highest SPAD value (63.7 ± 1.3), followed by BD (62.7 ± 1.2) and PESL (61.9 ± 0.9), and the CON treatment had the lowest (59.0 ± 1.4) (p < 0.05, Fig. 6(b)). SPAD values f were not significantly different between treatments at 16, 20 and 24 WAP.

Overall, plant height consistently increased across the four treatments over time, with PEUK having the tallest plants at 24 WAP (70.2 ± 1.7 cm). SPAD values were generally higher in the BD and PEUK treatments throughout the study period, with PEUK having the highest values at 12 WAP (63.7 ± 1.3) and 16 WAP (65.6 ± 1.4). Conversely, the CON treatment consistently had the shortest heights and lowest SPAD values across most time points, indicating that the mulching had improved the plant growth.

Yield per plant revealed differences between treatments at various harvest times (p < 0.05, Fig. 7(a)). At the first harvest, the BD treatment (324 ± 38 g) had the highest yield, followed by the PESL (296 ± 33 g) and PEUK (243 ± 19 g) treatments, and CON (111 ± 16 g) had the lowest. At the second harvest, the BD (214 ± 20 g), PESL (206 ± 20 g) and PEUK (202 ± 17 g) treatments continued to have the highest yields, while CON (74.3 ± 8.56 g) remained the lowest (p < 0.05, Fig. 7(a)). At the third harvest, there was a general reduction in yield, with values ranging from 90.5 ± 11.9 g (BD) to 64.7 ± 11.4 g (CON), with no significant differences between treatments. The fourth harvest revealed an overall increase in yield, with the BD (259 ± 30 g) and PEUK (246 ± 34 g) treatments having the highest yields. Although the PESL (202 ± 31 g) and CON (209 ± 22 g) treatments yielded lower amounts, these were not significantly different. At the fifth harvest, the PEUK (251 ± 38 g) and PESL (242 ± 25 g) treatments had the highest yield, and CON (149 ± 19 g) the lowest (p < 0.05, Fig. 7(a)). The sixth harvest revealed that there were no significant differences between the treatments. For total yield, the BD treatment gave the highest amount (1230 ± 84 g), followed by the PESL (1190 ± 56 g) and PEUK (1180 ± 59 g) treatments, and CON had the lowest (736 ± 59 g) (p < 0.05, Fig. 7(a)).

Overall, the BD treatment consistently yielded the highest, or among the highest, at all harvests, followed by PESL and PEUK. Notably, CON consistently had the lowest yields, or among the lowest, at all harvests, culminating in the lowest total yield. The BD treatment was the most productive throughout the growing period, with PESL and PEUK having comparable, but slightly lower yields, while CON consistently underperformed in terms of yield.

The fresh weight of plant roots, stems, leaves and remaining fruits per plant at the end of the season revealed significant differences between treatments (p < 0.05). The PESL, BD and

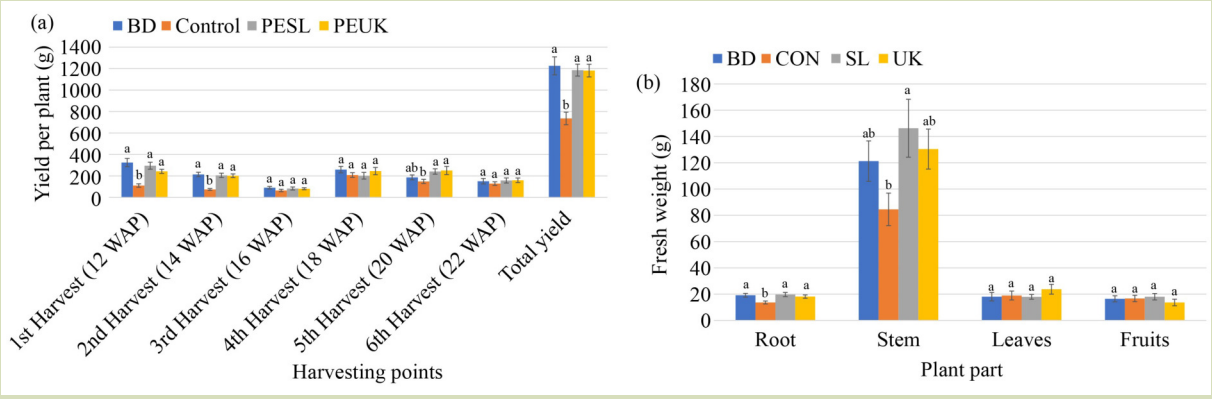


Fig. 7 (a) Yield per plant measured at the six different harvesting points, their total yield, and (b) fresh weights of plant root, stem, leaves, and remaining fruits per plant measured at the end of the season under four plastic film mulch treatments. CON, no mulching; BD, biodegradable mulch; PESL, reflective mulch; PEUK, non-biodegradable mulch; and WAP, weeks after planting. Values are means ± SEM, lowercase letters on the error bars indicate significant differences between four treatments (n = 4) (p < 0.05).

PEUK treatments had the highest root fresh weight at 19.7 ± 1.6, 19.2 ± 1.4 and 18.2 ± 1.3 g, respectively, and CON had the lowest (13.7 ± 1.1 g), differing from the other treatments (p < 0.05, Fig. 7(b)). Significant variations in stem fresh weight were observed across treatments indicating that the PESL (146 ± 22 g), PEUK (130 ± 15.2 g) and BD (121 ± 15 g) treatments gave the highest stem fresh weights, and CON (84.5 ± 12.4 g) the lowest (p < 0.05, Fig. 7(b)). The fresh weight of leaves per plant was not significantly different between treatments (p > 0.05), ranging from 23.8 to 18.0 g. The fresh weight of remaining fruits was likewise not significantly different between treatments, ranging from 18.0 to 13.7 g.

PESL consistently provided superior performance in root and stem fresh weights, and CON the lowest, underscoring its relatively poor performance compared to the other treatments.

4 Discussion

4.1 Soil chemical properties

The findings of this study demonstrate the substantial benefits of plastic mulching in improving soil physicochemical properties and enhancing crop performance in chili fields within the WZ of Sri Lanka, as previously observed by Bosland & Votava[1]. The consistently lower levels of soil available P in the control treatment compared to mulched treatments (Fig. 3(a)) indicate that mulching mitigates nutrient loss and enhances soil available P retention, which was observed in previous studies[38,39]. Plastic film mulching reduces soil exposure to high rainfall, surface runoff and high wind, thereby conserving and increasing soil available P in high-rainfall regions[17,40] similar to the WZ of Sri Lanka (Fig. 2). Additionally, mulching improves soil microbial activity by maintaining favorable moisture and temperature conditions, which in turn accelerates organic matter mineralization and nutrient release[39]. This may be another reason for higher P availability in mulched soils. However, the effect of mulching on NH_4^+ levels was inconclusive (Fig. 3(b)). Previous studies have found that PFM effectively mitigated N leaching and decreased N_2O emissions and NH_3 volatilization, resulting in higher NH_4^+ in mulched soils[41]. The consistently lower NO_3^- levels in the CON treatment (Fig. 3(c)) indicate that mulching effectively decreases NO_3^- leaching. Plastic mulches act as a barrier against surface water infiltration and deep percolation, conserving soil NO_3^-[42–44]. The sharp decline of soil NH_4^+ observed at 8 and 16 WAP across the four treatments (Fig. 3(b)) may be due to the higher rainfall. A decrease in soil NO_3^- from 16 WAP to the end of the season was observed in all treatments (Fig. 3(c)), which may be due to increased crop N intake during the reproductive stage and quicker organic N mineralization[45,46]. Also, the preferred form of N for chili is NO_3^- because it facilitates root growth, fruit production, water, and other nutrient uptake, resulting in a vigorous plant.

Soil pH remained unaffected by mulching treatments (Fig. 4(a)), which is consistent with findings of Ibarra-Jiménez

et al.[47], who observed that plastic mulches do not alter soil pH. However, earlier studies have shown that the PFM decreases soil pH[48,49] and the decline in pH across the four treatments from 16 WAP onward (Fig. 4(a)) may be attributed to the accumulation of organic acids or increased nitrification rates[50]. Mulched treatments had higher EC compared to the CON treatment (Fig. 4(b)). This increase in EC could be attributed to the accumulation of soluble salts and enhanced nutrient retention due to decreased leaching[51]. Plastic mulches create a microclimate that stabilizes soil processes, preventing the rapid loss of nutrients and salts[52]. The observed temporal variations in EC align with patterns of nutrient cycling and crop uptake during the growing season.

4.2 Soil physical properties

One of the most significant impacts of mulching observed in this study was soil moisture conservation. The CON treatment had the lowest soil moisture content at multiple time points (8, 16 and 24 WAP) (Fig. 5(a)), demonstrating the efficacy of mulches in reducing water evaporation and conserving soil moisture. This result corroborates earlier studies, which found that mulches reduce water loss by acting as physical barriers to direct sunlight and wind[53–56]. Also, by reducing weed growth, mulching may reduce water loss from the soil through transpiration[52]. Improved soil moisture is particularly advantageous in rainfed agricultural systems, where water availability is often erratic[42,56].

It is noteworthy that plastic film mulching generally improves crop productivity by creating optimal temperature conditions for plant growth[42,57], especially in cooler regions like the WZ of Sri Lanka. The thermal properties of mulching were also evident, with PEUK mulch consistently recording the highest soil temperatures than other treatments at most time points (Fig. 5(b)). Black plastic mulch such as PEUK absorbs most UV, visible and infrared solar radiation and re-emits it as thermal infrared radiation, effectively increasing soil temperatures[57]. Its ability to transfer heat to the soil depends on good contact between the mulch and the soil surface, as the soil has higher thermal conductivity than air. Under black plastic mulch in the daytime, soil temperatures are typically 2.8 °C higher at 5 cm depth and 1.7 °C higher at 10 cm depth compared to bare soil[58]. Plastic mulches, particularly darker ones, trap heat and elevate soil temperatures, which enhances root activity and nutrient uptake compared to bare soils[59,60] whereas reflective mulch keeps soil cooler as the silver side reflects sunlight[61]. These may be the reasons for the highest soil temperature of the PEUK treatment.

4.3 Plant growth and yield

The positive impact of mulching on plant performance metrics such as plant height (Fig. 6(a)), SPAD values (Fig. 6(b)), yield (Fig. 7(a)) and fresh biomass (Fig. 7(b)) was evident in this study. Previous research has shown that using PFM enhances yield parameters in chili and other crops in terms of plant height, the number of fruits per plant, fruit girth, fruit length, fruit quality and overall fresh fruit yield when compared to non-mulched and organic mulch treatments[62–65]. The plant height and SPAD values were the highest under PEUK and BD mulches (Fig. 6(a,b)), indicating that these treatments create optimal conditions for chili growth. The importance of using PFM is its ability to retain nutrients within the root zone, enabling crops to absorb nutrients more efficiently[9], suppressing weed growth to reduce competition[62], increasing soil moisture retention and modifying soil temperature[42]. These may lead to greater plant height and SPAD values in mulch treatments than in the control. The lower plant height and SPAD values in the control treatment at most of the time points highlight the adverse effects of chili production without mulching (Fig. 6(a, b)).

The most significant indicator of mulching benefits was yield. BD mulching consistently provided the highest yields, followed by PESL and PEUK mulches at most time points and finally in the total yield (Fig. 7(a)). The superior performance of BD mulch may be attributed to its dual role in conserving soil moisture and releasing nutrients (e.g., C, N, P and K) as it degrades with climate conditions, and mechanical and microbial activities[9]. However, its effectiveness and time duration depend on environmental conditions, material composition, and thickness of the mulch[9]. Conversely, the CON treatment gave the lowest yields (Fig. 7(a)), highlighting the critical role of mulching in improving resource use efficiency and crop productivity. This aligns with previous findings about chili[62] and other crops such as tomato and sweet corn[63,64]. The environmental benefits of biodegradable mulch, including reduced plastic waste and improved soil health, align with global efforts to promote sustainable agricultural practices[26,27].

Also, mulching improved fresh root and stem weights, with reflective (PESL) mulch giving the highest biomass accumulation (Fig. 7(b)). This supports earlier studies, which

found that plastic mulching promotes vigorous root growth by maintaining optimal soil moisture and aeration conditions[24], and fresh biomass of leaves and stems was comparatively higher under PFM[62]. Reflective film mulches provide additional advantages compared to non-biodegradable or biodegradable PFMs by improving plant resistance to pests in vegetables (beans)[61,63] as well as some diseases by repelling their hosts in some crops such as zucchini[64]. Reflective film mulch is particularly effective at increasing photosynthetically active radiation available for plants through reflected sunlight rather than direct sunlight, and it may cause enhanced photosynthesis in blueberries[65], cucumbers[64] and chili[66]. These may be the possible reasons for a higher yield and fresh weight of roots and stems from PESL treatment. The poor performance of the CON treatment underscores the importance of mulching in mitigating environmental stresses and enhancing plant resilience.

Overall, these findings strongly indicate the value of the adoption of plastic film mulching practices in chili production in the WZ of Sri Lanka. Mulching not only improves soil health and water use efficiency but also enhances crop performance. Future research could focus on the long-term impacts of mulching on soil organic matter dynamics and the economic viability of various mulch types in diverse soil types and climatic conditions.

5 Conclusions

The study demonstrates the significant potential of PFM for enhancing agricultural productivity in wet tropical regions while highlighting important differences between mulch types. The comparable performance of biodegradable mulch to non-biodegradable plastics for both soil improvement and crop yield is of significance. This, therefore, offers a pathway toward more sustainable agricultural practices in Sri Lanka's WZ. While all mulch types effectively improved soil moisture retention and nutrient availability, their distinct effects on soil temperature and plant growth dynamics suggest future opportunities for optimizing the selection of materials for PFM based on specific production/management goals and seasonal timing.

This study highlights the potential of PFM with biodegradable film as a viable alternative to non-biodegradable films in tropical regions with high rainfall. The findings demonstrate that biodegradable films can support agricultural productivity while offering environmental benefits. These results underscore the importance of investigating sustainable mulch options to reduce environmental impacts and preserve natural resources in tropical agriculture.

Acknowledgements

This research was supported by UKRI Global Challenges Research Fund (NE/V005871/1).

Compliance with ethics guidelines

Nipuna Thennakoon, Sidath Wickrama, Nalin Madhuranga, Chandima Jayasundara, Achini Dias, Meththa Gimhani, Mojith Ariyaratna, Anurudda Karunarathna, Surani Chathurika, Martine Graf, Michaela Reay, David Chadwick, and Davey Jones declare that they have no conflicts of interest or financial conflicts to disclose. This article does not contain any studies with human or animal subjects performed by any of the authors.

REFERENCES

1. Bosland P W, Votava E J. Peppers: Vegetable and Spice Capsicums, 2nd ed. New York: *CABI Publishing*, 2012
2. Wickramarathne W A G C P, Wathugala D L, Amarasekara D A B N, Kumarasinghe H K M S. Effect of UV treated silver on black polythene mulch on the growth and yield of *Capsicum annuum* L. (chili) var. MI2 AND MI3. *Tropical Agricultural Research and Extention*, 2021, **24**(3): 236
3. Department of Senses and Statistics (DCS). Agriculture and Environment Statistic Division. *DCS*, 2024. Available at DCS website on June 25, 2025
4. Sri Lanka Export Development Board (SLEDB). Annual Report 2023. *SLEDB*, 2023. Available at SLEDB website on June 25, 2025
5. Hewage S, Bandara S, Rathnayake D. Local Hybrid Chili

Cultivation and Dry Chili Production: Towards Spicing Up The Process. Colombo: *Hector Kobbekaduwa Agrarian Research and Training Institute (HARTI)*, 2022

6. Bu L D, Liu J L, Zhu L, Luo S S, Chen X P, Li S Q, Lee Hill R, Zhao Y. The effects of mulching on maize growth, yield and water use in a semi-arid region. *Agricultural Water Management*, 2013, **123**: 71–78
7. Fan Y, Ding R, Kang S, Hao X, Du T, Tong L, Li S. Plastic mulch decreases available energy and evapotranspiration and improves yield and water use efficiency in an irrigated maize cropland. *Agricultural Water Management*, 2017, **179**: 122–131
8. Steinmetz Z, Wollmann C, Schaefer M, Buchmann C, David J, Tröger J, Muñoz K, Frör O, Schaumann G E. Plastic mulching in agriculture. Trading short-term agronomic benefits for long-term soil degradation. *Science of the Total Environment*, 2016, **550**: 690–705
9. Kasirajan S, Ngouajio M. Polyethylene and biodegradable mulches for agricultural applications: a review. *Agronomy for Sustainable Development*, 2012, **32**(2): 501–529
10. Liu J, Bu L, Zhu L, Luo S, Chen X, Li S. Optimizing plant density and plastic film mulch to increase maize productivity and water-use efficiency in semiarid areas. *Agronomy Journal*, 2014, **106**(4): 1138–1146
11. Luo Z, Wang E, Sun O J. Can no-tillage stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments. *Agriculture, Ecosystems & Environment*, 2010, **139**(1–2): 224–231
12. Shah F, Wu W. Use of plastic mulch in agriculture and strategies to mitigate the associated environmental concerns. In: Sparks D L, ed. Advances in Agronomy. *Academic Press*, 2020, 231–287
13. Delgado A, Gómez J A. The soil: physical, chemical, and biological properties. In: Villalobos F J, Fereres E, eds. Principles of Agronomy for Sustainable Agriculture. Cham: *Springer International Publishing*, 2024, 15–30
14. Qin S, Li L, Wang D, Zhang J, Pu Y. Effects of limited supplemental irrigation with catchment rainfall on rain-fed potato in semi-arid areas on the western Loess Plateau, China. *American Journal of Potato Research*, 2013, **90**(1): 33–42
15. Song Q, Zhang F, Li X, Yue S, Luo Z, Li S. Understanding of maize root responses to changes in water status induced by plastic film mulching cultivation on the Loess Plateau, China. *Agricultural Water Management*, 2024, **301**: 108932
16. Qiang L, Hu H, Li G, Xu J, Cheng J, Wang J, Zhang R. Plastic mulching, and occurrence, incorporation, degradation, and impacts of polyethylene microplastics in agroecosystems. *Ecotoxicology and Environmental Safety*, 2023, **263**: 115274
17. Zhang S, Lövdahl L, Grip H, Tong Y, Yang X, Wang Q. Effects of mulching and catch cropping on soil temperature, soil moisture and wheat yield on the Loess Plateau of China. *Soil & Tillage Research*, 2009, **102**(1): 78–86
18. Gao Y, Xie Y, Jiang H, Wu B, Niu J. Soil water status and root distribution across the rooting zone in maize with plastic film mulching. *Field Crops Research*, 2014, **156**: 40–47
19. Wang C, Wang J, Zhang Y, Qin S, Zhang Y, Liu C. Effects of different mulching materials on the grain yield and water use efficiency of maize in the North China Plain. *Agriculture*, 2022, **12**(8): 1112
20. Xie J, Wang L, Li L, Anwar S, Luo Z, Zechariah E, Fudjoe S K. Yield, economic benefit, soil water balance, and water use efficiency of intercropped maize/potato in responses to mulching practices on the semiarid Loess Plateau. *Agriculture*, 2021, **11**(11): 1100
21. Mohammed A T, Irmak S. Maize response to coupled irrigation and nitrogen fertilization under center pivot, subsurface drip and surface (furrow) irrigation: soil-water dynamics and crop evapotranspiration. *Agricultural Water Management*, 2022, **267**: 107634
22. Filipović V, Romić D, Romić M, Borošić J, Filipović L, Mallmann F J K, Robinson D A. Plastic mulch and nitrogen fertigation in growing vegetables modify soil temperature, water and nitrate dynamics: experimental results and a modeling study. *Agricultural Water Management*, 2016, **176**: 100–110
23. Zhao Y, Mao X, Li S, Huang X, Che J, Ma C. A review of plastic film mulching on water, heat, nitrogen balance, and crop growth in farmland in China. *Agronomy*, 2023, **13**(10): 2515
24. Qi Y, Beriot N, Gort G, Lwanga E H, Gooren H, Yang X, Geissen V. Impact of plastic mulch film debris on soil physicochemical and hydrological properties. *Environmental Pollution*, 2020, **266**: 115097
25. Wang Z, Li M, Flury M, Schaeffer S M, Chang Y, Tao Z, Jia Z, Li S, Ding F, Wang J. Agronomic performance of polyethylene and biodegradable plastic film mulches in a maize cropping system in a humid continental climate. *Science of the Total Environment*, 2021, **786**: 147460
26. Sintim H Y, Bandopadhyay S, English M E, Bary A I, DeBruyn J M, Schaeffer S M, Miles C A, Reganold J P, Flury M. Impacts of biodegradable plastic mulches on soil health. *Agriculture, Ecosystems & Environment*, 2019, **273**: 36–49
27. Zhang M, Xue Y, Jin T, Zhang K, Li Z, Sun C, Mi Q, Li Q. Effect of long-term biodegradable film mulch on soil physicochemical and microbial properties. *Toxics*, 2022, **10**(3): 129
28. Wijesooriya H D S N, Debarawatta R D N, Yakandawala K, Dabarera R, Sanjeevanie W A P. Effect of growth and yield of brinjal (*Solanum melongena* L.) grown under different poly mulches. *Journal of Food & Agriculture*, 2015, **8**(1–2): 25–32
29. Jayawardane S S B D G, Weerasena L A. Crop Diversification in Sri Lanka. Rome: *Food and Agriculture Organization (FAO)*, 2001. Available at the FAO website on June 25, 2025
30. Mapa R B. Soil research and soil mapping history. In: Mapa R

B, ed. The Soils of Sri Lanka. World Soils Book Series. Cham: *Springer International Publishing*, 2020, 1–11

31. Land Use Division, Sri Lanka. Soil Map of Sri Lanka. Enschede: *ITC*, 1988. Available at European Commission's Joint Research Centre (JRC) website on June 25, 2025
32. Punyawardena B V R. Climate. In: Mapa R B, ed. The Soils of Sri Lanka. Cham: *Springer International Publishing*, 2020, 13–22
33. Department of Agriculture. Sri Lanka (DOA). HORDI Crop—Capsicum: *Capsicum annuum*. Peradeniya: *DOA*, 2024. Available at the DOA website on June 25, 2025
34. Blake G R. Bulk density. In: Black C A, ed. Methods of Soil Analysis. Part 1: Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling. Madison, WI, USA: *American Society of Agronomy*, 1965, 374–390
35. Murphy J, Riley J P. A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta*, 1962, **27**: 31–36
36. Mulvaney R L. Nitrogen-inorganic forms. In: Sparks D L, Page A L, Helmke P A, Loeppert R H, Soltanpour P N, Tabatabai M A, Johnston C T, Sumner M E, eds. Methods of Soil Analysis. Madison, WI, USA: *Soil Science Society of America, American Society of Agronomy*, 2018, 1123–1184
37. Miranda K M, Espey M G, Wink D A. A rapid, simple spectrophotometric method for simultaneous detection of nitrate and nitrite. *Nitric Oxide*, 2001, **5**(1): 62–71
38. Gu Y J, Han C L, Kong M, Shi X Y, Zdruli P, Li F M. Plastic film mulch promotes high alfalfa production with phosphorus-saving and low risk of soil nitrogen loss. *Field Crops Research*, 2018, **229**: 44–54
39. Li F M, Song Q H, Jjemba P K, Shi Y C. Dynamics of soil microbial biomass C and soil fertility in cropland mulched with plastic film in a semiarid agro-ecosystem. *Soil Biology & Biochemistry*, 2004, **36**(11): 1893–1902
40. Cheng H, Zhu X, Sun R, Niu Y, Yu Q, Shen Y, Li S. Effects of different mulching and fertilization on phosphorus transformation in upland farmland. *Journal of Environmental Management*, 2020, **253**: 109717
41. Liu H, Yang X, Liu G, Liang C, Xue S, Chen H, Ritsema C J, Geissen V. Response of soil dissolved organic matter to microplastic addition in Chinese loess soil. *Chemosphere*, 2017, **185**: 907–917
42. Ma D, Chen L, Qu H, Wang Y, Misselbrook T, Jiang R. Impacts of plastic film mulching on crop yields, soil water, nitrate, and organic carbon in Northwestern China: a meta-analysis. *Agricultural Water Management*, 2018, **202**: 166–173
43. Stroehlein J L, Oebker N F. Effects of nitrogen and phosphorus on yields and tissue analyses of chili peppers. *Communications in Soil Science and Plant Analysis*, 1979, **10**(3): 551–563
44. Wang L, Li X G, Lv J, Fu T, Ma Q, Song W, Wang Y P, Li F M. Continuous plastic-film mulching increases soil aggregation but decreases soil pH in semiarid areas of China. *Soil & Tillage Research*, 2017, **167**: 46–53
45. Bender S F, Wagg C, van der Heijden M G A. An underground revolution: biodiversity and soil ecological engineering for agricultural sustainability. *Trends in Ecology & Evolution*, 2016, **31**(6): 440–452
46. Lalitha M, Thilagam V K, Balakrishnan N, Mansour M. Effect of plastic mulch on soil properties and crop growth—A review. *Agricultural Reviews* 2010, **31**(2): 145–149
47. Ibarra-Jiménez L, Zermeño-González A, Munguía-López J, Rosario Quezada-Martín M A, De La Rosa-Ibarra M. Photosynthesis, soil temperature and yield of cucumber as affected by colored plastic mulch. *Acta Agriculturæ Scandinavica. Section B, Soil and Plant Science*, 2008, **58**(4): 372–378
48. Chakraborty D, Nagarajan S, Aggarwal P, Gupta V K, Tomar R K, Garg R N, Sahoo R N, Sarkar A, Chopra U K, Sundara Sarma K S, Kalra N. Effect of mulching on soil and plant water status, and the growth and yield of wheat (*Triticum aestivum* L.) in a semi-arid environment. *Agricultural Water Management*, 2008, **95**(12): 1323–1334
49. Sarkar S, Singh S R. Interactive effect of tillage depth and mulch on soil temperature, productivity and water use pattern of rainfed barley (*Hordium vulgare* L.). *Soil & Tillage Research*, 2007, **92**(1–2): 79–86
50. Yang J, Mao X, Wang K, Yang W. The coupled impact of plastic film mulching and deficit irrigation on soil water/heat transfer and water use efficiency of spring wheat in Northwest China. *Agricultural Water Management*, 2018, **201**: 232–245
51. Zhang S, Li P, Yang X, Wang Z, Chen X. Effects of tillage and plastic mulch on soil water, growth and yield of spring-sown maize. *Soil & Tillage Research*, 2011, **112**(1): 92–97
52. Ali Mari J, Soothar R K, Thidar M, Mangrio M A, Mirjat M U, Katohar I. Effect of plastic film mulch and irrigation water regimes on soil temperature pattern, plant growth and water productivity of maize. *Ecological Frontiers*, 2024, **44**(4): 752–759
53. Lamont W J. Plastic mulches for the production of vegetable crops. In: Orzolek M D, ed. A Guide to the Manufacture, Performance, and Potential of Plastics in Agriculture. Amsterdam: *Elsevier*, 2017, 45–60
54. Kader M A, Senge M, Mojid M A, Ito K. Recent advances in mulching materials and methods for modifying soil environment. *Soil & Tillage Research*, 2017, **168**: 155–166
55. Shashi K, Kumar S A. Effect of black plastic mulch on soil temperature and tomato yield. *Progressive Horticulture*, 2011, **43**(2): 337–339
56. Ashrafuzzaman M, Halim M A, Ismail M R, Shahidullah S M, Hossain M A. Effect of plastic mulch on growth and yield of chilli (*Capsicum annuum* L.). *Brazilian Archives of Biology and Technology*, 2011, **54**(2): 321–330

57. Kwabiah A B. Growth and yield of sweet corn (*Zea mays* L.) cultivars in response to planting date and plastic mulch in a short-season environment. *Scientia Horticulturae*, 2004, **102**(2): 147–166
58. Lourduraj A C, Sreenarayanan V V, Rajendran R, Ravi V, Padmini K, Pandiarajan T. Effect of plastic mulching on tomato yield and economics. *South Indian Horticulture*, 1996, **44**(5/6): 139–142
59. Nagalakshmi S, Palanisamy D, Eswaran S, Sreenarayanan V V. Influence of plastic mulching on chili yield and economics. *South Indian Horticulture*, 2002, **50**: 262–265
60. Scarascia-Mugnozza G, Sica C, Russo G. Plastic materials in European agriculture: actual use and perspectives. *Journal of Agricultural Engineering*, 2011, **42**(3): 15–28
61. Nottingham L B, Beers E H. Management of pear *Psylla* (Hemiptera: Psyllidae) using reflective plastic mulch. *Journal of Economic Entomology*, 2020, **113**(6): 2840–2849
62. Ding F, Ji D, Yan K, Dijkstra F A, Bao X, Li S, Kuzyakov Y, Wang J. Increased soil organic matter after 28 years of nitrogen fertilization only with plastic film mulching is controlled by maize root biomass. *Science of the Total Environment*, 2022, **810**: 152244
63. Nottingham L B, Kuhar T P. Reflective polyethylene mulch reduces Mexican bean beetle (Coleoptera: Coccinellidae) densities and damage in snap beans. *Journal of Economic Entomology*, 2016, **109**(4): 1785–1792
64. Summers C G, Mitchell J P, Stapleton J J. Management of aphid-borne viruses and *Bemisia argentifolii* (Homoptera: Aleyrodidae) in zucchini squash by using UV reflective plastic and wheat straw mulches. *Environmental Entomology*, 2004, **33**(5): 1447–1457
65. Muneer S, Kim J H, Park J G, Shin M H, Cha G H, Kim H L, Ban T, Kumarihami H M P C, Kim S H, Jeong G, Kim J G. Reflective plastic film mulches enhance light intensity, floral induction, and bioactive compounds in 'O'Neal' southern highbush blueberry. *Scientia Horticulturae*, 2019, **246**: 448–452
66. Mu L, Fang L. Effects of different mulching practices on the photosynthetic characteristics of hot pepper (*Capsicum annuum* L.) in a greenhouse in Northwest China. *Acta Agriculturæ Scandinavica. Section B, Soil and Plant Science*, 2015, **65**(8): 735–746