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Influence of integrated weed management on yield potential of field pea (*Pisum sativum*)

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Abstract

The present research was conducted to evaluate the impact of diverse weed control strategies on the growth and productivity of the field pea variety Aman. The research was undertaken at the Agronomy Department's experimental field, School of Agriculture Science, Technology and Research, Sardar Patel University, Balaghat (M.P.), during the rabi season of 2024. The trial followed a Randomized Block Design (RBD) with 14 treatments, each replicated three times. The treatment combinations included T₀ (Weedy Check), T₁ (Black Polythene Mulch), T₂ (Pendimethalin 30% EC @ 1.0 kg a.i./ha PE), T₃ (Imazethapyr 10% SL @ 55 g a.i./ha at 15-20 DAS), T₄ (Sodium Acifluorfen 16.5% EC + Clodinafop Propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15-20 DAS), T₅ (Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS), T₆ (Fomesafen 11.1% + Fluzifop-p-butyl 11.1% SL @ 220 g a.i./ha (RM) at 15-20 DAS), T₇ (Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE), T₈ (Black Polythene Mulch + Imazethapyr 10% SL @ 55 g a.i./ha at 15-20 DAS), T₉ (Black Polythene Mulch + Sodium Acifluorfen 16.5% EC + Clodinafop Propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15-20 DAS), T₁₀ (Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS), T₁₁ (Black Polythene Mulch + Fomesafen 11.1% + Fluzifop-p-butyl 11.1% SL @ 220 g a.i./ha (RM) at 15-20 DAS), T₁₂ (White Polythene Mulch), T₁₃ (Two Hand Weeding at 20 and 40 DAS), and T₁₄ (Mulching with Straws). The investigation sought to assess the efficacy of different weed management practices in field pea cultivation. Among the tested approaches, manual weeding at 20 and 40 days after sowing (T₁₃) emerged as the most effective strategy, demonstrating superior weed suppression by significantly reducing weed count and weed dry matter accumulation, thereby achieving the highest weed control efficiency. This treatment facilitated vigorous crop growth, evident in the maximum plant population, enhanced dry matter accumulation, higher branch numbers, and increased nodule formation per plant. Consequently, T₁₃ recorded the highest seed and straw yield, optimal harvest index, and maximum net returns. On the contrary, the weedy check (T₀) performed the worst, exhibiting severe weed infestation, reduced plant density, and the lowest yield levels. Treatments incorporating black polythene mulch alongside herbicides—notably T₁₀ (Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha) and T₇ (Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE)—effectively controlled weeds but fell short of achieving the yield and economic returns attained by T₁₃. Overall, T₁₃ (two manual weeding) emerged as the most productive and cost-effective weed management strategy for field pea cultivation. However, integrating manual weeding with advanced techniques such as black polythene mulch combined with herbicidal applications—notably T₁₀ and T₇—is recommended to further enhance crop performance and yield potential under the agro-climatic conditions of Balaghat, Madhya Pradesh.

Keywords: Benefit cost ratio, harvest index, polythene mulch, pendimethalin, Pea

Introduction

Field pea [*Pisum sativum* var. *arvense* (L.)], a member of the Leguminosae family, is a vital winter-season crop cultivated extensively for both fresh consumption and processed food applications. Its origins are traced to the Near East and the Mediterranean region, with evidence of domestication dating back to the early Neolithic era (Ambika *et al.*, 2022)^[2]. India remains the global leader in field pea production, with commercial cultivation predominantly occurring in the northern plains during the Rabi season, while in temperate hilly regions, it thrives during the summer months. Given its preference for a cool climate during early growth stages, field pea is optimally sown between early October and late November. Its development is most

favourable in environments that experience a seamless transition from cold to warm conditions. The cultivated area in India spans approximately 5.49 lakh hectares, yielding an annual production of 56.8 lakh metric tonnes and a productivity rate of 10.34 metric tonnes per hectare (DES, 2022) ^[7]. Weed competition emerges as a formidable constraint in field pea cultivation, significantly undermining crop yield and productivity. Empirical studies by Dungarwalet *et al.* (2003) ^[9] report that yield reductions due to weed infestation can range between 65.4% and 79.0%. Beyond diminishing crop yield, weeds exert adverse effects on soil fertility by depleting essential nutrients and compromising crop quality. To counteract these detrimental impacts, diverse weed management approaches, including ecological, mechanical, biological, and chemical strategies, have been explored. A contemporary approach—Integrated Weed Management (IWM)—advocates the synergistic deployment of direct and indirect weed control methods to ensure effective suppression of weed proliferation while maintaining environmental sustainability. Conventional weed control in field pea primarily relies on manual or mechanical interventions, often necessitating two to three cycles of hand weeding to sustain a weed-free field. However, manual weeding is a laborious and cost-intensive process, further exacerbated by labour shortages and logistical challenges, particularly during extended rainy spells that impede timely weeding operations. While mechanical weeding enhances soil aeration and conserves moisture, the escalating scarcity of agricultural labour has intensified the need for herbicidal alternatives in weed management. The identification of a selective and economically viable herbicide is pivotal in establishing effective weed control, particularly during the early phenological stages of field pea. Herbicidal applications offer a pragmatic solution under such constraints, mitigating labour dependency while ensuring robust weed suppression. Post-emergence herbicides, such as imazethapyr, fluazifop-p-butyl, propaquizafop, acifluorfen sodium, and fomesafen—whether applied individually or in ready-mix formulations—exhibit substantial efficacy in curbing weed establishment during the initial phases of field pea growth in the Kharif season. This underscores the severity of weed interference in field pea cultivation and highlights the imperative for developing a scientifically validated and economically feasible weed management regimen for this crop (Mishra *et al.*, 2023) ^[17]. Experimental evaluations of herbicidal efficacy against weed infestation in field pea are indispensable for multiple reasons. Weeds not only threaten crop yield and quality but also escalate production costs through increased labour requirements for manual weeding. Identifying an optimal herbicide that is both selective and cost-effective will facilitate the implementation of an efficient weed control strategy, mitigating the constraints associated with labour-intensive and weather-dependent weeding methods. Strategic herbicide application during the critical early growth phases of field pea will ensure a weed-free environment, fostering optimal crop development and maximizing yield potential. This research holds significant implications for the advancement of sustainable, economically viable weed management solutions, thereby enhancing overall production efficiency in field pea cultivation.

Materials and Methods

This research focused on evaluating the impact of various weed management strategies on the growth and yield of the field pea variety Aman. The study was carried out at the Student Research Farm within the Department of Agronomy at the School of

Agriculture Science Technology and Research, Sardar Patel University, Balaghat, Madhya Pradesh, during the Rabi season of 2024. It provides a comprehensive overview of the materials used and the methodologies implemented throughout the research process. Balaghat District is located in the south-eastern part of the Satpura Range and the upper Wainganga River valley, with coordinates ranging from 21°19' to 22°24' north latitude and 79°31' to 81°30' east longitude. The treatments consisted of T₀ (Weedy Check), T₁ (Black Polythene Mulch), T₂ (Pendimethalin 30% EC @ 1.0 kg a.i./ha PE), T₃ (Imazethapyr 10% SL @ 55 g a.i./ha at 15-20 DAS), T₄ (Sodium Acifluorfen 16.5% EC + Clodinafop Propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15-20 DAS), T₅ (Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS), T₆ (Fomesafen 11.1% + Fluzifop-p-butyl 11.1% SL @ 220 g a.i./ha (RM) at 15-20 DAS), T₇ (Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE), T₈ (Black Polythene Mulch + Imazethapyr 10% SL @ 55 g a.i./ha at 15-20 DAS), T₉ (Black Polythene Mulch + Sodium Acifluorfen 16.5% EC + Clodinafop Propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15-20 DAS), T₁₀ (Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS), T₁₁ (Black Polythene Mulch + Fomesafen 11.1% + Fluzifop-p-butyl 11.1% SL @ 220 g a.i./ha (RM) at 15-20 DAS), T₁₂ (White Polythene Mulch), T₁₃ (Two Hand Weedings at 20 and 40 DAS), and T₁₄ (Mulching with Straws). Weed count serves as a critical parameter for assessing weed population dynamics and the extent of infestation within agricultural fields. In the present study, weed enumeration was conducted within each replicated plot corresponding to different treatments at 25 and 50 days after sowing (DAS) as well as at harvest. The recorded data were subsequently subjected to statistical analysis. Prior to analysis, the weed count data underwent transformation using the square root method to standardize their distribution and ensure the derivation of statistically robust conclusions. Weed sampling was executed systematically using a quadrat-based approach (0.50 m × 0.50 m) at designated intervals of 25 DAS, 50 DAS, and harvest. The collected weed samples were initially sun-dried separately, followed by oven drying to achieve uniform moisture content, after which their dry biomass was recorded. The efficacy of weed control treatments was quantified through weed control efficiency (WCE), which was evaluated at 25 DAS, 50 DAS, and harvest. The effectiveness of each treatment in reducing weed infestation was determined using the following formula:

$$WCE = \frac{DMC - DMT}{DMC} \times 100$$

Where,

WCE = Weed control efficiency

DMC = Dry matter of weeds in control plot

DMT = Dry matter of weeds in treated plot

The height of five randomly selected plants per plot was measured using a meter scale from the ground level to the shoot apex at 25 DAS, 50 DAS, and harvest. The mean plant height for each replication was computed and subsequently analyzed statistically. For dry matter assessment, a single plant was randomly selected from each net plot at 25 DAS, 50 DAS, and harvest. These plants were excised at ground level, air-dried under shade, and subsequently oven-dried at a temperature of 60 to 65°C until a constant weight was attained. In each plot, the number of branches per plant was determined from randomly

selected specimens. The mean branch count per plant for each replication was recorded and subjected to statistical analysis. Similarly, the number of nodules per plant was counted from randomly selected plants at 45 DAS. The mean nodule count for each replication was computed and analyzed statistically. Post-harvest, the number of pods per plant was recorded from each selected plant across treatments and replications. The number of pods per plant is considered a principal yield attribute, and the collected data were systematically recorded and subjected to statistical analysis. The yield was calculated by weighing the total seed yield per plot. The readings for all the harvest per plot were recorded. The total seed yield/hectare was calculated by unitary method formula given below:

$$\text{Seed yield per hectare} = \frac{\text{Seed Yield per plot}}{\text{Size of individual plot}} \times 10,000 \text{ m}^2$$

Harvest index was computed by using following formula as suggested by Singh and Stoskoff (1971) [22]. The harvest index was worked out by using following formula:

$$\text{Harvest index (\%)} = \frac{\text{Seed yield (g)}}{\text{Biological yield (g)}} \times 100$$

The statistical analysis was conducted using Fisher and Yates (1967) [10].

Results and Discussion

In 2024, India surpassed China to become the world's most populous nation, with its population expected to expand from 1.38 billion to nearly 1.5 billion by 2030. This demographic surge necessitates an increase in food production from 309 million tonnes in 2020-21 to an estimated 345 million tonnes by 2030 (Sharma, 2021) [20]. Despite possessing only 2.4% of the global land area, India supports 18% of the world's population, placing immense pressure on small and marginal farmers, who are integral to national food security. However, the challenge of feeding this expanding populace is exacerbated by climate change, water scarcity, and diminishing cultivable land. Implementing efficient weed management strategies that consider environmental, economic, and social dimensions is imperative for ensuring sustainable agricultural productivity and improving farmer livelihoods. Unlike insect pests and pathogens, whose detrimental effects on crops are often conspicuous, weed-induced damage frequently goes unnoticed. Weeds are responsible for 37% of agricultural losses, surpassing the damage caused by insects (29%), diseases (22%), and other pests (12%). During the early stages of crop growth, slow-growing plants compete with weeds for essential resources such as moisture, nutrients, and sunlight, resulting in considerable yield reductions. Additionally, weeds serve as reservoirs for pests and pathogens, impair nutrient use efficiency, and degrade produce quality. An investigation by the ICAR-Directorate of Weed Research (Ghardeet *et al.*, 2018) [11] revealed that weed-induced yield losses vary across crops, ranging from 14% in rice to 36% in groundnut, translating into an annual economic loss of ₹78,591 crore across 16 major crops. Weed control expenses average ₹6,000/ha during the kharif season and ₹4,000/ha in the rabi season, comprising 33% and 22% of total cultivation costs, respectively (Yaduraju and Mishra, 2018) [25].

A) Weed parameters

1. Weed count; Weed dry matter and Weed control efficiency

The lowest weed count 17.96, 10.79 and 13.50 weeds/m²

observed at 25, 50 DAS and at harvest respectively, with treatment T₁₃ (Two hand weeding at 20 and 40 DAS) leading the results. Treatment T₁₀ (Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS) followed closely, with weed count of 20.99, 13.50 and 14.66 weeds/m² at the same intervals T₇ (Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE) coming next with 20.18, 14.91 and 16.59 weeds/m². In contrast, the T₀ (Weedy check) exhibited the highest weed count of 55.72, 63.81 and 72.70 weeds/m² at 25, 50 DAS and at harvest respectively. The lowest Weed dry matter 9.83, 11.12 and 12.23 g/m² observed at 25, 50 DAS and at harvest respectively, with treatment T₁₃ (Two hand weeding at 20 and 40 DAS) leading the results. Treatment T₁₀ (Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS) followed closely, with Weed dry matter of 11.35, 12.83 and 14.12 g/m² at the same intervals T₇ (Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE) coming next with 12.27, 13.90 and 15.19 g/m². In contrast, the T₀ (Weedy check) exhibited the highest Weed dry matter of 26.19, 29.21 and 32.48 g/m² at 25, 50 DAS and at harvest respectively. The highest Weed control efficiency 62.27, 61.77 and 62.08% observed at 25, 50 DAS and at harvest respectively, with treatment T₁₃ (Two hand weeding at 20 and 40 DAS) leading the results. Treatment T₁₀ (Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS) followed closely, with weed control efficiency of 56.31, 55.75 and 56.08% at the same intervals T₇ (Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE) coming next with 52.94, 52.27 and 52.94%. In contrast, the T₁ (Black Polythene Mulch) exhibited the lowest Weed control efficiency of 16.58, 16.59 and 16.58% at 25, 50 DAS and at harvest respectively. The lowest weed count, weed dry matter, and highest weed control efficiency observed in T₁₃ (two hand weeding at 20 and 40 DAS) can be attributed to the effectiveness of manual weed removal at critical growth stages. This approach directly reduces weed competition for resources such as nutrients, moisture, and sunlight, leading to lower weed biomass and better crop growth. The timing of the hand weeding ensures that weeds are controlled before they can significantly affect the crop's development, resulting in better weed suppression. T₁₀ (Black Polythene Mulch + Propaquizafop + Imazethapyr) also demonstrated strong results due to the combined effect of physical mulch and selective herbicides. The mulch effectively inhibits weed seed germination and growth, while the herbicides provide chemical control of surviving weeds, enhancing the overall weed control efficiency. T₇ (Black Polythene Mulch + Pendimethalin) similarly showed good control but was slightly less effective than T₁₀, as Pendimethalin's residual effect may have been less comprehensive than the combination of Propaquizafop and Imazethapyr. Similar findings were reported by Kumar *et al.* (2019) [15], Danga *et al.* (2020) [6] and Rani and Venkateswarlu (2022) [19].

B) Growth parameters

1. Plant height and Dry matter accumulation.

The tallest plants measured 27.55, 64.40 and 100.88 cm at 25, 50 DAS and at harvest respectively, with treatment T₁₃ (Two hand weeding at 20 and 40 DAS) leading the results. Treatment T₁₀ (Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS) followed closely, yielding heights of 27.03, 62.86 and 99.49 cm at the same intervals T₇ (Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE) coming next with

25.45, 60.76 and 97.23 cm. In contrast, the T₀ (Weedy check) exhibited the shortest heights of 19.23, 41.67 and 81.79 cm at 25, 50 DAS and at harvest respectively. The highest dry matter accumulation, recorded as 10.75, 26.56 and 38.42 g/plant at 25, 50 DAS, and harvest respectively, was achieved with treatment T₁₃ (two hand weeding at 20 and 40 DAS). This was closely followed by treatment T₁₀ (black polythene mulch combined with Propaquizafop 2.5% + Imazethapyr 3.75% ME at 125 g a.i./ha applied at 15–20 DAS), which yielded 9.56, 23.23 and 35.68 g/plant at the same intervals. Treatment T₇ (black polythene mulch with Pendimethalin 30% EC at 1.0 kg a.i./ha applied pre-emergence) ranked next, with values of 10.13, 21.43 and 33.16 g/plant. Conversely, the T₀ (weedy check) recorded the lowest dry matter accumulation, with 3.31, 7.12 and 11.13 g/plant at 25, 50 DAS, and harvest, respectively. The tallest plant height observed in T₁₃ (two hand weeding at 20 and 40 DAS) can be attributed to the direct removal of weeds, which reduces competition for essential growth resources like nutrients, moisture, and light. By eliminating weeds at critical growth stages, T₁₃ allows pea plants to establish better and utilize available resources more efficiently, leading to enhanced plant growth and higher biomass accumulation. T₁₀ (Black Polythene Mulch + Propaquizafop + Imazethapyr) also showed positive results due to the synergistic effect of the physical mulch and herbicides. The mulch helps conserve moisture and suppresses weed growth, while the herbicides control any surviving weeds. This results in better resource allocation for the pea plants, leading to improved growth parameters. Similarly, T₇ (Black Polythene Mulch + Pendimethalin) provided effective weed control through mulch and pre-emergence herbicide, although its overall effect on growth was slightly less pronounced than T₁₀, due to differing herbicide modes of action. Similar findings were reported by Shilurenla *et al.* (2022) [21] and Yadav *et al.* (2022) [24].

2. Number of branches per plant; number of nodules per plant and dry weight of nodules

The highest number of branches per plant, recorded as 24.00 branches was achieved with treatment T₁₃ (two hand weeding at 20 and 40 DAS). This was closely followed by treatment T₁₀ (black polythene mulch combined with Propaquizafop 2.5% + Imazethapyr 3.75% ME at 125 g a.i./ha applied at 15–20 DAS), having 23.67 branches. Treatment T₇ (black polythene mulch with Pendimethalin 30% EC at 1.0 kg a.i./ha applied pre-emergence) ranked next, with values of 21.00 branches. Conversely, the T₀ (weedy check) recorded the lowest number of branches per plant, with 11.33 branches. The highest number of nodules per plant, recorded as 12.67 nodules was achieved with treatment T₁₃ (two hand weeding at 20 and 40 DAS). This was closely followed by treatment T₁₀ (black polythene mulch combined with Propaquizafop 2.5% + Imazethapyr 3.75% ME at 125 g a.i./ha applied at 15–20 DAS), having 12.17 nodules. Treatment T₉ (Black Polythene Mulch + Sodium aciflourfen 16.5% EC + Clodinafop propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15–20 DAS) ranked next, with values of 9.67 nodules. Conversely, the T₀ (weedy check) recorded the lowest number of nodules per plant, with 8.33 nodules. The highest dry weight of nodules recorded as 4.33 milligrams was achieved with treatment T₁₃ (two hand weeding at 20 and 40 DAS). This was closely followed by treatment T₁₀ (black polythene mulch combined with Propaquizafop 2.5% + Imazethapyr 3.75% ME at 125 g a.i./ha applied at 15–20 DAS), having 4.03 milligrams. Treatment T₇ (black polythene mulch with Pendimethalin 30% EC at 1.0 kg a.i./ha applied pre-emergence) ranked next, with

values of 3.45 milligrams. Conversely, the T₀ (weedy check) recorded the lowest dry weight of nodules, with 0.52 milligrams. The highest number of branches, number of nodules, and maximum dry weight of nodules observed in T₁₃ (two hand weeding at 20 and 40 DAS) can be attributed to the effective control of weeds at critical growth stages. By minimizing weed competition for nutrients, water, and light, T₁₃ enables pea plants to allocate more resources towards vegetative growth and nodule formation. The removal of weeds allows the pea plants to maintain better root and shoot development, which supports increased branching and nodulation, essential for nitrogen fixation and overall plant health. T₁₀ (Black Polythene Mulch + Propaquizafop + Imazethapyr) also showed enhanced nodulation and branching, due to the dual effect of mulching and herbicide treatment. The black polythene mulch conserves moisture and controls weeds, while the herbicides selectively control unwanted vegetation, allowing pea plants to thrive and form more branches and nodules. Similarly, T₇ (Black Polythene Mulch + Pendimethalin) also contributed to increased branching and nodulation by suppressing weeds, though its effect was slightly less pronounced than T₁₀, as it relied solely on pre-emergence herbicide action. Similar findings were reported by Yadav *et al.* (2022) [24], Malviya and Saini (2023) [16] and Patidar *et al.* (2023) [18].

C) Yield parameters

3. Number of pods per plant, seeds per pod and test weight

The highest number of pods per plant recorded as 24.00 pods was achieved with treatment T₁₃ (two hand weeding at 20 and 40 DAS). This was closely followed by treatment T₁₀ (black polythene mulch combined with Propaquizafop 2.5% + Imazethapyr 3.75% ME at 125 g a.i./ha applied at 15–20 DAS), having 21.33 pods. Treatment T₇ (black polythene mulch with Pendimethalin 30% EC at 1.0 kg a.i./ha applied pre-emergence) ranked next, with values of 19.96 pods. Conversely, the T₀ (weedy check) recorded the lowest number of pods per plant, with 13.67 pods. The highest number of seeds per pod recorded as 9.00 seeds was achieved with treatment T₁₃ (two hand weeding at 20 and 40 DAS). This was closely followed by treatment T₁₀ (black polythene mulch combined with Propaquizafop 2.5% + Imazethapyr 3.75% ME at 125 g a.i./ha applied at 15–20 DAS), having 8.67 seeds. Treatment T₇ (black polythene mulch with Pendimethalin 30% EC at 1.0 kg a.i./ha applied pre-emergence) ranked next, with values of 8.35 seeds. Conversely, the T₀ (weedy check) recorded the lowest number of seeds per pod, with 7.33 seeds. The highest test weight recorded as 25.74 grams was achieved with treatment T₁₃ (two hand weeding at 20 and 40 DAS). This was closely followed by treatment T₁₀ (black polythene mulch combined with Propaquizafop 2.5% + Imazethapyr 3.75% ME at 125 g a.i./ha applied at 15–20 DAS), having 24.74 grams. Treatment T₇ (black polythene mulch with Pendimethalin 30% EC at 1.0 kg a.i./ha applied pre-emergence) ranked next, with values of 24.53 grams. Conversely, the T₀ (weedy check) recorded the lowest test weight, with 19.77 grams. The highest number of pods per plant, seeds per pod, and maximum test weight observed in T₁₃ (two hand weeding at 20 and 40 DAS) is largely due to effective weed control during critical growth stages. By eliminating competition from weeds, T₁₃ allows the pea plants to access essential resources like water, nutrients, and sunlight, leading to better reproductive growth and pod development. This improved resource availability results in an increased number of pods, more seeds per pod, and better seed quality, ultimately contributing to a higher test weight. Similarly, T₁₀ (Black

Polythene Mulch + Propaquizafop + Imazethapyr) also improves pod and seed development. The black polythene mulch maintains soil moisture and reduces weed pressure, while the herbicides selectively target weeds, ensuring that the pea plants have optimal growing conditions. This combined approach promotes better pod formation and seed quality. T₇ (Black Polythene Mulch + Pendimethalin) also positively impacts pod and seed parameters, although its effect is less pronounced than T₁₃, as it primarily depends on pre-emergence herbicide action, which may not be as effective in later growth stages. Similar findings were reported by Aktar *et al.* (2015)^[1]; Chaudhari *et al.* (2016)^[4].

4. Seed yield; Straw yield and biological yield

The highest seed yield per hectare recorded as 1840.12 kg/ha was achieved with treatment T₁₃ (two hand weedings at 20 and 40 DAS). This was closely followed by treatment T₁₀ (black polythene mulch combined with Propaquizafop 2.5% + Imazethapyr 3.75% ME at 125 g a.i./ha applied at 15–20 DAS), having 1756.11 kg/ha. Treatment T₇ (black polythene mulch with Pendimethalin 30% EC at 1.0 kg a.i./ha applied pre-emergence) ranked next, with values of 1711.27 kg/ha. Conversely, the T₀ (weedy check) recorded the lowest seed yield per hectare, with 720.40 kg/ha. The highest straw yield per hectare recorded as 3900.71 kg/ha was achieved with treatment T₁₃ (two hand weedings at 20 and 40 DAS). This was closely followed by treatment T₁₀ (black polythene mulch combined with Propaquizafop 2.5% + Imazethapyr 3.75% ME at 125 g a.i./ha applied at 15–20 DAS), having 3807.38 kg/ha. Treatment T₇ (black polythene mulch with Pendimethalin 30% EC at 1.0 kg a.i./ha applied pre-emergence) ranked next, with values of 3739.12 kg/ha. Conversely, the T₀ (weedy check) recorded the lowest straw yield per hectare, with 3118.88 kg/ha. The highest biological yield per hectare recorded as 5740.83 kg/ha was achieved with treatment T₁₃ (two hand weedings at 20 and 40 DAS). This was closely followed by treatment T₁₀ (black polythene mulch combined with Propaquizafop 2.5% + Imazethapyr 3.75% ME at 125 g a.i./ha applied at 15–20 DAS), having 5563.49 kg/ha. Treatment T₇ (black polythene mulch with Pendimethalin 30% EC at 1.0 kg a.i./ha applied pre-emergence) ranked next, with values of 5450.38 kg/ha. Conversely, the T₀ (weedy check) recorded the lowest biological yield per hectare, with 3839.28 kg/ha. The maximum seed yield, straw yield, and biological yield observed in T₁₃ (two hand weeding at 20 and 40 DAS) can be attributed to the effective and timely removal of weeds. By eliminating weed competition during critical growth stages, T₁₃ ensures that the pea plants have unhindered access to resources such as water, nutrients, and light. This optimal resource availability promotes vigorous growth, enhancing both vegetative (straw) and reproductive (seed) growth, ultimately increasing the biological yield. The effective weed management through hand weeding also prevents early weed establishment, reducing their negative impact on plant growth, leading to higher yields. In T₁₀ (Black Polythene Mulch + Propaquizafop + Imazethapyr), the black polythene mulch maintains soil moisture, while the herbicides selectively control weeds. This combination results in improved plant growth, leading to higher seed and straw yields. Similarly, T₇ (Black Polythene Mulch + Pendimethalin) reduces weed competition and maintains better moisture levels, although its overall impact is somewhat less than T₁₃, as it primarily addresses early-stage weed control, which has less influence on later growth stages. Consequently, these treatments contribute to increased seed and straw yields, thus improving biological yield. Findings were in accordance with findings of Bahar *et al.* (2017)

[3]; Kaur *et al.* (2018)^[14]; Gebregergiset *al.* (2019)^[12] and Verma and Kushwaha (2020)^[23].

5. Harvest index

The maximum harvest index recorded as 32.05% was achieved with treatment T₁₃ (two hand weedings at 20 and 40 DAS). This was closely followed by treatment T₁₀ (black polythene mulch combined with Propaquizafop 2.5% + Imazethapyr 3.75% ME at 125 g a.i./ha applied at 15–20 DAS), having 31.56%. Treatment T₇ (black polythene mulch with Pendimethalin 30% EC at 1.0 kg a.i./ha applied pre-emergence) ranked next, with values of 31.40%. Conversely, the T₀ (weedy check) recorded the lowest harvest index, with 18.77%. The highest harvest index in T₁₃ (Two hand weeding at 20 and 40 DAS) is primarily due to effective and timely weed control, which ensures optimal nutrient, water, and light availability for the pea plants. By eliminating weed competition during critical growth periods, T₁₃ allows the plants to allocate more resources toward reproductive growth, enhancing pod and seed formation. This results in a higher proportion of grain yield relative to total biological yield, thereby increasing the harvest index. T₁₀ (Black Polythene Mulch + Propaquizafop + Imazethapyr) also achieves a relatively high harvest index due to the combined effect of mulch maintaining moisture and herbicides controlling weeds. The increased moisture retention and reduced weed pressure support better reproductive growth, but not to the same extent as T₁₃, as the effectiveness of weed control may be slightly lower during later stages. T₇ (Black Polythene Mulch + Pendimethalin) provides good early stage weed control but does not provide the same level of weed suppression during the reproductive phase, leading to a lower harvest index compared to T₁₃ and T₁₀. Verma and Kushwaha (2020)^[23]; Chaithanya *et al.* (2021)^[5]; Dhayalet *al.* (2022)^[8] and Katoch *et al.* (2023)^[13] concluded similar findings working on field pea for integrated weed management practices.

D) Economics parameters

Maximum cost of cultivation was recorded in treatment T₁₀ (Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS) with (Rs 49,885 ha⁻¹) followed by T₉ (Black Polythene Mulch + Sodium aciflourfen 16.5% EC + Clodinafop propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15-20 DAS) having Rs 48,346 ha⁻¹ and the minimum (Rs 37,260 ha⁻¹) was recorded in treatment T₀ (Weedy check). Maximum gross returns were recorded in treatment T₁₃ (Two hand weeding at 20 and 40 DAS) with (Rs 1,22,109 ha⁻¹) followed by T₁₀ (Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS) having Rs 1,16,789 ha⁻¹ and the minimum (Rs 52,580 ha⁻¹) was recorded in treatment T₀ (Weedy check). Maximum net returns were recorded in treatment T₁₃ (Two hand weeding at 20 and 40 DAS) with (Rs 79,249 ha⁻¹) followed by T₇ (Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE) having Rs 68,469 ha⁻¹ and T₁₀ (Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS) having Rs 66,904 ha⁻¹ and the minimum (Rs 15,320 ha⁻¹) was recorded in treatment T₀ (Weedy check). Highest benefit cost ratio was recorded in treatment T₁₃ (Two hand weeding at 20 and 40 DAS) with (2.85) followed by T₇ (Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE) having 2.51 and T₁₀ (Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS) having 2.34 and the minimum (1.36) was recorded in treatment T₁ (Black Polythene Mulch). Similar findings were reported by Katoch *et al.* (2023)^[13] and Patidar *et al.* (2023)^[18].

Table 1: Effect of different weed management techniques on weed population and dry weight.

Treatment Symbols	Treatment combination	Weed count (weeds/m ²)			Weed dry matter (g/m ²)		
		At 25 DAS	At 50 DAS	At harvest	At 25 DAS	At 50 DAS	At harvest
T ₀	Weedy Check (No weeding)	55.72	63.81	72.70	26.19	29.21	32.48
T ₁	Black Polythene Mulch	26.28	19.08	23.81	21.82	24.34	27.05
T ₂	Pendimethalin 30% EC @ 1.0 kg a.i./ha PE	34.23	27.16	27.38	18.45	20.58	22.87
T ₃	Imazethapyr 10% SL @ 55 g a.i./ha at 15-20 DAS	35.10	32.42	31.55	16.93	18.89	20.98
T ₄	Sodium aciflourfen 16.5% EC + Clodinafop propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15-20 DAS	28.85	21.66	23.61	16.57	18.48	20.57
T ₅	Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS	43.05	33.54	35.34	15.06	16.81	18.64
T ₆	Fomesafen 11.1% + Fluzifop-p-butyl 11.1% SL @ 220 g a.i./ha (RM) at 15-20 DAS	30.96	19.69	21.96	17.33	19.33	21.46
T ₇	Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE	20.18	14.91	16.59	12.27	13.90	15.19
T ₈	Black Polythene Mulch + Imazethapyr 10% SL @ 55 g a.i./ha at 15-20 DAS	42.51	33.01	33.03	17.04	19.29	21.20
T ₉	Black Polythene Mulch + Sodium aciflourfen 16.5% EC + Clodinafop propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15-20 DAS	27.89	21.22	22.48	14.64	16.57	18.21
T ₁₀	Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS	20.99	13.50	14.66	11.35	12.83	14.12
T ₁₁	Black Polythene Mulch + Fomesafen 11.1% + Fluzifop-p-butyl 11.1% SL @ 220 g a.i./ha (RM) at 15-20 DAS	24.01	17.08	17.31	13.55	15.33	16.86
T ₁₂	White Polythene Mulch	25.16	20.10	21.71	18.49	20.91	23.01
T ₁₃	Two hand weeding at 20 and 40 DAS	17.96	10.79	13.50	9.83	11.12	12.23
T ₁₄	Mulching with straws	26.14	22.27	24.99	17.87	20.23	22.22
CD _{0.05}		3.20	2.33	1.86	1.93	2.08	2.56
SE. m (±)		1.11	0.81	0.64	0.67	0.72	0.88

Table 2: Effect of different weed management techniques on Weed control Efficiency and plant height of field pea

Treatment Symbols	Treatment combination	Weed control efficiency (%)			Plant height (cm)		
		At 25 DAS	At 50 DAS	At harvest	At 25 DAS	At 50 DAS	At harvest
T ₁	Black Polythene Mulch	16.58	16.59	16.58	19.23	41.67	81.79
T ₂	Pendimethalin 30% EC @ 1.0 kg a.i./ha PE	29.39	29.39	29.39	24.25	47.25	86.61
T ₃	Imazethapyr 10% SL @ 55 g a.i./ha at 15-20 DAS	34.98	34.98	34.98	23.69	46.69	87.43
T ₄	Sodium aciflourfen 16.5% EC + Clodinafop propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15-20 DAS	36.65	36.65	36.65	25.31	47.12	83.94
T ₅	Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS	41.98	41.98	41.98	23.93	54.50	87.08
T ₆	Fomesafen 11.1% + Fluzifop-p-butyl 11.1% SL @ 220 g a.i./ha (RM) at 15-20 DAS	33.44	33.45	33.44	22.30	43.50	88.54
T ₇	Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE	52.94	52.27	52.94	22.94	57.75	92.94
T ₈	Black Polythene Mulch + Imazethapyr 10% SL @ 55 g a.i./ha at 15-20 DAS	34.57	33.68	34.21	25.45	60.76	97.23
T ₉	Black Polythene Mulch + Sodium aciflourfen 16.5% EC + Clodinafop propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15-20 DAS	43.82	43.06	43.53	22.28	54.83	89.45
T ₁₀	Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS	56.31	55.75	56.08	22.64	53.10	94.15
T ₁₁	Black Polythene Mulch + Fomesafen 11.1% + Fluzifop-p-butyl 11.1% SL @ 220 g a.i./ha (RM) at 15-20 DAS	47.89	47.20	47.61	27.03	62.86	99.49
T ₁₂	White Polythene Mulch	28.99	28.07	28.64	22.08	50.35	94.14
T ₁₃	Two hand weeding at 20 and 40 DAS	62.27	61.77	62.08	22.94	49.64	87.90
T ₁₄	Mulching with straws	31.08	30.16	30.64	27.55	64.40	100.88
T ₀	Weedy Check (No weeding)	-	-	-	22.33	48.78	92.15
CD _{0.05}		6.65	6.56	7.00	2.85	3.61	1.91
SE. m (±)		2.30	2.26	2.42	0.98	1.24	1.00

Table 3: Effect of different weed management techniques on dry matter accumulation, number of branches, nodules, pods per plant of pea

Treatment Symbols	Treatment combination	Dry matter accumulation (g/plant)			No of branches per plant	No of nodules per plant	No of pods per plant
		At 25 DAS	At 50 DAS	At harvest			
T ₀	Weedy Check (No weeding)	3.31	7.12	11.13	11.33	8.33	13.67
T ₁	Black Polythene Mulch	6.39	13.29	17.84	13.67	10.67	16.67
T ₂	Pendimethalin 30% EC @ 1.0 kg a.i./ha PE	6.93	14.10	21.76	18.00	9.33	17.00
T ₃	Imazethapyr 10% SL @ 55 g a.i./ha at 15-20 DAS	5.48	11.23	16.16	16.00	10.00	17.33
T ₄	Sodium aciflourfen 16.5% EC + Clodinafop propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15-20 DAS	4.63	10.44	13.96	17.00	9.67	16.67
T ₅	Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS	7.45	15.53	23.50	16.00	10.67	19.67
T ₆	Fomesafen 11.1% + Fluzifop-p-butyl 11.1% SL @ 220 g a.i./ha (RM) at 15-20 DAS	8.85	17.61	27.66	20.00	9.67	21.67
T ₇	Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE	10.13	21.43	33.16	21.00	9.67	19.96
T ₈	Black Polythene Mulch + Imazethapyr 10% SL @ 55 g a.i./ha at 15-20 DAS	7.67	15.58	24.97	17.33	10.33	16.33
T ₉	Black Polythene Mulch + Sodium aciflourfen 16.5% EC + Clodinafop propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15-20 DAS	4.28	9.54	11.86	18.67	11.33	19.33
T ₁₀	Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS	9.56	23.23	35.68	23.67	12.17	21.33
T ₁₁	Black Polythene Mulch + Fomesafen 11.1% + Fluzifop-p-butyl 11.1% SL @ 220 g a.i./ha (RM) at 15-20 DAS	8.10	16.75	26.89	19.67	9.67	18.33
T ₁₂	White Polythene Mulch	8.55	19.04	26.08	22.00	9.67	18.00
T ₁₃	Two hand weeding at 20 and 40 DAS	10.75	26.56	38.42	24.00	12.67	24.00
T ₁₄	Mulching with straws	8.52	18.41	26.76	19.67	11.00	17.33
CD _{0.05}		0.52	1.03	2.46	2.33	1.61	2.19
SE. m (±)		0.18	0.35	0.85	0.81	0.55	0.75

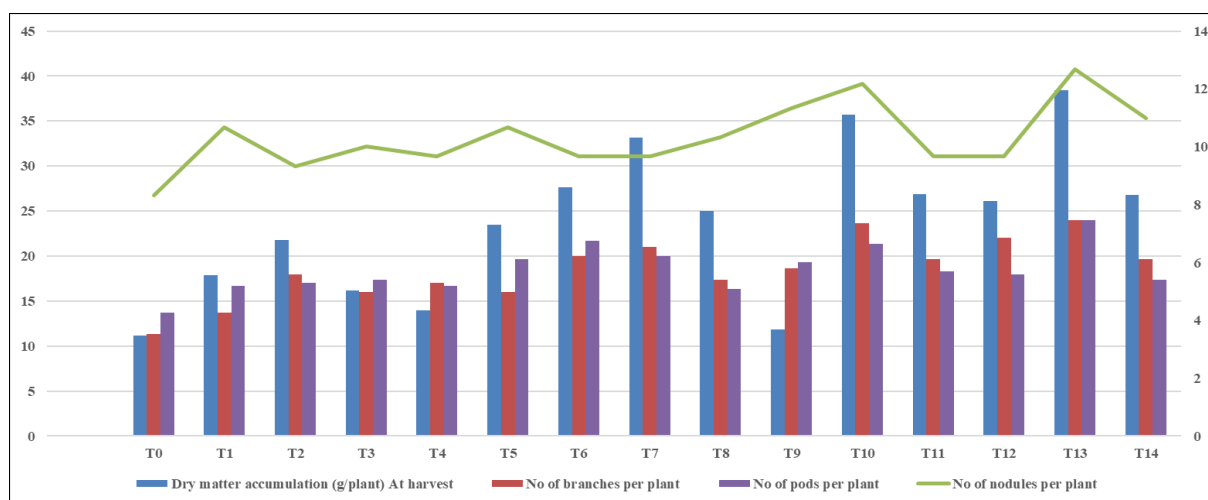
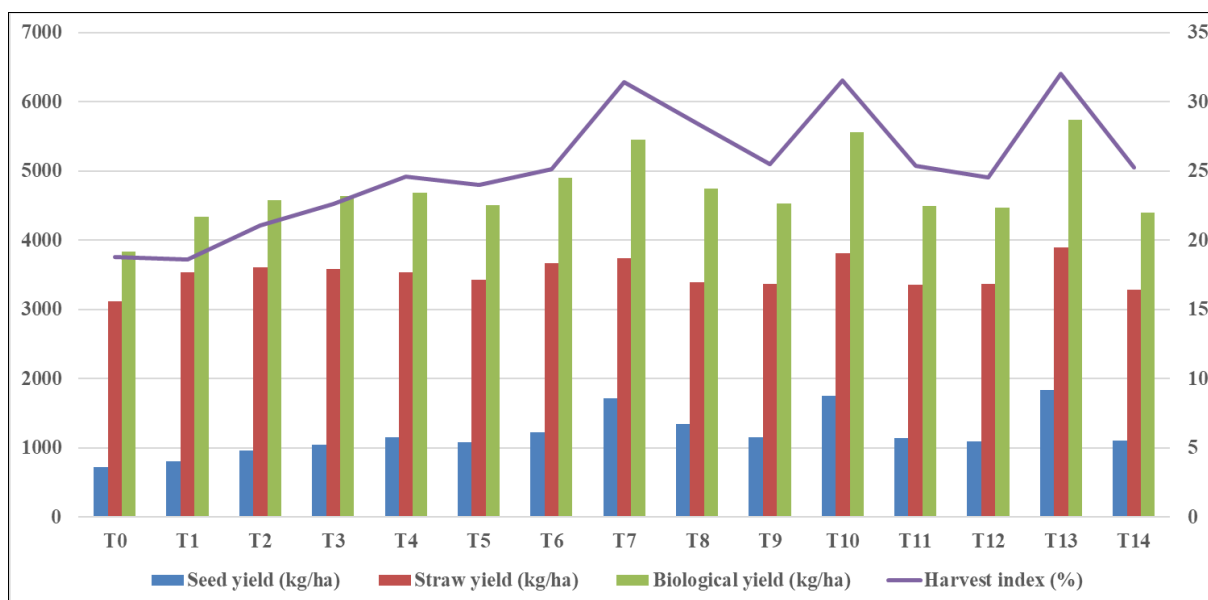
Table 4: Effect of different weed management techniques on yield parameters of pea

Treatment Symbols	Treatment combination	No of seeds per pod	100-seed weight (g)	Seed yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)	Harvest index (%)
T ₀	Weedy Check (No weeding)	7.33	19.77	720.40	3118.88	3839.28	18.77
T ₁	Black Polythene Mulch	8.33	20.79	806.30	3532.12	4338.42	18.63
T ₂	Pendimethalin 30% EC @ 1.0 kg a.i./ha PE	7.33	21.71	964.61	3614.47	4579.08	21.08
T ₃	Imazethapyr 10% SL @ 55 g a.i./ha at 15-20 DAS	8.00	23.03	1047.77	3587.94	4635.71	22.60
T ₄	Sodium aciflourfen 16.5% EC + Clodinafop propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15-20 DAS	8.00	24.76	1153.30	3536.72	4690.03	24.62
T ₅	Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS	7.33	24.32	1080.84	3426.46	4507.30	23.98
T ₆	Fomesafen 11.1% + Fluzifop-p-butyl 11.1% SL @ 220 g a.i./ha (RM) at 15-20 DAS	7.67	22.05	1229.50	3667.78	4897.28	25.11
T ₇	Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE	8.35	24.53	1711.27	3739.12	5450.38	31.40
T ₈	Black Polythene Mulch + Imazethapyr 10% SL @ 55 g a.i./ha at 15-20 DAS	8.00	19.53	1349.28	3394.48	4743.76	28.45
T ₉	Black Polythene Mulch + Sodium aciflourfen 16.5% EC + Clodinafop propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15-20 DAS	8.00	20.85	1154.22	3372.40	4526.61	25.50
T ₁₀	Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS	8.67	24.74	1756.11	3807.38	5563.49	31.56
T ₁₁	Black Polythene Mulch + Fomesafen 11.1% + Fluzifop-p-butyl 11.1% SL @ 220 g a.i./ha (RM) at 15-20 DAS	8.00	21.15	1141.31	3356.38	4497.69	25.38
T ₁₂	White Polythene Mulch	7.33	21.41	1097.75	3369.95	4467.70	24.57
T ₁₃	Two hand weeding at 20 and 40 DAS	9.00	25.74	1840.12	3900.71	5740.83	32.05
T ₁₄	Mulching with straws	8.33	20.74	1111.20	3286.13	4397.33	25.27
CD _{0.05}		1.37	1.39	39.22	163.22	153.05	1.20
SE. m (±)		0.47	0.47	13.54	56.34	52.83	0.47

Table 5: Economics as influenced by different treatments applied in Field pea

Treatment Symbols	Treatment combination	Cost of cultivation (Rs)	Gross return (Rs)	Net return (Rs)	BC ratio
T ₀	Weedy Check (No weeding)	37,260	52,580	15,320	1.41
T ₁	Black Polythene Mulch	43,260	58,974	15,714	1.36
T ₂	Pendimethalin 30% EC @ 1.0 kg a.i./ha PE	39,424	68,720	29,296	1.74
T ₃	Imazethapyr 10% SL @ 55 g a.i./ha at 15-20 DAS	37,783	73,630	35,847	1.95
T ₄	Sodium aciflourfen 16.5% EC + Clodinafop propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15-20 DAS	42,346	79,808	37,462	1.88
T ₅	Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS	43,885	75,130	31,245	1.71
T ₆	Fomesafen 11.1% + Fluzifop-p-butyl 11.1% SL @ 220 g a.i./ha (RM) at 15-20 DAS	41,105	84,774	43,669	2.06
T ₇	Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE	45,424	1,13,893	68,469	2.51
T ₈	Black Polythene Mulch + Imazethapyr 10% SL @ 55 g a.i./ha at 15-20 DAS	43,783	91,140	47,357	2.08
T ₉	Black Polythene Mulch + Sodium aciflourfen 16.5% EC + Clodinafop propargyl 8% EC @ 187.5 g a.i./ha (RM) at 15-20 DAS	48,346	79,370	31,024	1.64
T ₁₀	Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS	49,885	1,16,789	66,904	2.34
T ₁₁	Black Polythene Mulch + Fomesafen 11.1% + Fluzifop-p-butyl 11.1% SL @ 220 g a.i./ha (RM) at 15-20 DAS	47,105	78,548	31,443	1.67
T ₁₂	White Polythene Mulch	42,760	75,975	33,215	1.78
T ₁₃	Two hand weeding at 20 and 40 DAS	42,860	1,22,109	79,249	2.85
T ₁₄	Mulching with straws	40,760	76,530	35,770	1.88

Selling price of Field pea: Rs 60/kg
Selling price of stover: Rs 3/kg

**Fig 1:** Graphical representation of effect of different weed management techniques on dry matter accumulation, number of branches, nodules, pods per plant of pea**Fig 2:** Graphical representation of effect of different weed management techniques on yield parameters of pea

Conclusion

In the field pea cultivation study, various weed management practices were evaluated for their efficacy. The treatment involving two hand weeding at 20 and 40 days after sowing (T₁₃) consistently demonstrated superior results across multiple parameters. This treatment recorded the lowest weed counts, weed dry matter, and the highest weed control efficiency. Additionally, it led to the best plant growth, with the highest plant count, dry matter accumulation, branch number, and nodules per plant. Consequently, T₁₃ also resulted in the highest yield—both seed and straw yield—along with the best harvest index and net returns. On the other hand, the weedy check (T₀) exhibited the poorest performance across all aspects, with significantly higher weed counts, lower plant counts, and the lowest yields. Treatments using black polythene mulch, combined with herbicides, such as T₁₀ (Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS) and T₇ (Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE), provided effective weed control but did not match the performance of T₁₃ in terms of yield and profitability. Overall, T₁₃ emerged as the most effective and economical weed management practice for field pea cultivation. Thus, apart from manual weeding use of weeding techniques including (Black Polythene Mulch + Propaquizafop 2.5% + Imazethapyr 3.75% ME @ 125 g a.i./ha (RM) at 15-20 DAS) and (Black Polythene Mulch + Pendimethalin 30% EC @ 1.0 kg a.i./ha PE) may be suggested for higher crop productivity along with over all betterment of field pea under Balaghat (M.P.) conditions.

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