INTEGRATED WEED MANAGEMENT IN BLACKGRAM [*Vigna mungo* (L.) Hepper]

WITH PRE-MIX HERBICIDES

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(2022-11-159)

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KERALA, INDIA

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by

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THESIS

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2025

DECLARATION

I, hereby declare that this thesis entitled **"INTEGRATED WEED MANAGEMENT IN BLACKGRAM [*Vigna mungo* (L.) Hepper] WITH PRE-MIX HERBICIDES"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"INTEGRATED WEED MANAGEMENT IN BLACKGRAM [*Vigna mungo* (L.) Hepper] WITH PRE-MIX HERBICIDES"** is a record of research work done independently by **Mr. Nihal P.M. (2022-11-159)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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Nihal P.M.

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LIST OF ABBREVIATIONS

Abbreviation/Symbol	Expansion
ANOVA	Analysis of Variance
a.i	Active ingredient
BCR	Benefit cost ratio
BLW	Broad -leaf weeds
CD	Critical difference
cfu	Colony forming units
CRD	Completely randomised design
cm	Centimetre
cm^2	Centimetre square
DAS	Days after sowing
CPWC	Critical period of crop-weed competition
$dS\ m^{-1}$	Deci siemens per metre
DMP	Dry matter production
DAI	Days after incubation
EC	Electrical conductivity
et al.	Co-workers
Fig.	Figure
fb	Followed by
FYM	Farmyard manure
$g\ m^{-2}$	Gram per metre square
$g\ L^{-1}$	Gram per litre
HW	Hand weeding
K/K_2O	Potassium
KAU	Kerala Agricultural University
$kg\ ha^{-1}$	Kilogram per hectare
LAI	Leaf area index
$L\ ha^{-1}$	Litre per hectare

NS	Not-significant
PoE	Post-emergent
PE	Pre-emergent
YEMA	Media composition of Yeast extract mannitol agar
WCE	Weed control efficiency
WI	Weed index
m	Metre
mm	Millimetre
ml	Millilitre
mL L^{-1}	Millilitre per litre
N	Nitrogen
nos.	Numbers
NS	Not significant
OC	Organic Carbon
P/P_2O_5	Phosphorus
pH	Potential of hydrogen
RH	Relative humidity
SE m	Standard error of mean
t ha^{-1}	Tonnes per hectare
TPF	Triphenyl formazan
q ha^{-1}	Quintal per hectare
TNAU	Tamil Nadu Agricultural University
µL	Micro litre
@	At the rate of
®	Registered sign
viz.	Namely
%	Per cent
°C	Degree Celsius
₹	Rupees

INTRODUCTION

1. INTRODUCTION

Blackgram (*Vigna mungo* (L.) Hepper), a major pulse crop in India, holds a key role in both dietary and agricultural systems due to its high protein content and ability to fix atmospheric nitrogen. However, weed infestation is one of the primary constraints limiting its productivity. Rana *et al*. (2019) reported a yield reduction of 55.4 per cent in blackgram as a result of weed infestation. Weeds compete with blackgram for essential resources especially during the early stages of crop growth. During the initial growth stages, especially between three and six weeks after sowing, the crop offers poor competition to weeds (Choudhary *et al*., 2012). Effective weed management, therefore, is crucial to maximize blackgram productivity and ensure efficient resource utilization.

Traditional weed management in blackgram has predominantly relied on manual weeding and tillage practices, but these methods are labour-intensive and time-consuming, making them increasingly unsustainable in regions facing labour shortages and rising costs. Moreover, frequent tillage can degrade soil structure, impacting its long-term health and productivity. Given these challenges, there is a need to explore more efficient and low cost weed management practices. Herbicides offer a viable alternative, providing quick, cost-effective, and efficient weed control. However, continuous and indiscriminate use of herbicides can lead to adverse environmental effects, such as soil and water contamination, non-target crop damage, and the development of herbicide-resistant weed species. Thus, there is a need to adopt an integrated approach to weed management that amalgamates cultural, mechanical, and chemical methods to enhance efficacy and minimize negative environmental impacts.

Integrated weed management (IWM) is a comprehensive approach that brings together various weed control methods to achieve sustainable weed suppression. In recent years, the use of premix herbicides has gained attention as a potential tool within the IWM framework. Premix herbicides are formulations containing two or more active ingredients, specifically selected to target a broad spectrum of weed species. By offering multi-site action, premix herbicides are capable of reducing the chance of resistance development, providing effective control of both broadleaf weeds and grass weeds prevalent in blackgram (Sekhar *et al*., 2024). These formulations minimize the frequency of herbicide applications, reducing both labour costs and environmental exposure.

Among the various premix herbicides suitable for integrated weed management in blackgram, two promising combinations include pendimethalin + imazethapyr and propaquizafop + imazethapyr. These combinations have demonstrated effectiveness in controlling a range of weed species in legume crops, offering mode of action that contribute to comprehensive weed control.

Pendimethalin + imazethapyr is a pre-emergent herbicide combination that provides broad-spectrum control of both grass and broadleaf weeds. Pendimethalin, a dinitroaniline herbicide, acts primarily by inhibiting cell division, specifically targeting the root and shoot meristem regions of emerging weeds. This results in effective control of early-stage weeds, preventing their establishment and competition with blackgram seedlings for resources. On the other hand, imazethapyr belongs to the imidazolinone class of herbicides, which inhibits acetohydroxy acid synthase (AHAS), an enzyme critical for synthesizing essential branched-chain amino acids. This dual mechanism of action targets different physiological pathways in weed species, making it difficult for them to adapt and develop resistance. The combination also offers residual activity, providing extended weed control and reducing the need for subsequent applications.

Propaquizafop + imazethapyr is a selective post-emergent herbicide combination, effective for managing weeds that emerge after crop establishment. Propaquizafop, an aryloxyphenoxypropionate herbicide, inhibits Acetyl-CoA carboxylase (ACCase) activity in grasses, preventing fatty acid synthesis essential for cell membrane formation and resulting in grass weed desiccation. By combining propaquizafop with imazethapyr, this premix can control both grass and broadleaf weeds, ensuring comprehensive control over a range of weed species. Moreover, selective action of propaquizafop on grass weeds complements imazethapyr which control broadleaf species, leading to enhanced weed suppression in blackgram.

The newer options of premix herbicides offer broad spectrum control of weeds at very low doses. The use of pre and post-emergence herbicides as premix combination can broaden the window of weed management by broad spectrum weed control. However, the efficacy of herbicides can vary depending on the climatic and edaphic factors. The applied herbicides fallen on soil can influence the dynamics of soil microbial population, enzyme activity and beneficial microorganisms like *Rhizobium*.

In blackgram, integrated weed management using premix herbicides presents a promising approach to achieve sustainable weed control. In this backdrop, the present study was conducted to formulate an integrated weed management strategy using premix herbicides for blackgram intercropped in coconut garden

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Blackgram [*Vigna mungo* (L.) Hepper] is an extensively grown grain legume with noticeable significance from a standpoint focused on securing reliable access to nutritious food and maintaining robust dietary health. However, weeds pose a significant challenge, drastically reducing its yield. Integrated weed management offers an effective approach to keeping weed infestations below the economic threshold level. This emphasizes the need to identify weed management strategies that are both cost-effective and environmentally sustainable. This chapter reviews the research conducted on weed management practices for blackgram intercropped in coconut gardens.

2.1 IMPORTANCE OF PULSES

Pulses are a vital, nutrient-rich staple in the human diet, often called the ‘poor man's meat’ for their affordability and high protein content. They are globally recognized for their exceptional nutritional value, low calorie count, and low glycaemic index (GI), making them an essential part of a healthy diet. Pulses have an inherent ability to mobilize P, along with other essential nutrients and micronutrients, enriching the soil and supporting improved crop productivity.

Blackgram (*Vigna mungo* (L.) Hepper) holds a prominent position as a leading pulse crop in India. As a widely grown grain legume, blackgram plays a crucial role in ensuring food and nutritional security globally (Thakur *et al*., 2017). Blackgram ranks as the third most significant pulse crop cultivated in India, with the country being both the largest producer and consumer globally, contributing approximately 12 per cent of total pulse production. In 2020–21, India produced around 24.5 lakh tonnes of blackgram from an area of 4.6 million hectares, achieving an average productivity of 533 kg ha^{-1} (GOI, 2021). In India, blackgram contributes to 13 per cent of the total pulse area and 10per cent of the total pulse production (Manjri *et al*., 2018).

Blackgram thrives in tropical and subtropical regions, including marginal and sub-marginal lands. It is cultivated both as a sole crop and an intercrop, making it highly adaptable to various cropping systems. Its role in crop rotation is particularly valuable, as it enhances soil fertility and contributes to the sustainability of agricultural production systems. The crop is widely cultivated across several states in India, including Madhya Pradesh, Maharashtra, Andhra Pradesh, Tamil Nadu, Karnataka, and Uttar Pradesh.

Blackgram contains about 26 per cent protein, nearly three times the protein content of cereals (Kavitha *et al*., 2013). It is highly nutritious, providing significant amounts of carbohydrates (60 g/100 g), protein (20-25 g/100 g), P (385 mg/100 g), calcium (145 mg/100 g), and iron (7.8 mg/100 g). Studies have found that it is beneficial for controlling elevated cholesterol levels (Indira and Kurup, 2013). In addition to being a rich protein source, blackgram contributes to soil fertility through biological N fixation, making it an essential component in promoting sustainable agriculture. It enhances soil by fixing 70-90 kg ha^{-1} of N (Satish *et al*., 2018). It is highly valued as a short-duration crop due to its adaptability across seasons, thriving either as a sole crop, intercrop, or catch crop.

2.1.1. Blackgram as an intercrop in coconut garden

In Kerala, where land fragmentation and limited cultivable land pose significant challenges, intercropping blackgram in coconut plantations presents a sustainable and efficient approach to enhance its cultivation. Research indicated that light transmission in coconut plantations increased by 50 per cent in trees over 40 years old, enabling the successful cultivation of intercrops in the available spaces (Nelliat *et al.*, 1974). Further studies have shown that a sole coconut crop planted at a spacing of 7.5 m x 7.5 m utilized only 22.3 per cent of the land area effectively (Durieux, 1997). The average canopy air space utilization was around 30 per cent, while the interception of solar radiation is approximately 50 per cent (Thiruvarassan, 2014). Pooja *et al*. (2023) reported that varieties such as DBGV 5 (1183.33 kg ha^{-1}), VBN 5 (916.67 kg ha^{-1}), and Sumanjana (906.67 kg ha^{-1}) have demonstrated favourable yield and growth performance under the partial shade conditions typical of coconut gardens in the State.

2.2 WEED PROBLEM IN PULSES

One of the major problems encountered in the successful cultivation of pulses is the heavy infestation of weeds. Both the applied and native nutrients are heavily depleted by weeds. Effective weed management strategies are influenced by factors such as weed competition, weed types, and the control methods used. Reducing weed density below the threshold level is crucial to optimize crop yield and quality.

2.2 YIELD LOSS DUE TO WEEDS IN PULSES

During the 2020-21 period, India produced about 25.72 million tonnes of pulses, with an average yield of 0.892 t ha^{-1}, which is notably low. The productivity of pulses is often limited by various factors, with improper weed management being a significant contributor to reduced yields. Weed infestation reported to cause significant yield losses in pulse crops with yield drop by 21 to 97 per cent in pigeonpea, by 40 to 50 per cent in greengram and by 29 to 70 per cent in chickpea. Pea yields decreased by 25 to 35 per cent, lentils by 70 to 87 per cent, and rajma by 20 to 48 per cent. Late-sown chickpea experienced losses of 37 to70 per cent, while kabuli chickpea reduced by 85 per cent (Kumar and Singh, 2010a).

Weed competition can result in a yield decline of up to 96.5 per cent, depending on the weed species and the level of competition (Verma *et al.,* 2015). In comparison, weed induced yield losses in mung bean extended from 65.4 per cent to 79.0 per cent (Dungarwal *et al*., 2003). The yield reduction caused by weeds were recorded as 46.7 per cent in pigeonpea, 55.4 per cent in urdbean, 48.1 per cent in chickpea, 58.8 per cent in lentil, and 47.1 per cent in field pea. These variations in yield loss were largely influenced by weed pressure, crop management practices, and agro-climatic conditions (Kumar *et al.,* 2016).

The specific types of weeds and the level of competition between crops and weeds can result in substantial yield losses, potentially reaching as high as 96.5 per cent. The extent of yield reduction is determined by variables such as weed density, the duration of weed presence, the species composition of the weeds, and the soil fertility status (Chaudhari *et al.,* 2016).

Heavy weed infestation is the primary reason for the low yield of blackgram (Rao *et al*., 2010b). Uncontrolled weed growth can result in significant yield losses, ranging from 27 to 100 per cent (Singh and Singh, 2010). Weed infestation in blackgram caused notable yield losses of 44 to 83 per cent, highlighting the need for effective weed control to protect crop yields (Kumar and Singh, 2010b). This can significantly affect farmer's livelihoods and food production, particularly in regions where blackgram is a vital crop (Mansoori *et al.*, 2015b).

2. 3 WEED FLORA IN PULSES

The types of weeds found in pulse crops vary depending on the agro-ecological conditions and crop management practices. The composition of weed species and the degree of infestation in the field significantly influenced the extent of crop growth and yield reduction. Additionally, the composition of the weed community can change significantly depending on factors such as soil conditions, climate, crop rotation, and agricultural management practices.

The weed flora associated with pulse crops includes a diverse range of species such as *Ageratum conyzoides*, *Amaranthus viridis*, *Anagallis arvensis*, *Argemone maxicana*, *Asphodelus tenuifolius*, *Avena ludoviciana*, *Carthamus oxycantha*, *Celosia argentea*, *Chenopodium album*, *Cleome viscose*, *Commelina benghalensis*, *Convolvulus arvensis*, *Coronopus didymus*, *Cucumis trigonus*, *Cynodon dactylon*, *Cyperus difformis*, *Cyperus iria*, *Cyperus rotundus*, *Dactyloctenium aegyptium*, *Digera arvensis*, *Digitaria sanguinalis*, *Echinochloa colona*, *Echinochloa crus-galli*, *Eclipta alba*, *Eleusine indica*, *Eragrostis tenella*, *Euphorbia hirta*, *Fimbristylis* spp., *Fumaria parviflora*, *Gnaphalium indicum*, *Lathyrus aphaca*, *Launaea nudicaulis*, *Lolium temulentum*, *Medicago denticulate*, *Melilotus alba*, *Panicum maximum*, *Phalaris minor*, *Phyllanthus niruri*, *Physalis minima*, *Poa annua*, *Polygonum plebejum*, *Polypogon monspeliensis*, *Portulaca quadrifida*, *Rumex dentatus*, *Saccharum spontaneum*, *Setaria glauca*, *Solanum nigrum*, *Sorghum halepense*, *Spergula arvensis*, *Trianthema monogyna*, *Vicia hirsuta*, and *Vicia sativa*. Among these, *Cyperus rotundus* poses a significant threat to summer pulses (IIPR, 2009).

2. 3.1 Weed flora in blackgram

The extent of damage caused by weeds is closely linked to the specific weed species, their densities, and their interaction within the crop environment, with these factors varying across regions and growing seasons. Different weed species possess distinct competitive strengths, growth patterns, and resource demands, which result in varying levels of competition and crop impact. Sahay *et al*. (1999) identified several dominant weed species in the blackgram fields of the North Eastern Hill region of India, including *Echinochloa colona* (L.) Link, *Echinochloa crusgalli* Beav, and *Panicum repens* (L.) among grasses, *Cyperus rotundus* (L.) and *Cyperus difformis* (L.) among sedges, and *Sphaeranthus indicus* (L.), *Eclipta alba* (L.) Hassk, and *Cleome viscosa* (L.) among broad-leaf weeds. Additionally, *Eleusine indica, Cynodon dactylon, Bidens pilosa,* and *Mimosa pudica* were found to be dominant in this region.

Reddy *et al*. (2000) highlighted *Cyperus rotundus, E. colonum, Panicum sp.* and *Trianthema portulacastrum* as the major weeds causing stress to blackgram. Rana *et al*. (2008) also reported that *Trianthema portulacastrum, Digera arvensis, Echinochloa crusgalli, Parthenium hysterophorus, Phyllanthus niruri*, and *Cynodon dactylon* were among the most prevalent weeds in blackgram cultivation.

Rao *et al*. (2010a) observed that blackgram fields were predominantly infested by broad-leaf weeds such as *Grangea maderaspatana, Gnaphalium polycaulon, Nasturtium indicum, Chrozophora rottleri, Cardanthera uliginosa, Xanthium strumarium*, and grasses including *Echinochloa colona, Dinebra retroflexa,* and *Leptochloa chinensis*. According to Tomar (2011), the main grass weeds found in *kharif* blackgram included *Digitaria sanguinalis, Echinochloa colona, Echinochloa crus-galli, and Eleusine indica*, with *Cyperus rotundus* being the most prevalent sedge.

Mundra and Maliwal (2012) identified, key weed species in blackgram, as *Echinochloa* spp.*, Digeria arvensis*, *Eleusine indica* and *Cynodon dactylon* among the narrow-leaved weeds, *Cyperus rotundus* and *Cyperus difformis* among the sedges and *Parthenium hysterophorus, Amaranthus viridis,* and *Trianthema portulacastrum* among the broad-leaf weeds in a study conducted at Udaipur, Rajasthan.

Naidu *et al*. (2012) observed that the dominant weed species in blackgram experimental field at Naira, Andhra Pradesh, included *Vicia sativa, Cardiospermum* *halicacabum var. luridum, Grangea maderaspatana, Chrozophora rottleri, Phyllanthus maderaspatensis,* and *Xanthium strumarium*. Nirala *et al*. (2012) observed that during the *kharif* season, *Celosia argentea, Cynodon dactylon, Phyllanthus niruri,* and *Cyperus rotundus* were the predominant weed species present throughout the growth period of blackgram.

Aggarwal *et al*. (2014b) reported that the major weed flora in the blackgram fields at Ludhiana, Punjab, consisted of *Dactyloctenium aegyptiacum* (crowfoot grass), *Cyperus rotundus* (purple nutsedge), *Cynodon dactylon* (bermuda grass), *Commelina benghalensis* (benghal dayflower), *Eragrostis pilosa* (soft love grass), *Trianthema portulacastrum* (horse purslane), and *Digitaria arvensis* (wild crab grass). Yadav *et al*. (2015) identified *Cyperus rotundus, Echinochloa crusgalli, Commelina benghalensis, Phyllanthus niruri,* and *Digera arvensis* as the key weed species impacting blackgram cultivation in their experimental fields. Chaudhary *et al*. (2014) found *Parthenium hysterophorus, Cyperus rotundus, Digera arvensis,* and *Leptochloa chinensis* as the primary contributors to overall weed density in their study on weed management in blackgram conducted at Kanpur.

Jakhar *et al*. (2015) reported a variety of dicot weed species in blackgram fields, including *Amaranthus viridis, A. spinosus, Trianthema portulacastrum, Euphorbia hirta, Verbesina encelioides, Digera arvensis, Corchorus acutangulus, Phyllanthus niruri,* and *Physalis minima*. Additionally, monocot species such as *Cyperus rotundus, Dactyloctenium aegypticum, Cynodon dactylon, Digitaria sanguinalis*, and *Cenchrus biflorus* were identified as the prominent weed species contributing to the total weed density in blackgram.

Elankavi *et al*. (2019) noted that *Chloris barbata, Cyperus rotundus, Echinochloa colona*, *Digitaria longiflora*, *Commelina benghalensis*, and *Trianthema portulacastrum* were the dominant weed species observed in the blackgram fields.

2. 4 CROP WEED COMPETITION IN PULSES

The population density of weeds significantly affects how fiercely they compete with crops and the extent of yield loss that follows. Due to the slow initial growth of pulses, weeds tend to emerge earlier and gain a competitive edge, often exerting smothering effects on the crop. This smothering effect is intensified by allelopathic chemicals released by weeds. Crops like pigeonpea, chickpea, and lentil, with slower initial growth, are more susceptible. Although maintaining a completely weed-free environment is challenging, managing weeds during the crucial early growth stages is vital for achieving optimal yields. Later emerging weeds have less impact but still contribute to future weed population (Kumar *et al*., 2016).

2. 4.1 Crop weed competition in black gram

Weeds, irrespective of their composition, tend to emerge quickly, grow aggressively, with blackgram for vital resources including nutrients, moisture, sunlight, and space during its establishment and early growth stages, thereby declining its growth and yield. This competition is particularly intense in blackgram due to its slow initial growth and short-statured nature. During the rainy *(kharif*) season, heavy monsoon rainfall promotes vigorous weed growth, causing significant crop losses. As blackgram is a poor competitor against weeds (Choudhary *et al.,* 2012), effective weed management is crucial, especially during the early growth stages, to ensure optimal crop development. Weed emergence often coincides with the crop emergence, resulting in early crop-weed competition, which can cause yield decline up to 78 per cent or even result in complete crop failure (Gogoi *et al*., 1992). Singh (2007) also observed an inverse relationship between the dry matter content of weeds and the grain yield of blackgram.

Due to its limited competitive ability against weeds, blackgram is particularly vulnerable to these adverse effects (Choudhary *et al*., 2012). High temperature combined with frequent rains during the growing season led to heavy weed infestations significantly reducing the crop productivity. Weeds significantly reduced the photosynthetic efficiency, dry matter production, and allocation to the economic parts of blackgram. Uncontrolled weed growth can lower grain yield ranging from 29 to 62 per cent (Aggarwal *et al*., 2014a) and deplete essential soil nutrients (Kaur *et al*., 2010).

Depending on their type, density, and duration of competition, weeds may lead to grain yield losses ranging from 41.6 to 64.1 per cent (Singh, 2011).

Weeds generally have higher nutrient demands than crops, often absorbing more nutrients, and their competition for water, nutrients, and space can result in up to 45 per cent yield loss in blackgram (Yadav *et al.*, 2015). Season-long weed competition can reduce yields by 27 to 84 per cent, depending on weed type and intensity (Bhowmick *et al*., 2015). Plots left unchecked for weeds showed inferior yields stemming from intense competition for light, moisture, and nutrients (Yadav *et al*., 2015).

Seed yield reduction in blackgram due to weeds have been reported to vary between 50 to 87 per cent (Sukumar *et al*., 2018). Furthermore, extending crop-weed competition from 15 DAS to crop maturity resulted in significantly higher weed density and dry weight (Saravanane *et al*., 2020).

2. 4.2 Critical period of crop weed competition in pulses

Pulse crops are highly susceptible to early weed competition, with the impact of weeds becoming more pronounced when they emerge before of the crop does. The concept of the critical period of crop-weed competition plays a pivotal role in integrated weed management (IWM) programs. This period represents a specific phase in the crop growth cycle during which weed control is crucial to prevent significant yield losses. Weeds emerging outside this critical window, either before or after, generally do not cause substantial yield reductions (Kumar *et al*., 2016).

The critical period of crop-weed competition (CPWC) varies across pulse crops and is essential for optimal growth and yield. Kumar and Singh (2010b) reported initial 15–30 days after sowing as the most sensitive period for weed management in short-duration pulses like greengram, blackgram, and cowpea. For longer-duration pulses, such as pigeonpea, chickpea, pea, and lentil, weed control is most crucial during the period between 30 to 60 days after sowing. The critical period of crop-weed competition varied for different pulse crops with pigeon pea (15-60 DAS), green gram (15-30 DAS), blackgram (15-30 DAS), chickpea (30-60 DAS), lentil (30-60 DAS), and pea (30-45 DAS) (Reddy and Reddy, 2016).

2. 4.2.1 Critical period of crop weed competition in blackgram

Determining the critical period of crop-weed competition is crucial for formulating an effective weed management strategy for blackgram. This period represents the phase when the crop is most easily outcompeted by weeds, allowing for the implementation of timely and targeted control measures. Understanding this critical window helps farmers make informed decisions about the optimal timing and methods for weed control, thereby reducing the impact of weeds on crop growth and yield. The critical period of crop-weed competition spans from the early growth stages of the crop, when weeds can grow without significantly affecting yield, to the point where weed growth no longer influence yield outcome (Zimdahl, 1980).

Singh (1993) opined that the first four to five weeks were particularly crucial for blackgram, as weed emergence during this period was high. Rana *et al*. (2008) indicated that the critical period of weed competition for black gram occurred between 30 to 45 DAS, during which the crop should be kept weed-free to prevent significant yield loss. Allowing weeds to persist beyond 30 days resulted in a substantial reduction in yield. Similarly, a weed-free period extending beyond 30 DAS had further positive impact on yield, highlighting that the 30 to 45 DAS period is crucial for managing crop-weed competition (Vivek *et al*., 2008). Khot *et al*., (2016) reported that in blackgram, critical period spans approximately from 15 to 45 days after sowing.

2.5 EFFECT OF WEED MANAGEMENT PRACTICES ON GROWTH AND YIELD ATTRIBUTES OF PULSES

2.5.1 Hand weeding

In blackgram, weeds can be effectively managed through hand weeding. In *kharif* blackgram, two hand weeding at 20 and 40 DAS resulted in grain yields comparable to those of the weed-free treatment. However, weather conditions, particularly the wet field conditions during the rainy season, hindered the timely execution of hand weeding (Chand *et al*., 2004).

Asaduzzaman *et al*. (2010) noted that implementing two rounds of hand weeding and maintaining a plant spacing of 30 cm x 10 cm were particularly effective, in blackgram resulting in greater seed yields. Choudhary *et al*. (2012) reported that weed management in blackgram could be efficiently and cost-effectively achieved through two hand weeding at 15 and 30 days after sowing. Aggarwal *et al*. (2014c) reported the lowest weed dry weight in plots with two hand weeding at 20 and 40 DAS compared to all other weed control treatments at harvest.

Manual weeding, while effective, is labour-intensive and time-consuming, and it does not guarantee the removal of weeds at critical stages of crop-weed competition. Delayed weed removal is less effective in controlling weeds and achieving higher yields compared to timely intervention (Chandrakar *et al*., 2014).

Bhowmick *et al*. (2015) found that mechanical weed control can be implemented by performing one hand weeding at 20 DAS, followed by another at 40 DAS. Mansoori *et al*. (2015a) observed that use of two hand weeding sessions at 25 and 50 DAS resulted in the highest pod count per plant, seeds per pod, 1000-seed weight, seed yield, and weed control efficiency in blackgram.

Harisha *et al*. (2021a) found that drop in weed density and dry weight observed in plots receiving two hand weeding (15 and 30 DAS) was attributed to the complete removal of all weed categories through the physical uprooting of both above-ground and below-ground parts. Reddy *et al*. (2022) reported that the highest weed control efficiency in blackgram was achieved through two hand weeding at 20 and 40 DAS.

2.5.2 Chemical weed control

Herbicides offer several advantages, including ease of application, affordability, and superior weed control efficiency (WCE) compared to alternative methods. This leads to increased crop productivity and profitability, alongside reduced production costs (Baghel *et al*., 2020). The control of weeds in pulse crops has been facilitated by the evaluation and recommendation of multiple herbicides, which can be applied as pre-emergence treatments or incorporated into the soil before planting (Kumar *et al*., 2022). However, excessive herbicide application can be detrimental to plants and ecosystems, contributing to soil, water, and air contamination. While herbicidal weed control is generally cost-effective, selecting the appropriate herbicide and ensuring its efficacy are crucial for achieving optimal results. Given these challenges, herbicides provide an alternative for effective weed control. To enhance weed control efficacy while cutting down on application costs, employing formulated or tank-mixed herbicide combinations has been proposed as a more efficient strategy (Patel *et al*., 2014).

Herbicides recommended for use in blackgram include fenoxaprop-p-ethyl 9.3% EC, alachlor 50% EC, imazethapyr 10% SL with surfactant, propaquizafop 10% EC, quizalofop-ethyl 5%EC, propaquizafop 2.5% + imazethapyr 3.75% w/w ME, fluchloralin 50% EC, and pendimethalin 30% EC (GOI, 2020). The commonly used pre-emergence herbicides in black gram are alachlor, pendimethalin, fluchloralin, and nitrofen. In contrast, commonly used post-emergence herbicides include imazethapyr, quizalofop-ethyl, and clodinafop-propargyl (Sanbagavalli *et al*., 2016).

Several herbicides, including pendimethalin, fluchloralin, metolachlor, and alachlor, have been used to manage weeds in black gram but have demonstrated limited effectiveness in controlling diverse weed populations. Consequently, it is crucial to assess the efficacy of appropriate post-emergence herbicides, either individually or in combination, for effectively managing the dominant and varied weed flora associated with black gram (Kumawat *et al*., 2024).

2.5.2.1 Pendimethalin

Pendimethalin is widely used as pre-emergence herbicide in pulse crops, but its effectiveness in controlling a broad spectrum of weeds over long periods is limited. For comprehensive weed management throughout the season, a combination of pendimethalin and manual weeding at 30-35 DAS is generally recommended for crops like chickpea. However, this practice has been declining due to labour shortages at critical time of weeding and rising costs (Kumar *et al*., 2013a).

Pendimethalin (N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitroaniline) is an organic herbicide of the dinitroaniline group used for controlling grass weeds in various crops such as maize, sorghum, cowpea, soybean, and vegetables. It inhibits the synthesis of microtubulin, which is critical for the formation of microtubules necessary for cell wall development and chromosome movement during mitosis. The herbicide is primarily absorbed by young shoot organs, such as the hypocotyl or coleoptile, rather than roots. It effectively controls grass and broadleaf weeds selectively. Pendimethalin

30 EC applied at 750 g ha^{-1} as a pre-emergence treatment (2 DAS) has demonstrated selectivity in black gram without causing phytotoxicity (Dash *et al*., 2024).

Adhikary (2018) noted that pre-emergence spray of pendimethalin (1.0 kg ha^{-1}), subsequent post-emergence application of quizalofop-ethyl (50 g ha^{-1}) at 25 days after seeding reduced weed density, achieved a high weed control efficiency of 92.10%, and produced an average seed yield of 0.82 t ha^{-1}, a 48.35% increase over the weedy check in rainfed blackgram.

2.5.2.2 Imazethapyr

Imazethapyr is a selective systemic herbicide belonging to the imidazolinone group and is a broad-spectrum compound with both soil and foliar activity. It offers flexibility in application timing and exhibits low toxicity to mammals (Tan *et al*., 2005). This selective systemic herbicide effectively controls various annual and perennial grasses, as well as broad-leaf weeds (Sondhia and Varshney, 2010). It is a highly persistent, broad-spectrum herbicide with both soil and foliar activity, suitable for application as pre-plant incorporation, pre-emergence, or post-emergence. It is characterized by low toxicity to mammals (Sasikala *et al*., 2019).

In rainfed black gram, Nandan *et al*. (2011) found that post-emergence application of imazethapyr at 25 g ha^{-1} had no negative impact on growth parameters and produced grain yields comparable to two hand weeding sessions conducted at 20 and 40 days after sowing. Post emergence application (PoE) of imazethapyr, a broad-spectrum herbicide, is recommended for rainy-season pulses such as pigeonpea, blackgram, and greengram. However, in winter-season pulses like chickpea, lentil, and field pea, even at a lower dose of 15 g ha^{-1}, imazethapyr has shown toxicity (Kumar *et al*., 2013b).

In black gram, post-emergence application of imazethapyr has shown promising outcome (Aggarwal *et al*., 2014b). Late-emerging weeds were successfully managed with post-emergence spray of imazethapyr at 75 g ha^{-1}. However, its prolonged half-life can lead to carryover effects, negatively impacting subsequent cereal crops (Sondhia *et al*., 2015). Therefore, there is a need to explore alternative herbicides with distinct modes of action and improved leaching behaviour to achieve effective and broad-spectrum weed control.

Veeraputhiran and Chinnusamy (2008) found that post-emergence application of imazethapyr at 0.09 kg ha^{-1} outperformed applications at 0.06 and 0.075 kg ha^{-1}, with applications at 21 and 28 DAS showing similar efficacy, followed by 14 DAS. Nirala *et al*. (2012) reported that imazethapyr at 25 g ha^{-1} recorded the lowest weed density, dry matter production, weed intensity, weed growth rate, relative weed density, and highest weed control efficiency in blackgram.

Imazethapyr when used as post-emergence systemic herbicide is absorbed by both the roots and foliage, with translocation occurring through the xylem and phloem, and it accumulates in the meristematic regions (Lal *et al*., 2017). Currently, imazethapyr is recognized as an effective post-emergence herbicide for controlling grass and broad-leaf weeds in blackgram (Suryavanshi *et al*., 2018).

Singh *et al*. (2015a) reported that he application of imazethapyr at 25, 40, and 75 g ha^{-1} negatively affected various symbiotic parameters, including nodule number, nodule dry weight, and leghaemoglobin content, when compared to two hand weeding in greengram. Imazethapyr at 75 g ha^{-1} applied as PoE effectively controlled late-emerging weeds. However, its use is restricted by the selection of succeeding crops (Singh *et al*., 2018).

The post-emergence spray of imazethapyr at 60, 75, 100, and 150 g ha^{-1} resulted in a markedly higher seed yield in blackgram compared to the pre-emergence spray of pendimethalin (1 kg ha^{-1}), alachlor (1 kg ha^{-1}), and the post-emergence grass weed killer quizalofop-ethyl (75 g ha^{-1}) (Prajapati *et al*., 2018). Imazethapyr as post-emergence herbicide has demonstrated high efficiency for broad-spectrum weed control in *kharif* pulses, including black gram (Singh *et al*., 2022).

2.5.2.3 Propaquizafop

Propaquizafop is a selective post-emergence herbicide recommended for managing weeds in crops such as sugar beet, rapeseed, soybean, sunflower, various vegetables, fruit trees, vineyards, and forest trees. When applied at 100 g ha^{-1} as post-emergence treatment, propaquizafop remarkably weakened both the density and dry weight of grass weeds due to its selective action. It inhibited cell division and growth by disrupting the function of the enzyme acetyl-CoA carboxylase (ACCase) Pratap *et al*. (2018).

Propaquizafop, sprayed at 50 g ha^{-1} effectively suppressed grass weeds in soybean (Tiwari and Mathew, 2002). In a study conducted at Jabalpur to study the effect of propaquizafop and imazethapyr on weeds associated with blackgram, it was found that mixture of propaquizafop and imazethapyr at doses of 53+80 g ha^{-1} and 56+85 g ha^{-1} were proved to be highly effective in controlling weeds.

2.5.2.4 Herbicide combinations/ premix herbicides

The limited application flexibility and the emergence of herbicide-resistant weeds reduce the efficacy of various pre-emergence and post-emergence herbicides significantly impacting crop productivity. Utilizing a combination of herbicides could provide a viable solution to address these challenges.

Selective herbicides with a narrow spectrum are effective only against specific types of weeds, such as grasses or broad-leaf species, making them unsuitable for managing diverse weed populations (Nath *et al*., 2018). To address this limitation, herbicide mixtures, whether tank-mixed or pre-mixed, are recommended for achieving broad-spectrum weed control. Additionally, such combinations can minimize or delay the development of herbicide resistance by reducing the selective pressure exerted by individual herbicides (Farooq *et al*., 2013).

Herbicide mixtures with different modes of action contribute to the gradual development of resistant biotypes within weed species. Such combinations typically lower the frequency of resistance compared to the use of a single herbicide (Susha *et al*., 2018).

2.5.2.5 Pendimethalin + imazethapyr

Chandrakar *et al*. (2014) noted that early post-emergence spray of imazethapyr at 40 g ha^{-1} (15–20 DAS) and pre-emergence application of pendimethalin + imazethapyr (ready mix) at 1.0 kg ha^{-1} were effective in controlling weeds in black gram. Rao *et al*. (2010a) also reported that combined application of pendimethalin +

imazethapyr as pre-mix provided superior weed control. Among different treatments, standalone application of pendimethalin and the combination of imazethapyr + pendimethalin were particularly effective in reducing weed dry matter accumulation and achieving maximum seed yield in blackgram.

Yadav *et al.* (2015) observed that premix herbicide combinations, imazethapyr + imazamox (post-emergence) and pendimethalin + imazethapyr (pre-emergence), were more effectual in controlling all weed species in black gram compared to the individual application of pendimethalin as a pre-emergence herbicide or imazethapyr as a post-emergence treatment. Singh *et al*. (2016) reported that the pre-mix application of imazethapyr + pendimethalin at 1000 g ha^{-1} achieved the highest WCE compared to the standalone application of herbicides, whether applied as pre- or post-emergence. This pre-mix combination also resulted in a significant increase in black gram seed yield, with a reported 63.3 per cent improvement over the weedy check.

Shashidhar *et al*. (2020b), highlighted that pre-emergent pendimethalin 30 EC + imazethapyr 2 EC at doses of 0.75 kg and 1.0 kg ha^{-1}, were highly effective in reducing weed density and dry weight in blackgram compared to post-emergent treatments. These pre-emergent applications showed comparable efficacy to hand weeding at 20 and 40 DAS and demonstrated WCE of upto 83 per cent. The weed-free check recorded the highest WCE, over 90 per cent, due to continuous early weed removal, while weedy plots showed the highest nutrient competition and lowest yields.

Dhayal *et al*. (2022) reported that the lowest weed density and weed index, along with the highest crop growth parameters, were recorded with two manual weeding sessions at 20 and 40 DAS along with PE pendimethalin at 1.0 kg ha^{-1}, followed by PoE mixture of propaquizafop (2.5% w/w, 33.3 g ha^{-1}) and imazethapyr (3.75% w/w, 50 g ha^{-1}) at 20 DAS in blackgram.

According to Singh *et al*. (2018), among various herbicide treatments, pendimethalin + imazethapyr at 0.75 and 1.00 kg ha^{-1} resulted in significantly higher benefit-cost ratio compared to other herbicides. The increased gross and net returns, along with a higher BC ratio, were attributed to improved grain yields and reduced cultivation costs. Shashidhar *et al*. (2020a) reported that the pre-emergence spray of pendimethalin + imazethapyr (ready mix) at 1.0 kg ha^{-1} was efficient in black gram, resulting in a grain yield of 602 kg ha^{-1} and a stover yield of 1741 kg ha^{-1}. Reddy *et al*. (2023) reported that pendimethalin + imazethapyr at 1000 g ha^{-1} (pre-mix) has been found highly effective for managing mixed weed flora in black gram.

2.5.2.6 Propaquizafop + imazethapyr

In recent years, pre-mix post-emergence herbicides, such as propaquizafop + imazethapyr, have been introduced for weed control in pulses. The post-emergence application of propaquizafop + imazethapyr at rates of 53 + 74 g ha^{-1} and 56 + 78 g ha^{-1}, applied 30 DAS, effectively reduced the density and dry weight of grasses, sedges, and broad-leaf weeds. Root nodules per plant were appreciably higher in treated plots compared to the control plot. This treatment resulted in improved weed indices, as well as better yield attributes, seed yield, and haulm yields, which were comparable to the results achieved by two hand weeding at 20 and 40 DAS in soybean (Lal *et al*., 2017).

The post-emergence spray of propaquizafop (75 g ha^{-1}) alone controlled only grass weeds. However, its efficacy was enhanced when combined with imazethapyr, with the highest effectiveness observed when the propaquizafop + imazethapyr mixture was applied at rates of 53 + 80 g ha^{-1} or higher (56 + 85 g ha^{-1}). Yield-attributing traits and overall yield were superior under the propaquizafop + imazethapyr mixture applied at 56 + 85 g ha^{-1} (Panda 2015).

Kewat *et al*. (2015) found that a post-emergence spray combining propaquizafop and imazethapyr at 53 + 80 g ha^{-1} was identified as cost-effective for curbing weeds in black gram. The combined tank-mix application of propaquizafop + imazethapyr resulted in higher seed yield compared to other chemical treatments. Applying propaquizafop (50 g) + imazethapyr (100 g ha^{-1}) at 20 DAS was found to be as effective as hand weeding in influencing seed yield in soybean (Kumar *et al*., 2018).

The post-emergence application of propaquizafop at 75 g ha^{-1} was effective only against grassy weeds. However, its effectiveness found improved when used in combination with imazethapyr, with the highest efficacy observed at the mixture of propaquizafop + imazethapyr applied at 53 + 80 g ha^{-1} or higher rates (56 + 85 g ha^{-1}). It was concluded that the post-emergence spray of propaquizafop + imazethapyr mixture at 53 + 80 g ha^{-1} was the most cost-effective for controlling weeds in soybean. Yield attributes and yields were superior under the mixture applied at 56 + 85 g ha^{-1}, followed by 53 + 80 g ha^{-1}, both of which were comparable to hand weeding twice at 20 and 40 DAS (Panda 2015).

The combined application of herbicides proved to be more effectual than the use of an individual herbicide in achieving broad-spectrum weed control in black gram (Harisha *et al*., 2021b). The combination of propaquizafop + imazethapyr at 127 g ha^{-1} was effective in reducing total weed density and dry weight at 45 DAS and at harvest, compared to other post-emergence herbicides. This effectiveness was attributed to its dual mode of action in controlling weeds in blackgram (Reddy *et al*., 2021).

2.6. INTEGRATED WEED MANAGEMENT IN PULSES

Each method of weed control, whether manual, mechanical, cultural, biological, or chemical, possesses its own set of limitations. Relying on a single method is unlikely to achieve the desired level of weed control effectiveness (Yaduraju *et al*., 2015). Herbicides rarely provide 100 per cent weed control because many have a narrow spectrum of action, limiting their effectiveness across diverse weed species (Bajwa *et al*., 2015).

2.6.1 IWM in blackgram

Choudhary *et al*. (2012) reported that in black gram, pre-emergence application of pendimethalin at 1.5 kg ha^{-1}, followed by one hand weeding (HW) at 25 DAS, was comparable to two HW at 15 and 25 DAS in terms of seed yield, net returns, and the benefit-cost ratio. The integrated use of pendimethalin at 0.45 kg ha^{-1} along with hand weeding resulted in higher grain yield compared to the sole application of pendimethalin, even at higher doses, as the weeds not controlled by the herbicide were effectively managed through hand weeding (Singh *et al*., 2018).

A severe weed infestation in the unweeded check significantly diminished seed yield by 58.4 per cent compared to the pre-emergence application of pendimethalin + imazethapyr at 1000 g ha^{-1}, supported by hand weeding (Reddy *et al*., 2021).

The combination of pendimethalin + imazethapyr at 1000 g ha^{-1} (pre-mix) applied as pre-emergence, subsequent hand weeding (HW) at 30 DAS resulted in greater seed yield and benefit-cost ratio, alongside broad-spectrum weed control during the rainy season in black gram, and was comparable to two HW sessions at 15 and 30 DAS in terms of seed yield (Reddy *et al*., 2023).

Singh (2011) reported that during the summer season, pendimethalin applied at 0.75 kg ha^{-1}, pendimethalin at 0.45 kg ha^{-1} followed by HW at 25 DAS, two HW at 25 and 40 DAS, and a weedy check resulted in weed dry matter of 4.87, 3.45, 3.40, and 23.6 q ha^{-1}, respectively. The corresponding grain yields were 11.47, 11.75, 11.95, and 7.02 q ha^{-1}. Similarly, in the *kharif* season, these treatments produced weed dry matter of 4.16, 4.26, 2.90, and 20.9 q ha^{-1}, while the grain yields were recorded as 10.43, 10.76, 11.76, and 6.86 q ha^{-1}, respectively.

Choudhary *et al*. (2012) reported that pre-emergence pendimethalin spray at 1.5 L ha^{-1}, combined with one hand weeding at 25 DAS, was comparable to two HW at 15 and 25 DAS in terms of seed yield, net returns, and benefit-cost ratio. The higher grain yield under integrated weed control treatments (herbicide + hand weeding) is attributed mainly to the better control of weeds at various growth stages, along with the manual removal of emerging weeds through hand weeding. The reduced crop-weed competition, resulted in better yield attributes (Chhodavadia *et al*., 2013).

Kumari *et al*. (2023) demonstrated that the most effective method for managing weeds in summer irrigated blackgram was applying pendimethalin 30 per cent EC at 1 kg ha^{-1} as pre-emergence, followed by the use of a power-operated weeder at 20 DAS. This, combined with a crop spacing of 40 × 7.5 cm, resulted in the highest grain yield (881 kg ha^{-1}) and improved weed control efficiency. The strategy reduced weed competition during the critical growth stages of the crop, thereby enhancing its overall performance.

2.7 Effect of weed management practices on nodule characters

Herbicide which reduced the number of nodules formed per plant does so by restricting root growth, thereby limiting the number of root sites available for *Rhizobium* infection (Khan *et al.,* 2006). Herbicides that inhibit amino acid biosynthesis can have varying effects on *Rhizobium* species (Drew *et al.,* 2007). Punia *et al.* (2011) also reported that Chlorimuron ethyl application caused 20-30 per cent injury to legumes (clusterbean), including a reduction in nodule formation.

Ahemad and Khan (2010) reported that herbicides negatively impacted the symbiotic activity in lentils. The bacterium *Rhizobium leguminosarum*, responsible for nodulation in lentils, and its symbiotic association with the plant were affected by herbicides, leading to decreased nitrogenase activity and reduced biological N fixation by the crop.

Choudhary *et al.* (2012) reported that pre-emergence application of pendimethalin at 1.5 L ha^{-1}, fluchloralin at 1.5 L ha^{-1}, or a combination of these herbicides with hand weeding at 25 DAS resulted in a higher number of nodules and increased nodule dry weight in black gram, similar to hand weeding twice.

Goud *et al.* (2013) found that the application of imazethapyr and quizalofop-ethyl at 100 g ha^{-1} at 25 DAS caused the greatest decline in the number of nodules per plant, with reductions of 75.49 per cent and 67.65 per cent, respectively, compared to HW at 25 and 35 DAS in Akola.

Aggarwal *et al*. (2014a) reported a greater number of nodules and increased nodule dry weight with the integrated application of imazethapyr at 75 g ha^{-1} at 15 DAS, followed by two HW at 20 and 40 DAS, compared to the application of imazethapyr at 50 and 100 g ha^{-1} at 15 DAS, as well as at 20 DAS.

In green gram, two HW at 20 and 40 DAS achieved the highest number and dry weight of nodules per plant compared to various PE and PoE herbicides, as well as certain ready-mix formulations (Singh *et al*., 2019). Among various treatments, a greater number of nodules was observed in the plots where herbicides were not sprayed (HW) in comparison with those treated with pre- and post-emergence herbicides (Sah, 2022).

2.7.1 Effect of weed management practices on nutrient uptake of blackgram

The highest nutrient uptake by black gram was observed with hand weeding at 25-30 DAS and intercultivation at 45 DAS, which resulted in 126.25 kg ha^{-1} N, 28.20 kg ha^{-1} P, and 109.30 kg ha^{-1} K. After harvest, soil nutrient availability was also higher under these treatments, with values of 141.38 kg ha^{-1} N, 42.10 kg ha^{-1} P, and 298.53 kg ha^{-1} K. In contrast, the weedy check showed significantly lower nutrient levels, with 122.93 kg ha^{-1} N, 30.17 kg ha^{-1} P, and 220.10 kg ha^{-1} K (Anusha *et al*., 2024).

The weed-free treatment (T_2) resulted in significantly higher uptake of N (51.30 kg ha^{-1}), P (7.50 kg ha^{-1}), and K (23.68 kg ha^{-1}) by the crop, and it was comparable to the treatment where pendimethalin at 1.0 kg ha^{-1} was applied pre-emergence, subsequently HW at 30 DAS which recorded 49.72 kg ha^{-1} N, 7.25 kg ha^{-1} P, and 22.91 kg ha^{-1} K (Kavan *et al*., 2016).

2.7.2 Effect of weed management practices on nutrient removal by weeds in blackgram

Malhi *et al*. (2020) found that two HW at 25 and 45 DAS recorded the lowest N, P, and K uptake by weeds, a result that was comparable to the pre-emergence pre-mix combination of imazethapyr + imazamox at 80 g ha^{-1}.

The implementation of different weed management strategies did not have a substantial impact on the nitrogen, phosphorus, and potassium content in the grains and straw of blackgram crops. However, the highest N, P, and K content in both grains and straw were observed under the weed-free plot, while the lowest content was found in the weedy check. This treatment significantly impacted the nutrient uptake by both grains, straw, and the total uptake by blackgram (Sanspal *et al*., 2024). The unweeded check resulted in the highest uptake of N, P, and K due to uncontrolled weed growth throughout the season, which aligns with the findings of Singh *et al*. (2020), Khot *et al*. (2012) and Choudhry *et al*. (2012).

In weed-free plots, nutrient removal was negligible, while the highest nutrient depletion occurred in weedy check plots. Pendimethalin spray at 1.5 kg ha^{-1}, subsequently HW at 25 DAS, effectively reduced nutrient removal by weeds (Choudhary *et al*., 2012).

2.7.4 Effect of weed management practices on economics of cultivation

The application of imazethapyr + quizalofop ethyl, each at 75 g ha^{-1}, resulted in significantly taller plants, increased dry matter production, higher number of pods per plant, more seeds per pod, and a greater grain yield (826 kg ha^{-1}). It also led to higher net returns (Rs. 26,621 ha^{-1}) and a benefit-cost ratio of 2.76. Therefore, the use of these post-emergence herbicides, applied as a tank mix at 75 g ha^{-1} on 15 DAS, is recommended for effectively curbing emerged weeds in irrigated blackgram (Ramesh and Rathika, 2015).

Hand weeding twice at 20 and 40 DAS required more labour and incurred a higher cost (Rs 10,500 ha^{-1}), which led to a decrease in the marginal benefit cost ratio compared to herbicidal treatments. Similar findings were reported by Kewat *et al*. (2000) and Tiwari *et al.* (2007).

2.8 IMPACT OF HERBICIDES ON SOIL HEALTH

Herbicides, in contrast to insecticides and fungicides, require precise dosing and timing to effectively target specific crops. Improper usage can lead to significant crop damage or failure, as well as reduced herbicide efficacy. Applying herbicides at doses higher than recommended not only harms the crop but also negatively impacts the ecosystem, resulting in increased weed control costs (Ofosu *et al*., 2023).

2.8.1 Impact of herbicides on dehydrogenase enzyme activity

Dehydrogenase is an intracellular enzyme involved in microbial respiratory processes, primarily found in the surface layers of soil. As key enzymes in the respiratory chain, dehydrogenases play a vital role in energy production by oxidizing organic compounds and transferring two hydrogen atoms. These enzymes are essential components of microbial enzyme systems. Dehydrogenase activity serves as an indicator of biological redox systems and microbial activity in the soil, which significantly impacts nutrient availability for plants. Due to its presence in all living microbial cells, dehydrogenase enzyme activity is often used to assess soil biological (microbial) activity (Quilchano and Maranon, 2002).

Moreno *et al. (*2007) pointed out that dehydrogenase activity remained stable when treated with herbicides, possibly due to the stress process of soil microorganisms, which helped to maintain constant values.

Herbicide application can lead to a reduction in dehydrogenase enzyme activity in the soil. This is likely due to the toxic effects of the herbicides on soil microorganisms (Sathya *et al.,* 2018).

In some cases, weed-free conditions achieved through effective herbicide application can actually increase dehydrogenase activity compared to weedy control plots. This is because the lack of weed competition allows for better growth and activity of soil microbes (Jinger *et al.,* 2016). The specific impact on dehydrogenase activity depends on the type of herbicide used, its application rate, and the overall weed management strategy (Meher *et al.*, 2021).

Herbicidal weed management in blackgram may have dual effects, including both beneficial and detrimental impacts on soil dehydrogenase enzyme activity, depending on the specific practices employed. Careful selection and application of herbicides, along with complementary soil management techniques, can help maintain soil health and enzyme activity.

2.8.2 Impact of herbicides on microbial population

There is growing concern that herbicides impact not only the targeted weeds but also the microbial communities residing in the soil. These non-target effects can potentially impair essential soil functionalities, such as decomposition of organic matter, N cycling, and methane oxidation (Hutsch, 2001).

There are highly contrasting reports concerning the impact of herbicides on soil microflora. In field conditions, herbicides can significantly influence soil biota populations indirectly through their effects on vegetation, which serves as habitat and food for many organisms. Soil organisms often respond more to changes in vegetation caused by herbicide application than to the direct effects of the herbicides themselves (Grossbard and Davies, 1976; Haugland, 1994).

Herbicides can impact soil microbes directly by altering biosynthetic pathways, such as protein production, enzyme synthesis, and cellular membrane integrity. They may disrupt microbial functions like transport processes and affect plant growth regulators, including indole acetic acid and gibberellins. At high doses, herbicides can be toxic, potentially killing microorganisms, highlighting the importance of careful application to preserve soil microbial health (Cook and Hutter, 1981).

Microorganisms have the capacity to degrade certain herbicides, using them as a source of essential biogenic elements. However, some herbicides can adversely impact microbial communities. The total microbial count serves as a direct indicator of qualitative changes in soil microbial populations following herbicide application (Barman, 2008).

Microorganisms are often adversely affected by herbicides due to their toxic properties, leading to reduced abundance, activity, and community diversity prior to their degradation. However, soil microflora possess the ability to degrade herbicide residues, such as pendimethalin (Kocarek *et al.*, 2016) and imazethapyr (Singh *et al*., 2017), utilizing these compounds in their physiological processes (Singh and Singh, 2016). During degradation, organic herbicide residues release carbon, which contributes to an increase in populations of soil microflora (Bera and Ghosh, 2013).

Pendimethalin application led to a steady increase in the total population of soil microflora such as bacteria, fungi, and actinomycetes under cotton, following a brief lag phase during the crop growth period. However, after harvest, the presence of pendimethalin residue in the soil adversely impacted soil microorganisms (Balasubramanian and Sankaran, 2001).

Microbial activity, including populations of bacteria, fungi, azotobacter, and phosphate-solubilizing fungi, was observed to be highest in soils where no herbicides were applied. In rhizosphere soil, herbicides negatively affected the azotobacter population, while total bacterial counts remained unaffected. However, fungal populations were more sensitive to herbicide application compared to bacteria (Dhagat and Verma, 2009).

Research indicates that herbicides generally do not exert harmful effects on soil bacterial populations, allowing these microorganisms to maintain their abundance and activity despite herbicide application (Ahmad *et al.*, 2017).

Das *et al.* (2014) found that the application of herbicides such as pendimethalin (1.5 L ha^{-1}) and fluchloralin (1.5 L ha^{-1}), either alone or integrated with hand weeding

(Pendimethalin @ 1.5 L ha^{-1} + hand weeding at 25 DAS, and Fluchloralin @ 1.5 L ha^{-1} + hand weeding at 25 DAS) in blackgram, resulted in an increase in the population of total bacteria, actinomycetes, and fungi. The population increased by 24.57 per cent to 68.64 per cent, 21.32 per cent to 63.98 per cent, and 19.47 per cent to 57.10 per cent, respectively, compared to the weedy check at Mohanpur.

Raghavendra *et al.* (2017) observed that the population of general microflora increased with the age of the host up to 60 DAS, but declined at harvest, showing a decrease compared to the 60 DAS population. Among the treatments, both the weed-free and weedy check (control) plots recorded the highest microbial populations, in comparison to plots treated with various pre and post-emergence herbicides. The study highlighted that herbicides significantly affect the growth and multiplication of soil microorganisms.

Arora and Dubey (2014) found that the total population of bacteria, actinomycetes, and fungi in the soil decreased significantly within 15 days after the application of both herbicides compared to the control. Pendimethalin at 2.0 kg ha^{-1} and chlorimuron-p-ethyl at 18 g ha^{-1} had a more suppressive effect on microbial counts than their lower doses. However, the microbial population recovered to control levels within 30 days of application and remained at these levels at harvest.

The application of pendimethalin and alachlor, either alone or in combination with imazethapyr, showed no harmful effects on soil microorganisms or their activities. However, when fenoxaprop-p-ethyl was applied in combination with either pendimethalin or alachlor, it significantly reduced the fungal population in the root zone soil, including spore numbers, and also affected the colonization of mycorrhizal fungi in black gram roots (Sathya *et al.*, 2018).

If microorganisms are sensitive to a specific herbicide, its application can disrupt their vital metabolic processes (Oliveira and Pampulha, 2006), which in turn may impact the availability of essential nutrients in the soil (Nautiyal, 2006).

Pendimethalin, both alone and in combination with imazethapyr, as well as imazethapyr alone, were found to be safe for the populations of fungi and actinomycetes in soil. Microorganisms with low tolerance to herbicides may perform poorly under field conditions, ultimately diminishing their role in sustainable agriculture. Therefore, herbicides used for weed control should be selected carefully, ensuring that they do not harm beneficial microorganisms. In this study, pendimethalin alone and in mixture with imazethapyr were found to be safe for *Rhizobium* (*Rhizobium leguminosarum* M-1 and *Rhizobium leguminosarum* LSMR-1) as well as plant growth-promoting rhizobacteria (*Stenotrophomonas maltophilia* RB-3), making them suitable for use in legume cultivation without compromising soil health (Singh and Singh, 2020).

2.8.3 *in vitro* sensitivity of beneficial organisms to herbicides

Araújo *et al*., (2003) assessed the impact of glyphosate on microbial activity in Brazilian soils, and found that glyphosate application (2.16 mg kg^{-1} soil) enhanced microbial activity, showing a 10–15 per cent increase in CO_2 evolution and a 9 to19 per cent rise in FDA hydrolysis, with stronger responses in soils previously exposed to glyphosate. Actinomycetes and fungi populations increased after 32 days, while bacterial population slightly declined. High-pressure liquid chromatography (HPLC) detected the metabolite aminomethyl phosphonic acid (AMPA), indicating glyphosate degradation by soil microorganisms.

Adomako *et al*. (2013) conducted a study in Ghana and evaluated the effects of four commonly used herbicides atrazine, 2,4-D amine, glyphosate , and paraquat on soil microorganisms over a 15 days period. The herbicides were applied at the recommended field rate, half, and double the recommended rate. Bacterial and fungal population were measured at five-day intervals. While bacterial populations and organic matter percentage showed no significant difference ($p < 0.05$), paraquat significantly reduced bacterial populations at all time points (5, 10, and 15 days after treatment) at the half-rate. Glyphosate, 2,4-D amine, and atrazine also affected bacterial populations, with reductions of 12.7 per cent to 69.3 per cent.

2.8.3.1 *in vitro* sensitivity of *Rhizobium* to herbicide application

in vitro sensitivity of *Rhizobium* to herbicide application is a crucial factor in determining the impact of herbicides on legume cultivation. However, *in vitro* testing may not always reflect the actual toxicity under field conditions, as factors like the method of application and the herbicide degradation process can alter its effect on

Rhizobium. Consequently, both *in vitro* and field-based evaluations are essential for assessing the compatibility of herbicides with *Rhizobium* strains, ensuring effective weed control while maintaining the health of the legume- *Rhizobium* symbiosis.

Rhizobium leguminosarum M-1, *Rhizobium leguminosarum* LSMR-1, and plant growth-promoting rhizobacteria (PGPR), such as *Stenotrophomonas maltophilia* RB-3, demonstrated significant tolerance to pendimethalin alone, as well as its combination with imazethapyr. This tolerance is attributed to the ability of rhizobia and PGPR to employ mechanisms like biodegradation (Yang and Lee, 2008) and enzymatic hydrolysis (Herman *et al*., 2005) to mitigate the harmful effects of herbicides.

Jeenie *et al*., (2011) investigated the impact of the recommended pre-emergence herbicide pendimethalin, applied at two concentrations (9×10^4 ppm and 15×10^4 ppm), on the growth and survival of *Rhizobium* and phosphate-solubilizing bacteria (PSB) under laboratory conditions. The study further evaluated the field application of pendimethalin in combination with biofertilizers (*Rhizobium* and PSB) to enhance mungbean grain yield. Results indicated that the lower dose of pendimethalin (9×10^4 ppm) had no detrimental impact on the growth of *Rhizobium* and PSB, whereas the higher dose (15×10^4 ppm) was found to be safe for PSB but exerted a suppressive effect on Rhizobium.

The adoption of herbicide-tolerant Rhizobium strains, along with careful assessment of the compatibility between agrochemicals and *Rhizobium*, can help preserve the effectiveness of the legume-*Rhizobium* symbiosis. This approach ensures optimal plant growth even under herbicide stress, promoting both weed control and sustainable legume production.

Herbicide-based weed management has emerged as a viable strategy to enhance crop productivity by effectively controlling weed infestation. This review highlights that pre-emergence and post-emergence herbicides, particularly premix formulations, offer efficient and season-long weed suppression with minimal crop phytotoxicity. However, the sustainability of herbicide use depends on factors such as proper selection, dosage optimization, and integration with cultural and mechanical methods to mitigate resistance development and environmental risks. A well-balanced weed management approach combining premix herbicides with cultural methods can ensure optimum weed management in blackgram cultivation.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present study entitled 'Integrated weed management in blackgram [*Vigna mungo* (L.) Hepper] with pre-mix herbicides' was carried out at the College of Agriculture, Vellayani during summer 2024. The main objective of the research programme was to formulate an integrated weed management strategy using pre-mix herbicides for black gram intercropped in coconut garden. This chapter briefs the materials used and methods adopted during the course of investigation.

3.1 GENERAL DETAILS

3.1.1 Location

A field experiment was conducted at the block E of Instructional Farm, attached to College of Agriculture, Vellayani, Thiruvananthapuram. The experimental field was geographically located at 8° 25' 42"N latitude and 76° 59′ 16"E longitude, at an altitude of 29 m above mean sea level (MSL).

3.1.2 Climate and Season

The experiment was carried out during the summer season of 2024 between February to April 2024. Weather data on maximum and minimum temperatures, relative humidity, and rainfall were collected from the Class B Agromet Observatory of the Department of Agricultural Meteorology, College of Agriculture, Vellayani. The data were tabulated based on the standard meteorological weeks and are presented in Appendix I and graphically in Fig.1.

In general, sunny, warm conditions prevailed during the cropping period. The mean maximum and minimum temperature ranged between 32.5°C to 34.4 °C and 19.61°C to 25.67 °C respectively and mean RH I and RH II ranged between 86.85 per cent to 94.71 per cent and 64.28 per cent to 76.28 per cent, respectively with a mean evaporation of 4.19 mm per day. Mean bright sunshine hours varied from 3.48 h to 9.47 h. A total rainfall of 160.41 mm was received during the experimental period.

3.1.3 Soil

A composite soil sample was taken from a depth of 0-15 cm and analyzed for its chemical properties. The data obtained are presented in Table 1. The texture of soil in the experimental site was red sandy loam, acidic in reaction, medium in organic carbon, low in available nitrogen, high in available phosphorus and low in available potassium status.

Table 1. Chemical properties of the soil before the experiment

Sl.no.	Parameters	Content	Rating	Method
1	Soil reaction (pH)	5.6	Moderately acidic	pH meter (1:2:5 soil water ratio) (Jackson, 1973)
2	EC (dS m^{-1})	0.14	Normal	Conductivity meter (1:2:5 soil water ratio) (Jackson, 1973)
3	Organic carbon (%)	0.57	Medium	Walkley and Black rapid titration method (Walkley and Black,1934)
4	Available N (kg ha^{-1})	258	Low	Alkaline permanganate method (Subbiah and Asija, 1956)
5	Available P (kg ha^{-1})	38	High	Bray colorimetric method (Jackson, 1973)
6	Available K (kg ha^{-1})	92	Low	Ammonium acetate method (Jackson, 1973)

3.1.4 Cropping History of the Experimental Site

The experiment was conducted in a coconut garden that was previously intercropped with fodder cowpea. The palms belonged to the variety West Coast Tall (WCT) and were planted at a spacing of 7.5 m x 7.5 m. The palms were above 40 years old, permitting 60 per cent of the solar radiation to filter through the canopy.

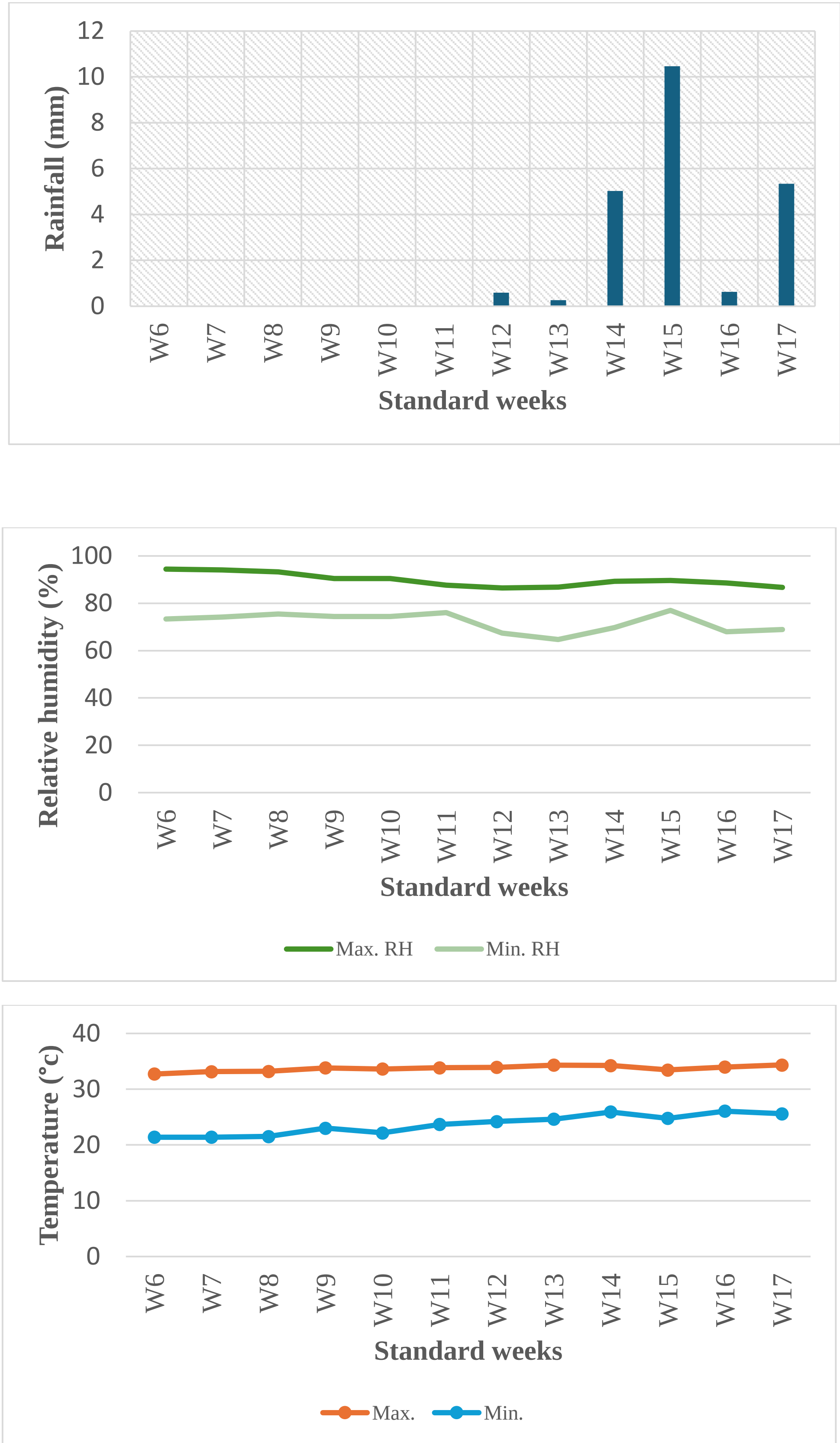


Fig.1 .Weather data during the cropping season (10/02/2024 to 29/04/2024)

3.2 MATERIALS

3.2.1 Crop and Variety

Blackgram [*Vigna mungo* (L.) Hepper] is a much preferred short duration crop as it survives better in all seasons either as sole crop, intercrop, or catch crop. The variety used for the study was DBGV-5 released from University of Agricultural Sciences (UAS), Dharwad, Karnataka. It matures in 80-85 days with a yield potential of 1.4 to 1.5 t ha^{-1}. It can tolerate partial shade and perform well in coconut gardens. The variety is moderately susceptible to *Cercospora* leaf spot and moderately resistant to powdery mildews and yellow mosaic virus (ICAR- Indian Institute of Pulses Research, 2018).

3.2.2 Source of Seed

The seeds for the experiment were procured from the University of Agricultural Sciences, Dharwad, Karnataka.

3.2.3 Rhizobium Culture

Bradyrhizobium culture containing strain BMBS 47 suitable for inoculation of blackgram was procured from the Department of Agricultural Microbiology, Tamil Nadu Agricultural University (TNAU), Coimbatore.

3.2.3 Manures and Fertilizers

Farmyard manure (FYM) with a nutrient content of 0.45, 0.17 and 0.50 per cent N, P_2O_5 and K_2O was used as the organic manure for the experiment. Urea (46% N), rajphos (20% P_2O_5) and muriate of potash (60% K_2O) respectively were used as the inorganic sources of nitrogen (N), phosphorus (P) and potassium (K) respectively.

3.2.4 Herbicides

The herbicides used in the experiment were both individual herbicides and premix combinations. The toxicity, technical information and other available data of the herbicides used are given in Table 2a and 2b.

Table 2a: Technical information of the herbicides used in the study

Common name	Pendimethalin	Imazethapyr	Propaquizafop
Chemical name	N-(1-ethylpropyl)-3,4 -dimethyl-2,6-dinitrobenzenamine	2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridine carboxylic acid	2-(propan-2-ylidene amino) oxyethyl (2R)-2-[4-(6- chloroquinoxalin-2-yl) oxyphenoxy] propanoate
Chemical group	Dinitroaniline	Imidazolinone	Aryloxyphenoxy propionate
Trade name	Dost Super	Pursuit ®	Agil
Formulation	38.7% CS	10% SL	10% EC
Physical state, colour and odour	liquid dark amber aromatic, moderate odour	liquid, green to dark brown, characteristic	Liquid, yellow-orange, chemical Faint
Acute oral toxicity LD_{50}(rat)	3,956 mg/kg	>5,000 mg/kg	2863 mg/kg
Manufacturer	UPL Limited, Gujrat	BASF	ADAMA Agan Limited.
Price (₹)	Rs 535/- for 700mL	Rs 714/- for 500 mL	Rs 710/- for 250 mL

Table 2b: Technical information of the premix herbicides used in the study

Common name	Pendimethalin (30%) + imazethapyr(2%)	Propaquizafop (2.5%)+ Imazethapyr(3.75%)
Chemical name	N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine + 2-[4,5- dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridine carboxylic acid	2-(propan-2-ylidene amino) oxyethyl (2R)-2-[4-(6-chloroquinoxalin-2-yl) oxyphenoxy] propanoate + 2-[4,5-dihydro-4-methyl-4-(1-methyl ethyl)-5-oxo-1H-imidazol-2-yl]-5-ethyl-3-pyridine carboxylic acid
Chemical group	Dinitroaniline and Imidazolinone	Aryloxyphenoxy propionate and Imidazolinone
Trade name	Penza	Shaked
Formulation	32 % EC	6.25% w/w ME
Physical state, colour and odour	Liquid amber to dark brown, characteristic agricultural chemical odour.	Liquid amber to dark brown, mild odour
Acute oral toxicity LD_{50}(rat)	Pendimethalin :1250-1500 mg/kg Imazethapyr : >5000 mg/kg	Propaquizafop: 2863 mg/kg Imazethapyr : >5000 mg/kg
Manufacturer	UNIKIL PESTICIDES PVT, LTD.	ADAMA Agan Limited.
Price (₹)	Rs 850/- for1000 mL	Rs 880/- for 400 mL

3.3 METHODS

3.3.1. Experimental Design and Layout

Design	: RCBD
Treatments	: 9
Replications	: 3
Season	: Summer 2024
Spacing	: 25 cm x 15 cm
Gross plot size	: 4 m x 3 m
Net plot size	: 3.5 m x 2.7 m

3.3.2 Treatments

T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}

T_2 - T1 *fb* HW at 30 DAS

T_3- PoE propaquizafop + imazethapyr 125 g ha^{-1}

T_4- T3 *fb* HW at 40 DAS

T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS

T_6- PE pendimethalin 1kg ha^{-1} *fb* PoE imazethapyr 50g ha^{-1}

T_7- PE pendimethalin 1kg ha^{-1} *fb* PoE propaquizafop 100g ha^{-1}

T_8- HW at 15 and 30 DAS

T_9- Weedy check

(PE- pre emergence on the next day of sowing; PoE- post emergence applied at two to four leaf stage of weed at 15 DAS; *fb*- followed by; HW- hand weeding; DAS- days after sowing)

3.3.3 Field Preparation

The space between the coconut palms were cleared by weeding, followed by shallow ploughing with the help of a tractor. The stubbles were removed and the land was levelled and brought to a fine tilth using a rotovator. Two-meter radius was left untouched from the base of each palm to limit the interruption from coconut roots

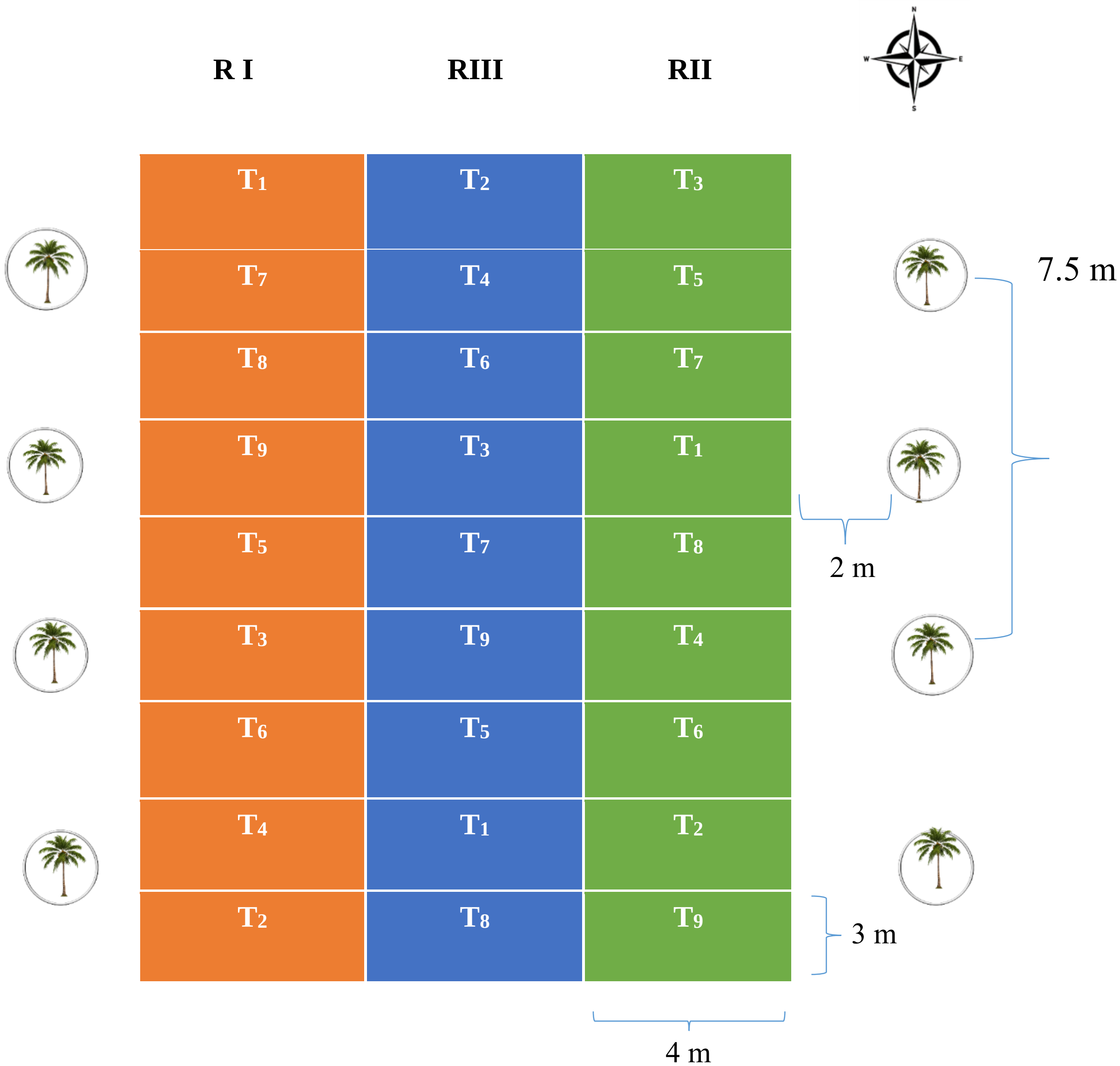


Fig. 2. Lay out of the experimental field

Plate 1. General view of the experimental field

Plate 2. Field preparation, sowing and harvest

towards the growth and development of the intercrop. The interspace was divided into 27 plots each with a gross plot size of 4m x 3m. Bunds of 30 cm were taken around each plot.

3.3.4 Lime Application

Lime at the rate of 250 kg ha^{-1} was uniformly applied to the plots at the time of final ploughing and the field was raked immediately.

3.3.5 Application of Manures and Fertilizers

Farmyard manure @ 20 t ha^{-1} was applied uniformly to all the treatment plots and mixed well. A nutrient dose of 20: 30: 30 kg NPK ha^{-1} was followed. Half the dose of N, full dose of P and K were applied as basal and the remaining N was applied in two equal split doses at 15 and 30 DAS. The crop was grown and managed as per the recommendations of Package of Practices (KAU, 2024).

3.3.6 Sowing of Seeds

The seeds of blackgram variety DBGV-5 were treated with *Bradyrhizobium* inoculant BMBS 47 at 250 g ha^{-1} using rice gruel water and shade dried for 30 minutes. The seeds were dibbled at three seeds per hole on the beds at a spacing of 25cm ×15 cm on 10/2/2024. Sowing was followed by irrigation for ensuring uniform germination.

3.3.7 After cultivation

The crop was thinned to one plant per pit one week after sowing to maintain optimum plant population. At 20 DAS, five plants in each plot were randomly selected and tagged as observation plants. The general view of the experimental site and crop at various stages of growth are presented in Plate 1and 3.

3.3.8 Weed management

Weed management practices including herbicide application and hand weeding were adopted as per the treatment schedule. The spray volume used for spraying the herbicides in the study was 500 L ha^{-1} and herbicides were sprayed with hand operated knapsack sprayer fitted with a flat fan nozzle. Pre-emergence application of herbicide was done on the next day of sowing and post emergence herbicides were applied at 15

DAS. In weed free check, hand weeding was done at 15 and 30 DAS and weedy check plot was maintained free of weed control practices.

3.3.9 Irrigation

The crop was irrigated daily during the initial period of establishment and later as and when required to ensure sufficient moisture in the beds.

3.3.9 Plant Protection

Rodent attack was noticed during the pod development stage, and bandicoot traps were used to control their population, keeping it below the damage threshold.

3.3.10 Harvest

Harvest of pods was completed with three pickings. Observational plants were pulled out and the yield attributing characters were recorded one day before the harvest. The dry pods from individual net plot area was picked, sun dried and threshed separately to determine seed yield. The remaining plant residues in the net plot area were uprooted, dried, and weighed to record haulm yield.

3.4 *IN VITRO* SENSITIVITY OF *Bradyrhizobium* TO PRE-MIX HERBICIDES

Laboratory experiments were undertaken separately to examine the *in vitro* sensitivity of *Bradyrhizobium* to two premix herbicides following standard procedures.

3.4.1 Source of Test organism

The blackgram specific *Bradyrhizobium* strain BMBS 47, was sourced from the Department of Agricultural Microbiology, Tamil Nadu Agricultural University (TNAU), Coimbatore.

3.4.2 Media and methodology used

For assessing *in vitro* sensitivity of *Bradyrhizobium*, yeast extract mannitol agar (YEMA) was used as the medium. Components of YEMA is shown in Table 3.

The medium was prepared by dissolving 26.8g of readymade YEMA (HiMedia Laboratories, Mumbai) in 1000 mL distilled water and boiling to ensure complete dissolution. The media was then sterilized by autoclaving at 15 lbs pressure (121°C) for

15 minutes. It was cooled to 45-50°C, mixed well and poured in sterile petri plates under aseptic conditions.

Table 3. Media composition of Yeast extract mannitol agar (YEMA)

Sl No.	Components	Quantity (g/L)
1.	Mannitol	10 g
2.	K_2HPO_4	0.5 g
3.	$MgSO_4.7H_2O$	0.2 g
4.	NaCl	0.1 g
5.	Yeast extract	1.0 g
6.	Agar	15 g

The *Bradyrhizobium* was tested for *in vitro* sensitivity to different concentrations of herbicides by disc diffusion method suggested by Bauer *et al.* (1966). The experimental details are as follows.

Design : Completely Randomised Design (CRD)

Treatments : 8 (7 different herbicide concentrations + control)

Replications : 3

3.4.3 Test Herbicides

1) Pendimethalin+ imazethapyr

2) Propaquizafop+ imazethapyr

3.4.3.1 Treatment details of Pendimethalin + imazethapyr

T_1 - 800 ppm

T_2 -1000 ppm

T_3-1200 ppm

T_4-1400 ppm

T_5 -1600 ppm

T_6 -1800 ppm

T_7 -2000 ppm

T_8 –control

3.4.3.2 Preparation of stock solution

Stock solution of pendimethalin + imazethapyr with a concentration of 1,00,000 ppm was prepared by dissolving 10 mL of the same in 100 mL sterile water. From this stock solution, 800, 1000, 1200, 1400, 1600,1800 and 2000µL were pipetted out and made upto 100 mL using sterile water in a 250 mL conical flask for disc diffusion test (Bauer *et al*.,1966).

3.4.3.3 Treatment details of Propaquizafop + imazethapyr

T_1-175 ppm

T_2-200 ppm

T_3-225 ppm

T_4-250 ppm

T_5 -275 ppm

T_6 -300 ppm

T_7 -325 ppm

T_8 –control

3.4.3.4 Preparation of stock solution

Stock solution of propaquizafop + imazethapyr having concentration of 20,000 ppm was prepared by dissolving 2 mL of same herbicide in 100 mL sterile water. From this stock solution, 175, 200, 225, 250, 275, 300, and 325 µL were pipetted out and made upto 100 mL using sterile water in a 250 mL conical flask for disc diffusion test (Bauer *et al*., 1966).

3.4.4 Procedure for assessing *in vitro* sensitivity of *Bradyrhizobium* to different herbicides

Solidified YEMA plates were swabbed evenly with a suspension from four-days old broth culture of *Bradyrhizobium* BMBS 47 using sterile cotton swabs. Sterile filter paper disc of 6 mm dipped in respective concentrations of herbicide were placed at three corners of the Petri plate. Sterile filter paper disc dipped in sterile water served as the control. The Petri plates were sealed and kept for three days incubation at room temperature.

3.4.5 Microbial Population in Soil

Soil samples were collected from the root zone and composite samples were prepared for estimating the population count of fungi, bacteria and actinomycetes using serial dilution followed by plating on appropriate microbial media (Johnson and Curl, 1972). The media used for isolation of different groups of microorganisms are given in table 4.

Table 4. Media used for estimation of microbial population

Sl. No.	Microflora	Media used	Reference
1.	Bacteria	Nutrient agar medium	Atlas (1993)
2.	Fungi	Martin’s rose bengal agar	Martin (1950)
3.	Actinomycetes	Ken Knight’s agar medium	Cappuccino and Sheman (1996)
4.	Nitrogen fixing bacteria	Jensen's Medium	Jensen (1942)
5.	Phosphate-solubilizing soil microorganisms	Pikovskayas agar	Pikovskaya(1948)

3.4.6 Isolation of Microorganisms Using General purpose and Specific media

Soil samples were collected from treatment plots, just before spraying, 15 and 30 days after spraying of pre and post-emergent herbicides. From the collected soil samples, 10 g was added to 90 mL sterile water in 250 mL conical flask and mixed thoroughly by keeping in an orbital shaker (200 rpm) for 20 min to obtain 10^{-1} dilution. All procedures that followed were carried out under aseptic conditions in a laminar air flow chamber. One mL aliquot from the soil suspension thus obtained, was transferred to a 9 mL sterile water blank, mixed well and the procedure repeated to make dilutions up to 10^{-7}. Nutrient agar, rose bengal agar and Kenknight agar media were sterilised, melted and cooled down to 45°C by keeping in a water bath. Pour plate technique was employed as the plating method. One mL of aliquots from appropriate dilutions were transferred to sterile Petri dishes and plates poured with molten agar. Three replications were maintained for each dilution. The plates after pouring were gently swirled to ensure uniform distribution of cells in the medium. After solidification of agar, the plates were incubated at 28 + 2ºC for 24-48 h in an inverted position and observed for microbial colonies.

3.5 OBSERVATIONS ON CROP

3.5.1 Growth Parameters

Leaving the single row of plants on the plot borders, five representative plants remaining diagonally in the same direction selected at random from each net plot area were tagged as observation plants for recording biometric observations. Growth characters were recorded at 20, 40, 60 DAS and at harvest from these five observation plants and mean values worked out.

3.5.1.2 Number of Leaves per Plant

Number of leaves in the tagged observation plants were counted at 20, 40, 60 DAS and at harvest and expressed as number per plant.

3.5.1.3 Number of Branches per Plant

Number of branches from the observation plants were counted and average number of branches per plant was worked out at 20, 40, 60 DAS and at harvest.

3.5.1.4 Leaf Area Index

For determining leaf area, the linear method was advocated, in which the length is multiplied by the greatest width of all the leaves. In observation plants, the length and breadth of fully opened and physiologically active leaves were measured. Leaf area was calculated in cm^2 at 20, 40, 60 DAS, and at harvest.

Leaf area = K x L x B x N

K (constant value) =0.631 (Montgomery, 1911)

L – Length of leaf, cm

B – Breadth of leaf, cm

N – Number of leaves per plant

Then LAI was worked out based on the formula developed by Watson (1952),

$$LAI = \frac{\text{Leaf area of plant } (cm^2)}{\text{Land area occupied by the plant } (cm^2)}$$

3.5.1.5 Dry Matter Production (DMP)

At harvest, five plants were chosen at random and uprooted outside the net plot area. The plant samples were first shade dried for two days to minimize moisture content before being oven dried at 65 ± 5°C to ensure constant weight. The average was calculated and expressed in g.

3.5.1.6 Phytotoxicity

The treated plots were observed closely, and the visual symptoms of herbicide toxicity on plants were recorded. Phytotoxicity rating of the crop was done seven days after post emergence herbicide application. Symptoms of injury were graded from zero to five using the toxicity scale suggested by Thomas and Abraham (2007).

Table 5. Scale for rating herbicide phytotoxicity in crop and weeds

Rating	Effect on weeds	Effect on crop
0	None	No injury
1	Slight control	Slight injury
2	Moderate control	Moderate injury
3	Good control	Severe injury
4	Very good control	Very severe injury
5	Complete control	Complete destruction

3.5.2. Nodule Parameters

At 50 per cent flowering, nodule parameters were assessed by randomly uprooting five plants from outside the net plot area while leaving the roots attached to the plants.

15 DAS

30 DAS

45 DAS

60 DAS

Plate 3. Crop at different growth stages

3.5.2.1 Total number of Effective Nodules per plant

Five plants were uprooted from each net plot area at 50 per cent flowering stage, without causing any damage to the roots. Soil adhered to the roots were removed by dipping the roots in bucket filled with clean water. After the removal of soil, nodules from each plant root was carefully removed.

The separated nodules were observed for colour by cutting the nodules using a sharp blade. The nodules which appeared pink colour were identified as effective and counted as effective nodules per plant. Nodules which appeared green in colour were considered as ineffective (Jordan, 1962).

3.5.2.2 Fresh Nodule Weight

Fresh weight of the nodules from each plant was recorded, average was worked out and expressed in mg per plant.

3.5.3 Yield and Yield Components

For computing the yield parameters, five plants in the net plot area were identified and tagged as observation plants.

3.5.3.1 Days to 50 per cent Flowering

The number of days taken by 50 per cent of plants in each plot to flower was recorded.

3.5.3.2 Number of Pods per Plant

Pods harvested were counted separately from the observational plants from each plot and the mean was computed.

3.5.3.3 Number of Seeds per Pod

Pods collected from observational plants from each plot were threshed separately, number of seeds contained in pods were counted and mean value recorded.

3.5.3.4 Hundred Seed Weight

The weight of 100 bold, fully filled blackgram seeds selected from each net plot were recorded and expressed in g.

3.5.3.5 Seed Yield per Plant

Seed yield per plant was calculated by separating the seeds from the pods of observational plants threshed, dried to a moisture content of 12 per cent and weighed. Average weight was computed and expressed in g per plant.

3.5.3.6. Haulm Yield per Plant

The observational plants uprooted after the harvesting of the pods were sun dried and weighed individually and the average weight was computed and expressed in g per plant.

3.5.3.7 Seed Yield per hectare

Seeds of each harvest from the net plot area of each treatment were threshed and dried to a moisture content of 12 per cent. Seeds thus obtained from each net plot area were weighed separately and expressed in kg ha^{-1}.

3.5.3.8. Haulm Yield per hectare

After separating seeds from harvested plants, remaining plant portions from each net plot area were sun dried and weighed to record haulm yield and expressed in kg ha^{-1}.

3.5.3.9 Harvest Index

Harvest index was calculated on the basis of the economic as well as the biological yields from the net plot, using the formula suggested by Donald and Hamblin (1976).

$$\text{HI} = \frac{\text{Seed yield}}{\text{Seed yield + Haulm yield}}$$

3.5.3.10 Weed Index (WI)

Weed index was calculated using the formula suggested by Gill and Vijayakumar (1969).

$$WI = \frac{X - Y}{X} \times 100$$

Where,

X- Yield from the treatment which recorded the minimum number of weeds

Y- Yield from the plot for which WI was to be determined

3.6 OBSERVATIONS ON WEEDS

The observations on weeds were taken at 15, 30 and 45 DAS using a quadrant of size 25 cm x 25 cm which was placed randomly in each plot. The weeds that were present within the quadrant were used to make the following information.

3.6.1 Weed Flora

Weed species present in the experimental area were identified and categorized into grasses, sedges and broadleaf weeds at 15, 30, and 45 DAS.

3.6.2 Weed Density

Weed density was determined by randomly placing a 0.25 m × 0.25 m quadrant at two different locations in each treatment plot at 15, 30, and 45 DAS and counting the number of weeds present inside that specific quadrant area. Weeds were classified into grasses, broad leaf weeds (BLW) and sedges and expressed as number m^{-2}.

3.6.3 Weed Dry Weight

Weeds were uprooted from the same area where the quadrant was put to record the density of weeds at 15, 30, and 45 DAS from each treatment plot. Uprooted weeds were shade dried for two days before being dried in a hot air oven at 70 ± 5^{o}C to attain a constant weight, and was expressed in g m^{-2}.

3.6.4 Relative Weed Density (Rd)

Relative density of grasses, sedges and BLW were calculated at 15, 30 and 45 DAS using the formula suggested by Philips (1959).

$$Rd = \frac{\text{Absolute density of a species}}{\text{Total absolute density of all species}} \times 100$$

3.6.5 Relative Weed Biomass

The oven dry weight of specific weed group at 15, 30 and 45 DAS to that of total weed flora dry weight was recorded and expressed in percentage.

3.6.6 Weed Control Efficiency

Weed control efficiency was worked out by adopting the formula put forth by Mani and Gautham (1973).

$$WCE = \frac{(WDWC - WDWT) \times 100}{WDWC}$$

where,

WCE - weed control efficiency

WDWC- weed dry weight in unweeded (control) plot

WDWT -weed dry weight in treated plot

3.7 ENZYME ANALYSIS

Enzyme assay was carried out at 15, 30 and 45 DAS. For analysis, soil samples were collected at 15 cm depth from each treatment and stored in polythene bag and analysis was completed within a week.

3.7.1 Dehydrogenase Activity

The dehydrogenase activity was assessed by the method described by Casida *et al*. (1964) and expressed as µg triphenyl formazon (TPF) g^{1} soil day^{1}.

3.8 CHEMICAL ANALYSIS

3.8.1 **Crop and Weed analysis**

The sample plants uprooted at harvest were separated into seed and haulm, chopped, shade-dried, and oven-dried at 65 ± 5^0C to a constant weight. The weed samples and plant samples were separately ground to fine powder and used for analysis. The required quantities of samples were weighed out accurately and subjected to single acid digestion for determining the N content and di-acid mixture for determining the P and K content.

3.8.1.1 Total N Content

The modified micro Kjedahl method (Jackson, 1973) was used for the determination of total nitrogen content in seed, haulm and that of weeds separately and was expressed in percentage.

3.8.1.2 Total P Content

The plant samples were digested in di-acid mixture and P content was determined by the vanado-molybdo phosphoric yellow colour method (Jackson, 1973). The intensity of colour was read at 420nm using Spectronic 20 spectrophotometer.

3.8.1.3 Total K Content

The potassium content in in the di-acid digest of seed, haulm and that of weeds was determined using the flame photometer (Jackson, 1973).

3.8.2 Nutrient Uptake by Crop

The total NPK uptake by blackgram was worked out by multiplying the nutrient content of seed and haulm with its respective DMP and expressed in kg ha^{-1}.

3.8.3 Nutrient Removal by Weeds

The NPK removal of weeds was estimated as the product of content of these nutrients and respective dry weight of weeds and expressed in kg ha^{-1}.

3.8.4 Soil Analysis

Composite soil sample was drawn from the experimental area before and after the experiment for the analysis of soil physical and chemical properties including pH, electrical conductivity, organic carbon and available N, P, K. The samples were sieved using a 2 mm sieve for pH, EC, available N, P and K estimation.

3.8.4.1 pH

The pH of the composite sample was found out by diluting it with water in the ratio 1: 2.5 and analyzed using a pH meter.

3.8.4.2 Electrical Conductivity

The electrical conductivity of the soil samples was estimated by using a conductivity meter and expressed in dSm^{-1}(Jackson, 1973).

3.8.4.3 Organic Carbon

For the estimation of soil organic carbon, the soil was sieved through a 0.2 mm sieve and analyzed by rapid titration method (Walkley and Black, 1934) and expressed in percentage.

3.8.4.4 Available N

For the estimation of available N in the composite sample, alkaline potassium permanganate method (Subbiah and Asija, 1956) was adopted and expressed in kg ha^{-1}.

3.8.4.5 Available P

For the estimation of available phosphorus in the composite sample, Bray I (0.03 N ammonium fluoride in 0.025 N hydrochloric acid) method was adopted as described by Jackson (1973) and estimated using a spectrophotometer and expressed in kg ha^{-1}.

3.8.4.6 Available K

For the estimation of available potassium, neutral normal ammonium acetate extraction method was used and was estimated using a Flame photometer (Jackson, 1973) and expressed in kg ha^{-1}.

3.8.5 Microbial analysis

3.8.5.1 Microbial count in soil

The microbial count was estimated before spraying, at 15 and 30 days after spraying and expressed as colony forming units (cfu) g^{-1} soil.

3.8.5.2 Inhibition zone

The observations on inhibition zone in mm were recorded at 3 days after incubation and the growth was visually categorized as positive culture growth (+) around the disc and inhibited culture growth (-) around the disc.

3.9 ECONOMICS OF CULTIVATION

Economics of cultivation was worked out for the experiment based on the cost of cultivation and prevailing market price of the crop.

3.9.1 Net income

Net income was calculated by the formula and was expressed as ₹ ha^{-1}

$$\text{Net income (₹ ha}^{-1}) = \text{Gross income (₹ ha}^{-1}) - \text{Cost of cultivation (₹ ha}^{-1})$$

3.9.2 Benefit Cost ratio (B:C ratio)

The benefit cost ratio (BCR) was calculated using the formula

$$\text{BCR} = \frac{\text{Gross income (₹ ha}^{-1})}{\text{Cost of cultivation (₹ ha}^{-1})}$$

3.10 STATISTICAL ANALYSIS

The data generated from the experiments for RCBD and CRD were statistically analysed using analysis of variance technique (ANOVA) and the critical difference was determined using the General R-shiny based Analysis Platform Empowered by Statistics (GRAPES) software system designed by the Department of Statistics, College of Agriculture, Vellayani. The F test was used to determine the significance and critical differences were computed for comparison whenever treatments were shown to be significant (Cochran and Cox, 1965).

RESULTS

4. RESULTS

Field and lab experiments of the research work entitled 'Integrated weed management in blackgram [*Vigna mungo* (L.) Hepper] with pre-mix herbicides' was carried out at Department of Agronomy, College of Agriculture, Vellayani, Thiruvananthapuram district, Kerala during February to April 2024 with an objective to formulate an integrated weed management strategy using pre-mix herbicides for black gram intercropped in coconut garden. The data obtained were statistically analysed and results are detailed in the chapter.

4.1 OBSERVATIONS ON CROP

4.1.1 Growth Parameters

4.1.1.1 Plant Height

Results on the effect of weed management practices on plant height of blackgram intercropped in coconut garden at 20, 40, 60 DAS and at harvest are presented in Table 6.

The results revealed that plant height was not significantly influenced by weed management practices at all the stages of observation.

4.1.1.2 Number of Leaves per Plant

Results on the effect of weed management practices on number of trifoliate leaves per plant of blackgram at 20, 40, 60 DAS and at harvest at are presented in Table 7. The results revealed that number of trifoliate leaves per plant was not significantly influenced by weed management practices at all stages of observation.

4.1.1.3 Number of Branches per Plant

Results on the effect of weed management practices on number of branches per plant of blackgram at 20, 40, 60 DAS and at harvest at are presented in Table 8. The results revealed that number of branches per plant was not significantly influenced by weed management practices at all stages of observation.

4.1.1.4 Leaf Area Index (LAI)

Results on the effect of weed management practices on leaf area index of black gram at 20, 40, 60 DAS are presented in the Table 9. Perusal of the data revealed that leaf area index was not significantly affected by weed management practices adopted.

4.1.1.5 Herbicide Phytotoxicity

The symptoms of phytotoxicity on crop was observed 7 days after herbicide application and was scored as per the scale by Thomas and Abraham (2007) and observations are presented in Table 10. The symptoms of phytotoxicity was observed as mild stunting in the premix combination, pendimethalin + imazethapyr applied on the next day of sowing. The symptoms persisted upto 10 days after herbicide application and recovered by 15 days after application. No signs of phytotoxicity were observed in the plots treated with other herbicide sprays.

4.1.1.6 Number of effective nodules per plant

The results on the effect of weed management practices on the number of effective nodules per plant at 50 per cent flowering are depicted in Table 11.

A significant variation among the treatments was observed with respect to the number of effective nodules produced per plant. Pre-emergence application of pendimethalin 1kg ha^{-1} followed by propaquizafop 100g ha^{-1} resulted in higher effective nodules per plant (31.67) and was on par with T_4 (29.67), T_3 (25.33) and T_9 (24.67). A significantly lower number of effective nodules per plant was observed in T_2 (15.33) and was on par with T_5 (17.33), T_6 (18.33), T_1 and T_8 (18.67).

4.1.1.7 Fresh weight of nodules

Effect of weed management practices on the nodule fresh weight of blackgram at 50 per cent flowering are presented in Table11. The data revealed that fresh weight of nodules was not significantly influenced by weed management practices. However, the nodule fresh weight ranged between 111.67 mg to 182.03 mg per plant.

Table 6. Effect of weed management practices on plant height, cm

Treatments	Plant height			
	20 DAS	40 DAS	60 DAS	harvest
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	15.92 ± 1.57	56.97 ± 3.88	57.22 ± 4.34	64.40 ± 1.05
T_2- T_1 *fb* HW at 30 DAS	15.75 ± 1.51	51.30 ± 5.68	54.78 ± 4.14	60.13 ± 4.16
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1} at 15 das	16.55 ± 0.26	60.03 ± 7.62	53.44 ± 7.07	58.0 ± 6.43
T_4- T_3 *fb* HW at 40 DAS	16.87 ± 1.45	54.33 ± 2.68	61.39 ± 2.70	66.47 ± 3.15
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	16.95 ± 1.20	57.07 ± 3.07	54.78 ± 1.26	65.80 ± 5.16
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1} at 15 DAS	15.52 ± 3.50	53.57 ± 1.68	58.22 ± 6.62	67.53 ± 3.02
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	16.23 ± 0.60	58.10 ± 4.71	55.33 ± 2.08	62.47 ± 2.03
T_8- HW at 15 and 30 DAS	17.20 ± 0.98	55.90 ±10.82	54.78 ± 2.78	63.40 ± 0.70
T_9- Weedy check	17.78 ± 0.56	50.23 ± 6.17	54.67 ± 5.29	63.20 ± 1.06
SEm (±)	0.76	3.09	2.69	2.14
CD (0.05)	NS	NS	NS	NS

Table 7. Effect of weed management practices on number of leaves per plant

Treatments	Number of trifoliate leaves per plant			
	20 DAS	40 DAS	60 DAS	Harvest
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	4.67 ± 0.17	18.22 ± 5.58	25.22 ± 2.84	16.00 ± 2.33
T_2- T_1 *fb* HW at 30 DAS	4.56 ± 0.10	19.50 ± 3.17	28.52 ± 4.71	16.78 ± 3.03
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	4.50 ± 0.00	20.33 ± 1.20	24.07 ± 4.33	14.89 ± 1.64
T_4- T_3 *fb* HW at 40 DAS	4.72 ± 0.10	19.78 ± 6.20	25.93 ± 4.16	12.22 ± 1.02
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	4.56 ± 0.10	17.33 ± 3.40	30.96 ± 8.09	15.11 ± 4.35
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	4.67 ± 0.17	19.11 ± 1.69	27.33 ± 0.91	13.89 ± 1.35
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	4.33 ± 0.29	23.28 ± 5.80	26.19 ± 8.79	13.11 ± 3.20
T_8- HW at 15 and 30 DAS	4.67 ± 0.29	19.94 ± 4.79	24.07 ± 6.72	12.56 ± 2.50
T_9- Weedy check	4.39 ± 0.39	17.39 ± 4.72	21.59 ± 6.73	10.78 ± 2.91
SEm (±)	0.11	2.52	3.17	1.53
CD (0.05)	NS	NS	NS	NS

Table 8. Effect of weed management practices on number of branches per plant

Treatments	Number of branches per plant			
	20 DAS	40 DAS	60 DAS	At harvest
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	2.83 ± 0.29	6.44 ± 0.38	6.67 ± 0.76	6.773 ±0.20
T_2- T_1 *fb* HW at 30 DAS	2.50 ± 0.50	6.22 ± 0.69	6.83 ± 1.04	7.433 ±0.75
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	2.50 ± 0.50	6.33 ± 0.58	7.17 ± 0.29	6.87 ± 0.23
T_4- T_3 *fb* HW at 40 DAS	2.67 ± 0.29	6.22 ± 0.51	6.83 ± 0.76	7.00 ± 0.00
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	2.33 ± 0.29	6.22 ± 0.38	6.50 ± 0.50	6.89 ± 0.20
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	2.67 ± 0.29	6.22 ± 0.69	6.50 ± 0.50	7.10 ± 0.17
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	2.67±0.29	6.22 ± 0.69	7.17 ± 1.16	7.40 ± 0.35
T_8- HW at 15 and 30 DAS	2.83 ± .29	5.89 ± 1.02	7.00 ± 0.87	7.10 ± 1.02
T_9- Weedy check	2.67 ± 0.29	5.89 ± 1.17	6.00 ± 0.50	6.11 ± 0.19
SEm (±)	0.21	0.22	0.45	0.25
CD (0.05)	NS	NS	NS	NS

Table 9. Effect of weed management practices on leaf area index

Treatments	Leaf area index		
	20 DAS	40 DAS	60 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	1.70 ± 0.08	4.55 ± 0.69	4.85 ± 0.85
T_2- T_1 *fb* HW at 30 DAS	1.71 ± 0.08	4.38 ± 0.85	4.95 ± 2.75
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	1.65 ± 0.13	4.60 ± 0.49	4.93 ± 0.58
T_4- T_3 *fb* HW at 40 DAS	1.65 ± 0.02	4.77 ± 0.43	5.01 ± 0.28
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	1.67 ± 0.18	4.00 ± 0.59	4.41 ± 1.22
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	1.67 ± 0.06	4.30 ± 1.34	4.69 ± 0.23
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	1.68 ± 0.01	4.96 ± 0.46	5.15 ± 1.48
T_8- HW at 15 and 30 DAS	1.52 ± 0.51	3.80 ± 0.92	4.13 ± 0.63
T_9- Weedy check	1.50 ± 0.15	3.42 ± 1.84	3.85 ± 0.62
SEm (±)	0.12	0.57	0.65
CD (0.05)	NS	NS	NS

Table 10.Visual assessment of phytotoxicity in blackgram 7 days after herbicide application

Herbicides		Phytotoxicity score	Effect on crop
Pre emergence	pendimethalin + imazethapyr 800 g ha^{-1} (premix)	1	Slight injury
	pendimethalin 1kg ha^{-1}	0	No injury
Post emergence	propaquizafop+ imazethapyr 125 g ha^{-1}(premix)	0	No injury
	imazethapyr 50g ha^{-1}	0	No injury
	propaquizafop 100g ha^{-1}	0	No injury

Table 11. Effect of weed management practices on nodule parameters of black gram at 50 per cent flowering.

Treatment	Nodule parameters	
	Total number of effective nodules per plant	Fresh weight of nodules (mg per plant)
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	18.67 ± 3.05^{bc}	137.00 ± 43.55
T_2- T_1 *fb* HW at 30 DAS	15.33 ± 2.52^{c}	123.73 ± 14.00
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	25.33 ± 3.21^{ab}	127.33 ± 14.57
T_4- T_3 *fb* HW at 40 DAS	29.67 ± 6.66^{a}	146.33 ± 60.45
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	17.33 ± 1.15^{c}	111.67 ± 10.60
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	18.33 ± 2.52^{bc}	130.23 ±114.30
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	31.67 ± 6.81^{a}	182.03 ± 53.50
T_8- HW at 15 and 30 DAS	18.67 ± 2.08^{bc}	163.00 ± 46.78
T_9- Weedy check	24.67 ± 5.51^{ab}	160.00 ± 52.43
SEm (±)	2.36	32.71
CD (0.05)	7.086	NS

4.2. YIELD AND YIELD COMPONENTS

4.2.1 Days to 50 per cent flowering

The results on the effect of weed management practices on days to 50 per cent flowering are depicted in Table 12.

Perusal of the data revealed a significant variation in the number of days required to reach 50 per cent flowering in black gram raised as intercrop in coconut garden. In general, the number of days to attain 50 per cent flowering ranged between 39.67 to 43.

Among the weed management practices. T_3 resulted in early flowering (39.67 days) and is comparable with T_4 (40.67 days) and T_7 (40. 67 days). Application of pendimethalin + imazethapyr resulted in more number of days (43.00 days) to reach flowering and was on par with T_2 (42.67 days), T_9 (42 days) and T_6 (41.67 days).

Table 12. Effect of weed management practices on days to 50 per cent flowering

Treatment	Days to 50 per cent flowering
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	43.00 ± 1.00^{a}
T_2- T_1 *fb* HW at 30 DAS	42.67 ± 1.16^{ab}
T_3- PoE propaquizafop + imazethapyr 125 g ha^{-1}	39.67 ± 0.58^{d}
T_4- T_3 *fb* HW at 40 DAS	40.67 ± 0.58^{cd}
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	41.33 ± 0.58^{bc}
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	41.67 ± 1.53^{abc}
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	40.67 ± 0.58^{cd}
T_8- HW at 15 and 30 DAS	41.33 ± 0.58^{bc}
T_9- Weedy check	42.00 ± 1.00^{abc}
SEm (±)	0.50
CD (0.05)	1.499

4.2.2 Number of pods per plant

The results on the effect of weed management practices on number of pods per plant are depicted in Table 13.

The results showed that weed management practices had significant influence on the number of pods produced per plant. Among the weed management practices, T_4 resulted in more number of pods (36.00) and was comparable with T_7 (35.83) which was followed by T_5 (33.11) and T_6 (32.89). Weedy check recorded the lowest number of pods (14.24) and was followed by T_8 (26.33) and T_2 (29.22).

4.2.3 Number of seeds per pod

The results on the effect of weed management practices on number of seeds per pod are presented in Table13.

The number of seeds per pod did not show significant variation among the treatments. However, the number of seeds per pod ranged between 5.78 to 6.44.

4.2.4 Hundred seed weight

The results on the effect of weed management practices on 100 seed weight of blackgram are presented in Table 13.

Hundred seed weight of blackgram was significantly influenced by weed management practices. Among the weed management practices, T_2 recorded higher hundred seed weight (5.33g) and was on par with T_4 (5.17g), T_1 (5.13g) which was followed by T_8 (5.05g), T_7 (5.02 g) and T_3 (5.01g). However, weedy check yielded the lowest value for 100 seed weight (4.80g).

Table 13. Effect of weed management practices on number of pods per plant, number of seeds per pod and hundred seed weight

Treatments	Number of pods per plant	Number of seeds per pod	Hundred seed weight (g)
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	30.15 ± 3.13^{cd}	6.11 ± 0.40	5.13 ± 0.16^{abc}
T_2- T_1 *fb* HW at 30 DAS	29.22 ± 0.20^{d}	6.11 ± 0.51	5.33 ± 0.06^{a}
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	32.15 ± 1.61^{bc}	6.33 ± 0.34	5.01 ± 0.03^{bc}
T_4- T_3 *fb* HW at 40 DAS	36.00 ± 1.86^{a}	6.44 ± 0.20	5.17 ± 0.16^{ab}
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	33.11 ± 1.58^{b}	6.33 ± 0.34	4.93 ± 0.15^{cd}
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	32.89 ± 3.20^{b}	6.33 ± 0.34	4.99 ± 0.08^{bcd}
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	35.83 ± 0.44^{a}	6.44 ± 0.196	5.02 ± 0.11^{bc}
T_8- HW at 15 and 30 DAS	26.33 ± 1.53^{e}	5.80 ± 0.51	5.05 ± 0.08^{bc}
T_9- Weedy check	14.24 ± 0.99^{f}	5.78 ± 0.51	4.80 ± 0.10^{d}
SEm (±)	0.83	0.16	0.07
CD (0.05)	2.497	NS	0.204

4.2.5 Seed yield per plant

The results on the effect of weed Management practices on seed yield per plant are presented in Table 14.

Seed yield per plant varied significantly among the weed management practices tested. Post emergence application of propaquizafop+ imazethapyr 125 g ha^{-1} at 15 DAS followed by hand weeding resulted in the highest seed yield per plant (9.60 g) and was followed by T_7 (9.23g) T_6 (8.3g), T_5 (8.23g) and T_3 (8.14g). The lowest seed yield per plant was recorded in weedy check (3.54 g) and was followed by hand weeding at 15 and 30 DAS (6.16 g).

4.2.6 Haulm yield per plant

The results on the effect of weed management practices on haulm yield per plant are presented in the Table 14.

A significant variation was observed among the weed management practices with respect to the haulm yield per plant. Among the weed management practices, T_5 resulted in higher haulm yield per plant (14.07g) and was on par with T_4 (13.90g), T_6 (13.77g), T_7 (13.40 g), T_1 (12.62g) and T_2 (12.50 g). The lowest haulm yield per plant was recorded in weedy check (7.04g) and followed by hand weeding (9.90 g).

4.2.7 Seed yield per ha

The results on the effect of weed management practices on seed yield per ha are presented in Table 14.

Perusal of the data revealed a significant variation in seed yield per hectare among the weed management practices tested. Post emergence application of propaquizafop+ imazethapyr at 125 g ha^{-1} followed by hand weeding resulted in higher seed yield per ha (1793 kg ha^{-1}) and was comparable with T_7 (1731 kg ha^{-1}). This was followed by T_6 (1556 kg ha^{-1}), T_5 (1544 kg ha^{-1}), T_3 (1526 kg ha^{-1}), T_2 (1423 kg ha^{-1}) and T_1 (1412 kg ha^{-1}). The lowest seed yield per ha was recorded in weedy check (658 kg ha^{-1}) and followed by hand weeding (1150 kg ha^{-1}).

4.2.8 Haulm yield per ha

The results on the effect of weed management practices on haulm yield per hectare are presented in the Table 14.

Results showed significant variation in haulm yield per ha among the weed management practices tested. Among the strategies tested for weed control, T_5 (3658.2 kg ha^{-1}) resulted in higher haulm yield per ha and was comparable with T_4 (3616 kg ha^{-1}), T_6 (3581.93 kg ha^{-1}) and T_7 (3485.73 kg ha^{-1}). The lowest haulm yield per hectare was recorded in weedy check (1917.5kg ha^{-1}) and was followed by hand weeding (1917.50 kg ha^{-1}).

4.2.9 Dry matter production per plant

The results on the effect of weed management practices on dry matter production per plant is presented in the Table 15.

The impact of weed management practices on dry matter production per plant was found to be significant. Among the approaches adopted for weed management, pre emergence application of pendimethalin 1kg ha^{-1} followed by propaquizafop 100g ha^{-1} resulted in plants with significantly higher dry matter production per plant (22.5 g) which was comparable with T_4 (21.88 g), T_6 (21.25 g) and T_5 (20.5 g). The lowest dry matter production per plant was recorded in weedy check (13.38 g) which was on par with T_3 (17.00 g) and T_8 (15.12 g).

4.2.10 Harvest index

The influence of weed management practices on harvest index of blackgram is presented in Table 15.

The data on harvest index showed that it was not significantly influenced by weed management practices. However, the values of harvest index ranged between 0.26 to 0.33.

4.2.11 Weed index

The extent of yield reduction caused by weeds was evaluated by using the treatment with the highest recorded yield in each replication as the control. The statistically analyzed data is presented in Table 15.

Data revealed that weed index showed significant variation among the weed management practices. The plots where no weed management practices were undertaken or unweeded control resulted in the highest yield reduction with a weed index of 54.44 per cent. Amongst the weed management practices, yield reduction was lower in T_4 (2.45%) and was on par with T_7 (5.35%). This was followed by T_6 (15.63%), T_5 (15.93%) and T_3 (17.06%). However, hand weeding twice resulted in yield reduction of 37.58 per cent.

Table 14. Effect of weed management practices on yield parameters of blackgram

Treatments	Yield parameters			
	Seed yield per plant (g)	Haulm yield per plant (g)	Seed yield ha^{-1} (kg)	Haulm yield ha^{-1} (kg)
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	7.53 ± 0.09[d]	12.63 ± 1.42[ab]	1412 ± 194.45[c]	3282 ± 369.13[ab]
T_2- T_1 *fb* HW at 30 DAS	7.60 ± 0.05[d]	12.50 ± 0.50[ab]	1423 ± 140.59[c]	3250 ± 130.00[ab]
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1} at 15 das	8.14 ± 0.11[c]	12.00 ± 1.00[b]	1526 ± 158.58[bc]	3120 ± 260.00[b]
T_4- T_3 *fb* HW at 40 DAS	9.60 ± 0.20[a]	13.90 ± 0.78[a]	1793 ± 169.01[a]	3614 ± 203.07[a]
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	8.23 ± 0.30[c]	14.07 ± 1.26[a]	1544 ± 116.96[bc]	3658 ± 328.23[a]
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1} at 15 DAS	8.31 ± 0.20[c]	13.78 ± 1.41[ab]	1556 ± 242.13[bc]	3581 ± 367.39[a]
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	9.23 ± 0 .20[b]	13.41 ± 0.53[ab]	1731 ± 94.12[ab]	3485 ± 136.63[ab]
T_8- HW at 15 and 30 DAS	6.16 ± 0.10[e]	9.90 ± 0 .57[c]	1150 ± 171.12[d]	2574 ± 149.13[c]
T_9- Weedy check	3.54 ± 0.07[f]	7.04 ± 1.31[d]	658 ± 46.70[e]	1917 ± 227.50[d]
SEm (±)	0.10	0.62	68.85	151.29
CD (0.05)	0.285	1.843	206.414	453.569

Table 15. Effect of weed management practices on dry matter production per plant, harvest index and weed index

Treatment	Dry matter production per plant (g)	Harvest index	Weed index (%)
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	18.62 ± 0.38^{bcd}	0.30 ± 0.05	23.37 ± 4.43^{c}
T_2- T_1 *fb* HW at 30 DAS	17.50 ± 0.50^{cd}	0.30 ± 0.02	22.39 ± 7.82^{c}
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	17.00 ± 1.00^{cde}	0.33 ± 0.04	17.06 ± 2.29^{c}
T_4- T_3 *fb* HW at 40 DAS	21.88 ± 0.13^{ab}	0.33 ± 0.03	2.45 ± 3.79^{d}
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	20.50 ± 2.50^{abc}	0.30 ± 0.02	15.93 ± 1.85^{c}
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	21.25 ± 1.25^{ab}	0.30 ± 0.03	15.63 ± 6.40^{c}
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	22.50 ± 4.50^{a}	0.33 ± 0.02	5.35 ± 9.27^{d}
T_8- HW at 15 and 30 DAS	15.12 ± 0.88^{de}	0.31 ± 0.02	37.58 ± 5.22^{b}
T_9- Weedy check	13.38 ± 2.63^{e}	0.26 ± 0.02	54.44 ± 2.13^{a}
SEm (±)	1.24	0.02	3.28
CD (0.05)	3.728	NS	9.819

4.3 WEED PARAMETERS

4.3.1 Weed Flora

Table 16 presents the predominant species of weeds observed in the experimental field.

The predominant weed flora in the experimental field was grasses. However, more diversity was observed in the flora of broad leaf weeds (BLW). *Megathyrsus maximus* and *Eleusine indica* were the grass species present in the experimental field. The major BLW species observed were *Phyllanthus niruri, Mollugo pentaphylla, Spermacoce latifolia, Richardia scabra, Euphorbia hirta, Commelina diffusa, Synedrella nodiflora, Trianthema portulacastrum* and *Odenlandia umbellata. Cyperus rotundus* was the only sedge present in the field.

4.3.2 Weed density (number m^{-2})

The data on weed density per square meter recorded at 15, 30 and 45 DAS are presented in Table 17.

Effect of weed management practices on weed density per square meter was found to be significant at all the growth stages.

At 15 DAS, T_2 resulted in lower weed density (1.00 m^{-2}) and was on par with T_1 (2.33 m^{-2}), T_7 (9.33 m^{-2}), T_6 (9.33 m^{-2}), T_5 (10.00 m^{-2}) T_3 (13.67 m^{-2}) and T_4 (20.33 m^{-2}). A significantly higher weed density was observed in T_8 (72.67 m^{-2}) which was on par with T_9 (62.00 m^{-2}).

At 30 DAS, a significantly lower weed density was observed in T_1 (1.00 m^{-2}) and T_2 (1.00 m^{-2}) which was on par with T_7 (5.33 m^{-2}), T_4 (5.67 m^{-2}) and T_6 (6.33 m^{-2}). Weedy check recorded the highest weed density (50.00 m^{-2}) which was followed by T_8 (25.33 m^{-2}).

At 45 DAS, a significantly lower weed density was recorded in T_2 (1.33 m^{-2}) and was on par with T_5 (1.67 m^{-2}), T_1 (3.33 m^{-2}), T_6 (4.67 m^{-2}), T_7 (6.00 m^{-2}) and T_4 (8.33 m^{-2}). The unweeded control (46.67 no.m^{-2}) recorded a higher weed count and was on par with hand weeding twice (40.67 no.m^{-2}).

Table 16. Major weed flora of the experimental field

Common Name	Scientific Name	Malayalam name	Family
Grasses			
Guinea grass	*Megathyrsus maximus*	*Kuthira pullu*	Poaceae
Indian goose grass	*Eleusine indica*	*Mathanga pullu*	Poaceae
Sedges			
Purple nutsedge	*Cyperus rotundus*	*Muthanga*	Cyperaceae
Broad Leaf Weeds			
Red spurge	*Euphorbia hirta*	*Tharavu*	Euphorbiaceae
Button weed	*Spermacoce latifolia*	*Vellatharavu*	Rubiaceae
Mexican clover	*Richardia scabra*		Rubiaceae
Climbing dayflower	*Commelina diffusa*	*Vazhappadathi*	Commelinaceae
Cinderella weed	*Synedrella nodiflora*	*Venapacha*	Asteraceae
Touch-me-not	*Mimosa pudica*	*Thottavadi*	Fabaceae
Stone breaker	*Phyllanthus niruri*	*Keezharnelli*	Phyllanthaceae
Carpet weed	*Mollugo pentaphylla*	*Parpadakapullu*	Aizoaceae
Desert horse purslane	*Trianthema portulacastrum*	*Vellathazhuthama, Manal vallikeera*	Aizoaceae
Indian madder	*Odenlandia umbellata*	*Nonganampullu*	Rubiaceae
Common purslane	*Portulaca oleraceae*	*Kozhuppa cheera*	Portulacaceae
Wild mustard	*Cleome viscosa*	*Manja kadugu*	Cleomaceae
Indian nettle	*Acalypha indica*	*Kuppameni*	Euphorbiaceae

Small square weed	*Mitracarpus hirtus*	*Thaval*	Rubiaceae
Fringed spider flower	*Cleome rutidosperma*	*Neelavela*	Cleomaceae
Tropical spiderwort	*Commelina benghalensis*	*Vazhapadathi*	Commelinaceae
Sessile joyweed	*Alternanthera sessilis*	*Vayal cheera*	Amaranthaceae

Table 17. Effect of weed management practices on weed density at 15, 30 and 45 DAS, number m^{-2}

Treatment	Weed density		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	2.33 ± 2.31^{b}	1.00 ± 0.00^{c}	3.33 ± 2.31^{c}
T_2- T_1 *fb* HW at 30 DAS	1.00 ± 0.00^{b}	1.00 ± 0.00^{c}	1.33 ± 0.58^{c}
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	13.67 ± 5.51^{b}	10.33 ± 6.66^{bc}	20.33 ± 7.51^{b}
T_4- T_3 *fb* HW at 40 DAS	20.33 ± 4.73^{b}	5.67 ± 4.62^{bc}	8.33 ± 2.89^{bc}
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	10.00 ± 5.57^{b}	11.67 ± 8.50^{bc}	1.67 ± 0.58^{c}
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	9.33 ± 3.79^{b}	6.33 ± 2.08^{bc}	4.67 ± 2.31^{c}
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	9.33 ± 6.43^{b}	5.33 ± 4.04^{bc}	6.00 ± 7.81^{bc}
T_8- HW at 15 and 30 DAS	72.67 ± 66.15^{a}	25.33 ± 22.50^{b}	40.67 ± 14.84^{a}
T_9- Weedy check	62.00 ± 5.57^{a}	50.00 ± 22.60^{a}	46.67 ± 16.86^{a}
SEm (±)	12.86	6.78	5.12
CD (0.05)	38.566	20.321	15.352

4.3.2 Weed dry weight

The data on the weed dry weight recorded at 15, 30 and 45 DAS are presented in the Table18.

The effect of weed management practices on weed dry weight was significant at all the growth stages.

At 15 DAS, T_2 resulted in lower dry weight (0.27 g m^{-2}) and was on par with all the treatments except T_8 and T_9. A significantly higher weed dry weight was observed in T_8 (23.83 g m^{-2}) followed by T_9 (21.67 g m^{-2}).

AT 30 DAS, T_2 resulted in lower weed dry weight (0.13 g m^{-2}) and was on par with all treatments except weedy check (46.50 g m^{-2}) where the highest weed dry weight was recorded.

At 45 DAS, T_2 resulted in lower weed dry weight (0.13 g m^{-2}) and was comparable with all treatments except weedy check where the highest weed dry weight (110.00 g m^{-2}) was recorded among the treatments.

4.3.3 Weed control efficiency

The effectiveness of weed management practice in reducing weed biomass was calculated by taking weed dry weight in untreated control plot.

The influence of weed management practices on weed control efficiency in blackgram at 15 DAS, 30 DAS and 45 DAS are presented in the Table19.

The analysis of data revealed that weed control efficiency was significantly modified by the weed management practices adopted.

Critical analysis of the data at 15 DAS showed higher weed control efficiency in T_2 (98.19%) and was comparable with T_1 (96.80%), T_6 (88.73%), T_5 (79.76%), and T_4 (78.53%).

At 30 DAS, significantly higher weed control efficiency of 99.72% was recorded in T_2 and was comparable with T_1 (99.50%), T_6 (97.55%) and T_7 (94.97%). This was followed by T_4 (89.35%) and T_8 (89.06%).

At 45 DAS, T_2 resulted in higher weed control efficiency (99.87%) and was comparable with T_5 (99.44%), T_1 (99.31%), T_6 (98.00%), T_7 (97.03), T_4 (96.01%) and was followed by T_3 (91.82%). Weed control efficiency was the least in weedy check (0%).

Table 18. Effect of weed management practices on weed dry weight in blackgram at 15, 30 and 45 DAS, g m^{-2}

Treatment	Weed dry weight		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	0.43 ± 0.49^b	0.20 ± 0.10^b	0.77 ± 0.59^b
T_2- T_1 *fb* HW at 30 DAS	0.27 ± 0.21^b	0.13 ± 0.06^b	0.13 ± 0.06^b
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	3.87 ± 2.76^b	6.67 ± 4.73^b	5.00 ± 1.73^b
T_4- T_3 *fb* HW at 40 DAS	3.83 ± 1.04^b	4.50 ± 1.32^b	4.00 ± 1.50^b
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	3.17 ± 1.76^b	7.17 ± 6.82^b	0.43 ± 0.50^b
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	2.00 ± 0.87^b	1.10 ± 0.78^b	2.03 ± 1.50^b
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	4.00 ± 1.32^b	2.50 ± 2.00^b	4.13 ± 6.39^b
T_8- HW at 15 and 30 DAS	23.83 ± 15.61^a	4.30 ± 2.34^b	15.67 ± 5.30^b
T_9- Weedy check	21.67 ± 15.88^a	46.50 ± 13.60^a	110.00 ± 31.66^a
SEm (±)	4.31	2.88	6.19
CD (0.05)	12.917	8.643	18.546

Table 19. Effect of weed management practices on weed control efficiency at 15, 30 and 45 DAS, per cent

Treatment	Weed control efficiency (%)		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	96.80 ± 4.45^{ab}	99.50 ± 0.35^{a}	99.31 ± 0.54^{a}
T_2- T_1 *fb* HW at 30 DAS	98.19 ± 2.05^{a}	99.72 ± 0.05^{a}	99.87 ± 0.09^{a}
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	76.05 ± 26.19^{bc}	86.41 ± 6.29^{c}	91.82 ± 7.95^{bc}
T_4- T_3 *fb* HW at 40 DAS	78.53 ± 7.83^{abc}	89.35 ± 5.06^{bc}	96.01 ± 2.04^{ab}
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	79.76 ± 18.67^{abc}	86.54 ± 10.37^{c}	99.44 ± 0.48^{a}
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	88.73 ± 6.97^{abc}	97.55 ± 1.91^{ab}	98.00 ± 1.84^{ab}
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	74.11 ± 18.70^{c}	94.97 ± 4.17^{abc}	97.03 ± 4.28^{ab}
T_8- HW at 15 and 30 DAS	23.08 ± 25.22^{d}	89.06 ± 4.63^{bc}	84.91 ± 7.48^{c}
T_9- Weedy check	--	--	--
SEm (±)	6.87	3.11	2.29
CD (0.05)	20.826	9.44	6.952

4.3.3 Relative Weed Density

The results on the effect of weed management practices on relative density of grasses, sedges and BLW are detailed in Tables 20, 21 and 22.

4.3.4.1 Relative Density of Grasses

The data on relative density of grasses revealed that it was significantly influenced by the weed management practices at 15, 30 and 45 DAS.

At 15 DAS, among the weed management practices T_1, T_5 and T_6 resulted in lower relative density of grasses (0 %) and was comparable with T_7 (16.67 %) and T_2 (33.33 %) T_3 (35.15 %). Higher relative density of grasses was noticed in weedy check (58.61%) and was on par with T_8 (45.16%) and T_4 (47.48%).

At 30 DAS, T_1 (0%), T_2 (0%), T_5 (0%), T_6 (0%) and T_7 (0%) resulted in lower relative density of grasses. However, higher relative density of grasses was noticed in weedy check (29.31%) and was on par with T_8 (28.50 %).

At 45 DAS, T_1, T_2, T_5, T_6 and T_7 resulted in lower relative density of grasses (0%) and was on par with T_4 (6.67 %). However, the highest relative density of grasses was recorded in weedy check (37.54 %).

4.3.4.2 Relative Density of Sedges

Examination of the data showed no significant impact of weed management practices on the relative density of sedges at 15 DAS, 30 DAS, and 45 DAS.

4.3.4.3 Relative Density of BLW

The data indicated no significance influence of weed management practices on relative density of BLW at 15 DAS and 45DAS.

At 30 DAS, T8 resulted in lower relative density of broad leaf weed and was comparable with T_9 (71.01 %), T_3 (73.61 %), T_4 (79.80 %) and T_7 (88.89 %). However, higher relative density of broad leaf weed was recorded in T_1 and T_2 (100 %) and was on par with T_5 (96.67 %).

Table 20. Effect of weed management practices on relative density of grasses, per cent

Treatment	Relative weed density of grasses (%)		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	0.00^{c}(0.17)	0.00^{b}(0.17)	0.00^{c}(0.17)
T_2- T_1 *fb* HW at 30 DAS	33.33 ± 57.74^{abc}(0.58)	0.00^{b}(0.17)	0.00^{c}(0.17)
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	35.15 ± 13.40^{abc}(0.63)	26.39 ± 22.95^{a}(0.51)	12.00 ± 10.42^{b}(0.35)
T_4- T_3 *fb* HW at 40 DAS	47.48 ± 26.95^{ab}(0.75)	20.20 ± 17.75^{a}(0.45)	6.67 ± 11.55^{bc}(0.27)
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	0.00^{c}(0.17)	0.00^{b}(0.17)	0.00^{c}(0.17)
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	0.00^{c}(0.17)	0.00^{b}(0.17)	0.00^{c}(0.17)
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	16.67 ± 28.87^{bc}(0.38)	0.00^{b}(0.17)	0.00^{c}(0.17)
T_8- HW at 15 and 30 DAS	45.16 ± 21.74^{ab}(0.73)	28.50 ± 17.48^{a}(0.55)	4.50 ± 7.80^{bc}(0.24)
T_9- Weedy check	58.61 ± 26.93^{a}(0.88)	29.31 ± 19.84^{a}(0.56)	37.54 ± 16.83^{a}(0.65)
SEm (±)	(0.16)	(0.09)	(0.05)
CD (0.05)	(0.491)	(0.273)	(0.159)

(The data were subjected to arcsine transformation and transformed values are given in parenthesis)

Table 21. Effect of weed management practices on relative density of sedges, per cent

Treatment	Relative weed density of sedges (%)		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	13.33 ± 23.09 (0.34)	0.00(0.17)	16.67 ± 28.87(0.38)
T_2- T_1 *fb* HW at 30 DAS	0.00(0.17)	0.00(0.17)	0.00(0.17)
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	5.00 ± 5.00 (0.24)	0.00(0.17)	3.23 ± 3.13(0.20)
T_4- T_3 *fb* HW at 40 DAS	6.67 ± 11.55(0.27)	0.00(0.17)	0.00(0.17)
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	8.33 ± 14.43(0.29)	3.33 ± 5.77(0.22)	16.67 ± 28.87(0.38)
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	13.33 ± 23.09(0.34)	0.00(0.17)	5.56 ± 9.62(0.25)
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	21.43 ± 25.75(0.45)	11.11± 19.24(0.32)	8.90 ± 15.40(0.29)
T_8- HW at 15 and 30 DAS	0.89 ± 1.55(0.17)	1.31 ±2.26(0.18)	21.45 ±23.18(0.44)
T_9- Weedy check	0.00(0.17)	0.76 ± 1.31(0.16)	0.00(0.170)
SEm (±)	(0.11)	(0.05)	(0.12)
CD (0.05)	NS	NS	NS

(The data were subjected to arcsine transformation and transformed values are given in parenthesis)

Table 22. Effect of weed management practices on relative density of BLW, per cent

Treatment	Relative density of BLW		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	80.00 ± 34.64 (1.16)	100.00^{a}(1.40)	83.33 ± 28.87(1.20)
T_2- T_1 *fb* HW at 30 DAS	66.67 ± 57.74 (0.99)	100.00 ^{a}(1.40)	100.00(1.40)
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	59.85 ± 8.79 (0.89)	73.61 ± 22.95^{bc} (1.06)	84.77 ± 7.84(1.18)
T_4- T_3 *fb* HW at 40 DAS	45.86 ± 35.26 (0.74)	79.80 ± 17.75^{abc}(1.13)	93.33 ± 11.55(1.30)
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	91.67 ± 14.43 (1.28)	96.67 ± 5.77^{ab}(1.35)	83.33 ± 28.87(1.20)
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	86.67 ± 23.09 (1.23)	100.00 ^{a}(1.40)	94.44 ± 9.62 (1.32)
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	61.90 ± 20.62 (0.92)	88.89 ±19.24^{abc}(1.25)	91.11 ± 15.40(1.28)
T_8- HW at 15 and 30 DAS	53.94 ± 20.46 (0.83)	70.19 ± 15.41^{c}(1.00)	79.89 ± 8.46 (1.11)
T_9- Weedy check	41.39 ± 26.93 (0.70)	71.01 ± 17.14^{c}(1.01)	63.41 ± 16.21 (0.93)
SEm (±)	(0.21)	(0.11)	(0.13)
CD (0.05)	NS	(0.322)	NS

(The data were subjected to arcsine transformation and transformed values are given in parenthesis)

4.3.4 Relative Weed Biomass

Results on the effect of weed management practices on relative biomass of grasses, sedges and BLW are detailed in Tables 23, 24 and 25.

4.3.4.1 Relative Weed Biomass of Grasses

The relative biomass data of grasses showed a significant influence of weed management practices at 30 and 45 DAS.

At 30 DAS, T_1, T_2, T_5, T_6 and T_7 resulted in lower relative biomass of grasses (0%) and was comparable with T_4 (28.48 %). A higher relative biomass of grasses was recorded in weedy check (42.40 %) and was on par with T_3 (41.11%) and T_8 (38.21 %).

At 45 DAS, $T_{1,}$ T_2, T_5, T_6, T_7 resulted in lower relative biomass of grasses (0%) and was comparable with T_4 (8.33 %) and T_8 (13.01 %). However, the highest relative biomass of grasses was recorded in weedy check (85.92 %).

4.3.4.2 Relative Weed Biomass of Sedges

Perusal of the data on relative weed biomass of sedges revealed no significant influence of weed management practices at 15 DAS, 30 DAS and 45 DAS.

4.3.4.3 Relative Weed Biomass of BLW

The data on relative biomass of BLW indicated no significance influence of weed management practices at 15 DAS.

However, the relative biomass of BLW was significantly influenced by weed management practices at 30 and 45 DAS.

At 30 DAS, T_8 (52.27%) recorded a lower relative weed biomass of BLW and was comparable with weedy check (57.21 %), T3 (60.28 %), T_4 (71.52 %) and T_7 (84.21%). However, T_1 and T_2 recorded a higher value of relative weed biomass of BLW (100 %).

At 45 DAS, the lowest weed biomass of BLW was recorded in weedy check (14.08 %) followed by T_8 (60.71%), T_3 (61.67 %), T_7 (81.16 %). Pre emergence of pendimethalin + imazethapyr 800 g ha^{-1} followed by hand weeding recorded higher relative biomass of BLW (100 %) which was comparable with T_4 (91.67 %), T_6 (86.67 %), T_1 (86.11 %) and T_5 (83.33 %).

Table 23. Effect of weed management practices on relative biomass of grasses, per cent

Treatment	Relative biomass of grasses (%)		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	0.00 ± 0.00(0.17)	0.00 ± 0.00^{b} (0.17)	0.00 ± 0.00^{c} (0.17)
T_2- T_1 *fb* HW at 30 DAS	33.33 ± 57.74(0.58)	0.00 ± 0.00^{b}(0.17)	0.00 ± 0.00^{c} (0.17)
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	32.46 ± 23.46(0.58)	41.11 ± 41.68^{a}(0.67)	30.56 ± 33.68^{b}(0.55)
T_4- T_3 *fb* HW at 40 DAS	37.62 ± 15.67(0.65)	28.48 ± 24.82^{ab}(0.53)	8.33 ± 14.43^{bc} (0.29)
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	22.22 ± 38.49(0.43)	0.00 ± 0.00^{b} (0.17)	0.00 ± 0.00^{c} (0.17)
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	0.00 ± 0.00(0.17)	0.00 ± 0.00^{b} (0.17)	0.00 ± 0.00^{c} (0.17)
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	16.67 ± 28.87 (0.38)	0.00 ± 0.00^{b} (0.17)	0.00 ± 0.00^{c} (0.17)
T_8- HW at 15 and 30 DAS	50.40 ± 25.60 (0.79)	38.21 ± 29.85^{a} (0.64)	13.01 ±22.53^{bc}(0.34)
T_9- Weedy check	59.42 ± 21.64 (0.89)	42.40 ± 31.88^{a}(0.70)	85.92 ± 14.50^{a} (1.21)
SEm (±)	(0.19)	(0.15)	(0.09)
CD (0.05)	NS	(0.435)	(0.278)

(The data were subjected to arcsine transformation and transformed values are given in parenthesis)

Table 24. Effect of weed management practices on relative biomass of sedges, per cent

Treatment	Relative biomass of sedges (%)		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	20.00 ± 34.64(0.41)	0.00 ± 0.00(0.17)	13.89 ± 24.06(0.35)
T_2- T_1 *fb* HW at 30 DAS	0.00 ± 0.00(0.17)	0.00 ± 0.00(0.17)	0.00 ± 0.00(0.17)
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	9.71 ± 8.73(0.32)	0.00 ± 0.00(0.17)	7.78 ± 8.39(0.28)
T_4- T_3 *fb* HW at 40 DAS	9.52 ± 16.50(0.30)	0.00 ± 0.00(0.17)	0.00 ± 0.00(0.17)
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	17.78 ± 20.37 (0.41)	2.78 ± 4.80 (0.21)	16.67 ± 28.87(0.38)
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	13.33 ± 23.09(0.34)	0.00 ± 0.00(0.17)	13.33 ± 23.09(0.34)
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	24.67 ± 22.97(0.49)	15.79 ± 27.35(0.37)	18.84 ± 32.63(0.40)
T_8- HW at 15 and 30 DAS	2.85 ± 4.93 (0.21)	9.52 ± 16.50(0.30)	26.28 ± 22.76(0.51)
T_9- Weedy check	0.00 ± 0.00(0.17)	0.39 ± 0.67(0.15)	0.00 ± 0.00 (0.17)
SEm (±)	(0.13)	(0.07)	(0.14)
CD (0.05)	NS	NS	NS

(The data were subjected to arcsine transformation and transformed values are given in parenthesis)

Table 25. Effect of weed management practices on relative biomass of BLW, per cent

Treatment	Relative weed biomass of BLW (%)		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	80.00 ± 3 4.64 (1.16)	100.00 ± 0.00^{a} (1.4)	86.11 ± 24.06^{ab} (1.22)
T_2- T_1 *fb* HW at 30 DAS	66.67 ± 57.74(0.99)	100.00 ± 0.00^{a} (1.4)	100.00 ± 0.00^{a} (1.40)
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	57.84 ± 20.25 (0.87)	60.28 ± 39.59^{bc} (0.92)	61.67 ± 30.59^{ab} (0.91)
T_4- T_3 *fb* HW at 40 DAS	52.86 ± 25.83 (0.82)	71.52 ± 24.82^{abc} (1.04)	91.67 ± 14.43^{ab} (1.28)
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	60.00 ± 40.00 (0.92)	97.22 ± 4.81^{ab} (1.36)	83.33 ± 28.87^{ab} (1.20)
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	86.67 ± 23.09 (1.23)	100.00 ± 0.00^{a} (1.40)	86.67 ± 23.09^{ab} (1.23)
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	58.66 ± 11.29 (0.88)	84.21 ± 27.35^{abc} (1.20)	81.16 ± 32.63^{ab} (1.17)
T_8- HW at 15 and 30 DAS	46.76 ± 26.00 (0.75)	52.27 ± 16.60^{c} (0.81)	60.71 ± 16.90^{b} (0.90)
T_9- Weedy check	40.58 ± 21.64 (0.68)	57.21 ± 31.47^{c} (0.86)	14.08 ± 14.50^{c} (0.36)
SEm (±)	(0.22)	(0.16)	(0.17)
CD (0.05)	NS	(0.463)	(0.497)

(The data were subjected to arcsine transformation and transformed values are given in parenthesis)

4.4 ENZYME ANALYSIS

4.4.1 Dehydrogenase Enzyme Activity

The influence of weed management practices on dehydrogenase enzyme activity in soil is presented in Table 26.

The critical analysis of data on dehydrogenase enzyme activity indicated that weed management practices significantly influenced the dehydrogenase enzyme activity at 15, 30 and 45 DAS.

At 15 DAS, T_4 resulted in the highest dehydrogenase enzyme activity (5.22 µg TPF g^{-1}soil d^{-1}), followed by T_3 (4.30 µg TPF g^{-1}soil d^{-1}), T_6 (4.16 µg TPF g^{-1}soil d^{-1}) and T_8 (4.07 µg TPF g^{-1}soil d^{-1}). A significantly lower dehydrogenase activity was recorded in T_1 (2.77 µg TPF g^{-1}soil d^{-1}) and T_5 (2.40 µg TPF g^{-1}soil d^{-1}).

At 30 DAS, T_7 resulted in a significantly higher dehydrogenase enzyme activity (9.24 µg TPF g^{-1}soil d^{-1}) and was on par with T_6 (8.93 µg TPF g^{-1}soil d^{-1}). This was followed by T_5 (7.78 µg TPF g^{-1}soil d^{-1}), T_8 (7.31 µg TPF g^{-1}soil d^{-1}) and T_4 (7.26 µg TPF g^{-1}soil d^{-1}). However, the lowest was recorded in T_1 (3.50 µg TPF g^{-1}soil d^{-1}) and was followed by T_2 (5.02 µg TPF g^{-1}soil d^{-1}) and T_3 (5.80 µg TPF g^{-1}soil d^{-1}).

At 45 DAS, T_4 resulted in higher dehydrogenase enzyme activity (16.05µg TPF g^{-1}soil d^{-1}) which was comparable with T_5 (15.99 µg TPF g^{-1}soil d^{-1}), T_3 (15.82 µg TPF g^{-1}soil d^{-1}), and followed by T_6 (15.27 µg TPF g^{-1}soil d^{-1}), T_1 (15.20 µg TPF g^{-1}soil d^{-1}) and T_2 (14.11 µg TPF g^{-1}soil d^{-1}). However, a lower activity was recorded in weedy check (8.94 µg TPF g^{-1}soil d^{-1}) which was comparable with T_8 (9.35µg TPF g^{-1}soil d^{-1}) and T_7 (10.08 µg TPF g^{-1}soil d^{-1}).

Table 26. Effect of weed management practices on dehydrogenase enzyme activity at 15, 30 and 45 DAS

Treatment	Dehydrogenase enzyme activity (µg triphenyl formazan (TPF) g^{-1} soil day^{-1})		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	2.77 ± 0.20^{d}	3.50 ± 0.14^{g}	15.20 ± 0.34^{b}
T_2- T_1 *fb* HW at 30 DAS	3.41 ± 0.35^{c}	5.02 ± 0.07^{f}	14.11 ± 0.69^{c}
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	4.30 ± 0.12^{b}	5.80 ± 0.11^{e}	15.82 ± 0.33^{a}
T_4- T_3 *fb* HW at 40 DAS	5.22 ± 0.20^{a}	7.26 ± 0.23^{d}	16.05 ± 0.18^{a}
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	2.40 ± 0.34^{e}	7.78 ± 0.20^{c}	15.99 ± 0.21^{a}
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	4.16 ± 0.21^{b}	8.93 ± 0.11^{a}	15.27 ± 0.65^{b}
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	2.47 ± 0.16^{de}	9.24 ± 0.23^{a}	10.08 ± 0.46^{d}
T_8- HW at 15 and 30 DAS	4.07 ± 0.05^{b}	7.31 ± 0.33^{d}	9.35 ± 0.32^{e}
T_9- Weedy check	3.48 ± 0.16^{c}	8.21 ± 0.34^{b}	8.94 ± 0.06^{e}
SEm (±)	0.12	0.13	0.17
CD (0.05)	0.370	0.386	0.510

4.5 PLANT ANALYSIS

4.5.1 NPK content of crop

The effect of weed management practices on NPK content of haulm and seed of blackgram is presented in Table 27.

4.5.1.1 Nitrogen content

The results revealed that the weed management practices have significant effect on the nitrogen content of seeds of the crop. However, the nitrogen content of haulm was found unaffected. Among the treatments tested, T_2, T_7 recorded a higher seed N content (4.72 %) which was followed by T_1 (4.48 %), T_3 (4.26 %) and T_6 (4.09 %). Weedy check resulted in lower seed N content (2.99 %) which was on par with T_8 (3.08 %).

4.5.1.2 Phosphorus content

Examination of the data revealed that weed management practices significantly affected the phosphorus content of the seeds of blackgram. Amongst the practices, T_2 resulted in the highest seed phosphorus content (0.59 %) which was followed by T_4 (0.49 %) and T_1 (0.48 %). T_5 resulted in lower phosphorus content of seed (0.40 %), which was comparable to T_6 (0.40 %), T_9 (0.41 %), T_8 (0.42 %), and T_7 (0.42 %).

4.5.1.3 Potassium content

The results indicated that weed management practices significantly influenced the potassium content of blackgram seed. Amongst the treatments tested, T_3 resulted in higher potassium content (1.15 %), which was comparable to T_2 (1.10 %). Hand weeding twice resulted in lower total potassium content (0.75 %), which was on a par with T_5 (0.79%), T_9 (0.79 %), T_4 (0.80 %) and T_6 (0.81 %).

Table 27. Effect of weed management practices on NPK content of blackgram, per cent

Treatment	Haulm (%)			Seed (%)		
	N	P	K	N	P	K
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	2.63	0.35	0.78	4.48 ± 0.06^{b}	0.48 ± 0.02^{b}	1.07 ± 0.04^{b}
T_2- T_1 *fb* HW at 30 DAS	2.72	0.32	0.85	4.72 ± 0.12^{a}	0.59 ± 0.03^{a}	1.10 ± 0.04^{ab}
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	2.93	0.37	0.88	4.26 ± 0.11^{bc}	0.39 ± 0.04^{c}	1.15 ± 0.03^{a}
T_4- T_3 *fb* HW at 40 DAS	2.44	0.34	0.75	3.60 ± 0.20^{d}	0.49 ± 0.02^{b}	0.80 ± 0.07^{cd}
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	2.66	0.32	0.78	3.58 ± 0.15^{d}	0.40 ± 0.02^{c}	0.79 ± 0.01^{cd}
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	2.65	0.29	0.79	4.09 ± 0.10^{c}	0.40 ± 0.03^{c}	0.81± 0.03^{cd}
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	2.55	0.32	0.78	4.72 ± 0.17^{a}	0.42 ± 0.03^{c}	0.83 ± 0.06^{c}
T_8- HW at 15 and 30 DAS	2.87	0.36	0.93	3.08 ± 0.20^{e}	0.42 ± 0.04^{c}	0.75 ± 0.03^{d}
T_9- Weedy check	3.01	0.26	0.73	2.99 ± 0.09^{e}	0.41± 0.02^{c}	0.79 ± 0.01^{cd}
SEm (±)	0.25	0.02	0.05	0.08	0.02	0.02
CD (0.05)	NS	NS	NS	0.235	0.047	0.067

4.5.2 Nutrient uptake by crop

The results on the influence of weed management practices on the NPK uptake by crop are presented in Table 28.

4.5.2.1 N uptake

The impact of weed management practices on nitrogen uptake by the crop was found to be significant. Amongst the weed management practices, T_7 showed the highest N uptake at 402.92 kg ha^{-1}, followed by T_6 (351.58 kg ha^{-1}), T_2 (331.48 kg ha^{-1}), and T_1 (331.38 kg ha^{-1}). The weedy check resulted in lower N uptake of 199.26 kg ha^{-1}, which was comparable to T_8 (219.88 kg ha^{-1}).

4.5.2.2 P uptake

The weed management practices had significantly influenced the P uptake by the crop. A significantly higher P uptake of 42.97 kg ha^{-1} was recorded in T_4 and was comparable withT_7 (38.60 kg ha^{-1}) and T_2 (38.22 kg ha^{-1}). The lowest P uptake of 21.18 kg ha^{-1}was recorded under weedy check and was followed by T_8 (27.67 kg ha^{-1}), T_3 (32.03 kg ha^{-1}).

4.5.2.3 K uptake

The effect of weed management practice on K uptake of blackgram was found to be significant. A significantly higher K uptake of 169.63 kg ha^{-1} was recorded in T_3 (post-emergence propaquizafop+ imazethapyr 125 g ha^{-1}) and was on par with T_7 (169.33 kg ha^{-1}), T_2 (164.92 kg ha^{-1}), T_1 (164.02 kg ha^{-1}), T_4 (161.06 kg ha^{-1}), and T_6 (159.15 kg ha^{-1}). The treatment weedy check resulted in the lowest K uptake by the crop (95.79 kg ha^{-1}) and was followed by T_8 (118.77 kg ha^{-1}).

Table 28. Effect of weed management practices on NPK uptake by crop, kg ha^{-1}

Treatment	NPK uptake by crop		
	N	P	K
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	331.38 ± 16.47^{b}	36.70 ± 2.14^{bc}	164.02 ± 10.25^{ab}
T_2- T_1 *fb* HW at 30 DAS	331.48 ± 19.17^{b}	38.22 ± 1.49^{ab}	164.92 ± 2.06^{ab}
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	316.37 ± 31.36^{b}	32.03 ± 4.69^{cd}	169.63 ± 9.73^{a}
T_4- T_3 *fb* HW at 40 DAS	328.54 ± 21.34^{b}	42.97 ± 1.00^{a}	161.06 ± 11.25^{ab}
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	315.35 ± 14.97^{b}	34.98 ± 2.05^{bc}	150.16 ± 9.90^{b}
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	351.58 ± 27.70^{b}	34.41 ± 2.03^{bc}	159.15 ± 10.32^{ab}
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	402.92 ± 40.04^{a}	38.60 ± 1.69^{ab}	169.33 ± 7.46^{a}
T_8- HW at 15 and 30 DAS	219.88 ± 17.70^{c}	27.67 ± 2.4^{d}	118.77 ± 14.11^{c}
T_9- Weedy check	199.26 ± 19.23^{c}	21.18 ± 4.10^{e}	95.79 ± 4.58^{d}
SEm (±)	14.21	1.62	5.74
CD (0.05)	42.596	4.862	17.206

4.5.3 Nutrient content of weeds

4.5.3.1. Nitrogen content weed at 15, 30 and 45 DAS

The results on the effect of weed management practices on the nitrogen content of weeds at 15, 30 and 45 DAS are presented in the Table 29.

The results revealed that weed management practices have a significant effect on nitrogen content of weeds at all the stages of observation.

At 15 DAS, hand weeding at 15 and 30 DAS resulted in lower nitrogen content of weeds (2.20 %) and was on par with T_1 (2.28%). However, post-emergence propaquizafop + imazethapyr 125 g ha^{-1} followed by hand weeding at 40 DAS resulted in higher nitrogen content of weed (3.53%) and was on par with T_7 (3.51%).

At 30 DAS, T_1 resulted in the lowest nitrogen content of weeds (2.22 %) and was followed by T_2 (2.60 %). The treatment T_3 (3.86%) had the highest N content at 30 DAS and was followed by T_4 (3.12%) and T_7 (3.03 %).

At 45 DAS, among the weed management practices, T_1 resulted in a significantly lower nitrogen content of weed (1.98) and was on par with T_3 (2.00 %), T_2 (2.07 %) and T_9 (2.09 %). However, a significantly higher weed N content was recorded in T_6 (2.95%) and was on par with T_5 (2.84 %) and T_8 (2.80 %).

4.5.3.2. Phosphorus content of weed at 15, 30 and 45 DAS

The results on the effect of weed management practices on the phosphorus content of weed at 15, 30 and 45 DAS are presented in the Table 30.

The results showed significant variation with respect to the phosphorus content of weeds at all stages of observation. At 15 DAS, the treatments T_1 and T_7 resulted in lower phosphorus content of the weed (0.16) and was on a par with T_5 (0.18). However, the highest P content of weed was recorded in T_4 (0.36 %) and was followed by T_6 (0.27 %), T_3 (0.25%) and T_2 (0.23%).

At 30 DAS, T_1 resulted in significantly lower P content (0.15%) and was on par with T_2 (0.16%) and T_5 (0.19%). However, a significantly higher P content was recorded in T_3 (0.29%) and was comparable with T_4 (0.27 %,) T_8 (0.26 %) and T_7 (0.25 %).

Amongst the weed management practices, T_3 and T_4 resulted in lower P content (0.20%) at 45 DAS and was comparable with T_8 (0.22%) and T_7 (0.24%). However, a significantly higher P content of weeds was recorded in T_1 (0.30%) and was on par with T_2 (0.29%), T_6 (0.25%) and T_9 (0.25%).

4.5.3.3. Potassium content of weed at 15, 30 and 45 DAS

The results on the effect of weed management practices on the potassium content of weeds at 15, 30 and 45 DAS are presented in Table 31.

The results showed that the weed management practices had a notable influence on the potassium content of the weeds at all stages of observation.

At 15 DAS, among the weed management practices, T_1 resulted in the lowest K content of weeds (0.51%) which was followed by T_2 (0.56%) and T_9 (0.59%). The treatment T_5 resulted in the highest K content of weeds (1.01%) and was followed by T_3 (0.86%), T_7 (0.80%) and T_4 (0.80%).

At 30 DAS, among weed management practices T_6 resulted in lower K content (0.55 %) and was on par with T_8 (0.56 %), T_1 (0.57 %), T_2 (0.58 %). The treatment T_5 resulted in the highest K content of weed at 30 DAS (1.10%) followed by T_7 and T_9 (0.92%).

Among the weed management practices T_2 (0.60%) resulted in lower K content of weeds at 45 DAS which was comparable with T_1 (0.62%), T_4 (0.62%) weedy check (0.63%) and T_3 (0.65%). However, a significantly highest K content of weeds was recorded in T_5 (0.93%) followed by T_8 (0.80%), T_7 (0.78%), and T_6 (0.71%).

4.5.4. **Nutrient removal by weeds**

The influence of weeds management practices on nutrient removal by weeds are presented in Table 32, 33, and 34

The results revealed that the weed management practices have a significant effect on the nutrient removal by weeds at 15, 30 and 45 DAS.

Table 29. Effect of weed management practices on nitrogen content of weeds at 15, 30 and 45 DAS, per cent

Treatment	Nitrogen content of weed		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	2.28 ± 0.09^{f}	2.22 ± 0.12^{f}	1.98 ± 0.17^{d}
T_2- T_1 *fb* HW at 30 DAS	3.30 ± 0.15^{c}	2.60 ± 0.09^{e}	2.07 ± 0.15^{cd}
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	2.84 ± 0.09^{d}	3.86 ± 0.31^{a}	2.00 ± 0.14^{d}
T_4- T_3 *fb* HW at 40 DAS	3.53 ± 0.11^{a}	3.12 ± 0.12^{b}	2.48 ± 0.09^{b}
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	3.40 ± 0.09^{bc}	2.84 ± 0.09^{d}	2.84 ± 0.09^{a}
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	2.84 ± 0.09^{d}	2.76 ± 0.09d^{e}	2.95 ± 0.08^{a}
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	3.51 ± 0.08^{ab}	3.03 ± 0.15b^{c}	2.26 ± 0.09^{c}
T_8- HW at 15 and 30 DAS	2.20 ± 0.09^{f}	2.89 ± 0.17^{cd}	2.80 ± 2.66^{a}
T_9- Weedy check	2.43 ± 0.11^{e}	2.93 ± 0.23^{cd}	2.09 ± 0.12^{cd}
SEm (±)	0.04	0.06	0.07
CD (0.05)	0.129	0.168	0.197

Table 30. Effect of weed management practices on phosphorus content of weeds at 15, 30 and 45 DAS, per cent

Treatment	Phosphorus content of weed		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	0.16 ± 0.05^{d}	0.15 ± 0.02^{c}	0.30 ± 0.07^{a}
T_2- T_1 *fb* HW at 30 DAS	0.23 ± 0.02^{bcd}	0.16 ± 0.02^{c}	0.29 ± 0.01^{ab}
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	0.25 ± 0.03^{bc}	0.29 ± 0.04^{a}	0.20 ± 0.01^{c}
T_4- T_3 *fb* HW at 40 DAS	0.36 ± 0.07^{a}	0.27 ± 0.11^{a}	0.20 ± 0.02^{c}
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	0.18 ± 0.04^{bcd}	0.19 ± 0.02^{bc}	0.24 ± 0.05^{bc}
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	0.27 ± 0.10^{b}	0.23 ± 0.03^{ab}	0.25 ± 0.01^{abc}
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	0.16 ± 0.03^{d}	0.25 ± 0.04^{ab}	0.24 ± 0.03^{bc}
T_8- HW at 15 and 30 DAS	0.21 ± 0.02^{bcd}	0.26 ± 0.03^{ab}	0.22 ± 0.02^{c}
T_9- Weedy check	0.18 ± 0.02^{cd}	0.28 ± 0.01^{a}	0.25 ± 0.04^{abc}
SEm (±)	0.03	0.03	0.02
CD (0.05)	0.092	0.075	0.057

Table 31. Effect of weed management practices on potassium content of weeds at 15, 30 and 45 DAS, per cent

Treatment	Potassium content of weed		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	0.51 ± 0.03[f]	0.57 ± 0.04[c]	0.62 ± 0.06[cd]
T_2- T_1 *fb* HW at 30 DAS	0.56 ± 0.02[e]	0.58 ± 0.02[c]	0.60 ± 0.03[d]
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	0.86 ± 0.04[b]	0.62 ± 0.04[c]	0.65 ± 0.04[cd]
T_4- T_3 *fb* HW at 40 DAS	0.80 ± 0.04[c]	0.91 ± 0.04[b]	0.62 ± 0.06[cd]
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	1.01 ± 0.02[a]	1.10 ± 0.19[a]	0.93 ± 0.05[a]
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	0.61 ± 0.02[d]	0.55 ± 0.09[c]	0.71 ± 0.13[bc]
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	0.80±0.02[c]	0.92±0.03[b]	0.78 ± 0.03[b]
T_8- HW at 15 and 30 DAS	0.62 ± 0.03[d]	0.56 ± 0.06[c]	0.80 ± 0.02[b]
T_9- Weedy check	0.59 ± 0.01[de]	0.92 ± 0.05[b]	0.63 ± 0.04[cd]
SEm (±)	0.01	0.05	0.03
CD (0.05)	0.043	0.136	0.090

4.5.4.1 Nitrogen removal by weeds

The influence of weeds management practices on N removal by weeds at 15 DAS, 30 DAS and 45 DAS are presented in Table 32.

At 15 DAS, a significantly lower nitrogen removal was recorded in T_2 (0.08 kg ha^{-1}) and was on par with T_1 (0.10 kg ha^{-1}), T_6 (0.56 kg ha^{-1}), T_5 (1.07 kg ha^{-1}), T_3 (1.08 kg ha^{-1}) and T_7 (1.40 kg ha^{-1}). However, a higher value of nitrogen removal by weeds was recorded in weedy check (5.30 kg ha^{-1}) which was comparable with T_8 (5.21 kg ha^{-1}).

At 30 DAS, T_1 and T_2 resulted in significantly lower nitrogen removal by weed (0.04 kg ha^{-1}) and was on par with T_6 (0.30 kg ha^{-1}), T_7 (0.74 kg ha^{-1}), T_4 (1.41 kg ha^{-1}), T_8 (1.42 kg ha^{-1}), T_5 (1.99 kg ha^{-1}). However, weedy check recorded the highest removal of nitrogen (13.44 kg ha^{-1}).

At 45 DAS, T_2 recorded significantly lower N removal by weed (0.03 kg ha^{-1}) and was comparable with T_1, T_5 (0.15 kg ha^{-1}), T_6 (0.60 kg ha^{-1}), T_7 (0.90 kg ha^{-1}), T_4 (1.00 kg ha^{-1}), T_3 (1.54 kg ha^{-1}) and T_8 (4.38 kg ha^{-11}). Weedy check resulted in the highest removal of nitrogen by weeds (23.10 kg ha^{-1}).

4.5.4.2 Phosphorus removal by weeds

The influence of weed management practices on P removal by weeds at 15, 30, and 45 DAS are presented in Table 33.

At 15 DAS, T_2 resulted in significantly lower removal of P by weeds (0.003 kg ha^{-1}) and was comparable with T_1 (0.007 kg ha^{-1}), T_5 (0.063 kg ha^{-1}), T_6 (0.057), T_7 (0.067), T_3 (0.103 kg ha^{-1}) and T_4 (0.137 kg ha^{-1}). However, a higher removal of P by weeds was recorded in T_8 (0.480 kg ha^{-1}) and was comparable with weedy check.

At 30 DAS, both T_1 and T_2 resulted in lower P removal by weed (0.001 kg ha^{-1}) and was comparable with T_6 (0.023 kg ha^{-1}), T_7 (0.063 kg ha^{-1}), T_4 (0.130 kg ha^{-1}) T_8 (0.127 kg ha^{-1}), T_5 (0.143 kg ha^{-1}) and T_3 (0.187 kg ha^{-1}). However, weedy check recorded the highest P removal of 1.307 kg ha^{-1}.

At 45 DAS, all the weed management practices resulted in a significantly lower P removal by weed and were comparable with each other except T_9. The highest P removal by weeds was recorded in weedy check (2.85 kg ha^{-1}).

Table 32. Effect of weed management practices on N removal by weeds at 15, 30 and 45 DAS, kg ha^{-1}

Treatment	N removal by weeds		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	0.10 ± 0.11^b	0.04 ± 0.03^c	0.15 ± 0.12^b
T_2- T_1 *fb* HW at 30 DAS	0.08 ± 0.07^b	0.04 ± 0.01^c	0.03 ± 0.01^b
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	1.08 ± 0.75^b	2.51 ± 1.62^b	1.54 ± 1.10^b
T_4- T_3 *fb* HW at 40 DAS	1.35 ± 0.38^b	1.41 ± 0.43^{bc}	1.00 ± 0.38^b
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	1.07 ± 0.57^b	1.99 ± 1.86^{bc}	0.15 ± 0.12^b
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	0.56 ± 0.24^b	0.30 ± 0.22^c	0.60 ± 0.46^b
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	1.40 ± 0.43^b	0.74 ± 0.59^{bc}	0.90 ± 1.39^b
T_8- HW at 15 and 30 DAS	5.21 ± 3.37^a	1.42 ± 0.54^{bc}	4.38 ± 1.45^b
T_9- Weedy check	5.30 ± 3.96^a	13.44 ± 3.03^a	23.10 ± 7.23^a
SEm (±)	1.01	0.70	1.46
CD (0.05)	3.041	2.088	4.377

Table 33. Effect of weed management practices on P removal by weeds at 15, 30 and 45 DAS, kg ha^{-1}

Treatment	P removal by weeds		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	0.007 ± 0.012^b	0.001^b	0.023 ± 0.021^b
T_2- T_1 *fb* HW at 30 DAS	0.003 ± 0.006^b	0.001^b	0.003 ± 0.006^b
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	0.103 ± 0.085^b	0.187 ± 0.112^b	0.167 ± 0.129^b
T_4- T_3 *fb* HW at 40 DAS	0.137 ± 0.032^b	0.130 ± 0.070^b	0.083 ± 0.035^b
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	0.063 ± 0.040^b	0.143 ± 0.131^b	0.013 ± 0.015^b
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	0.057 ± 0.040^b	0.023 ± 0.021^b	0.050 ± 0.040^b
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	0.067 ± 0.038^b	0.063 ± 0.047^b	0.107 ± 0.168^b
T_8- HW at 15 and 30 DAS	0.480 ± 0.282^a	0.127 ± 0.057^b	0.350 ± 0.140^b
T_9- Weedy check	0.397 ± 0.315^a	1.307 ± 0.345^a	2.850 ± 1.227^a
SEm (±)	0.08	0.07	0.24
CD (0.05)	0.249	0.218	0.718

4.5.4.3 K removal by weeds

The influence of weed management practices on K removal by weeds at 15 30, and 45 DAS are presented in Table 34.

Results showed that K removal by weeds was significantly influenced by the weed management practices.

At 15 DAS, both the treatments T_1 and T_2 resulted in lower K removal by weeds (0.02 kg ha^{-1}) and was comparable with T_6 (0.12 kg ha^{-1}), T_4 (0.31 kg ha^{-1}), T_5 (0.31 kg ha^{-1}), T_3 (0.32 kg ha^{-1}), T_7 (0.32 kg ha^{-1}). However, a higher K removal by weeds was observed in T_8 (1.46 kg ha^{-1}) which was comparable with weedy check.

At 30 DAS, treatments T_1 and T_2 resulted in lower K removal by weeds (0.01 kgha^{-1}) and was comparable with T_6 (0.06 kg ha^{-1}), T_7 (0.23 kg ha^{-1}), T_8 (0.28 kg ha^{-1}), T_3 (0.41kg ha^{-1}), T_4 (0.41 kg ha^{-1}). However, the highest K uptake by weeds was observed in weedy check (4.22 kg ha^{-1})

At 45 DAS, T_2 resulted in lower K removal by weeds (0.01 kg ha^{-1}) which was on par with T_1 (0.05 kg ha^{-1}), T_5 (0.05 kg ha^{-1}), T_6 (0.13 kg ha^{-1}), T_4 (0.25 kg ha^{-1}), T_7 (0.32 kg ha^{-1}) and T_3 (0.50 kg ha^{-1}). However, the highest K uptake by weeds was observed in weedy check (6.90 kg ha^{-1}).

Table 34. Effect of weed management practices on K removal by weeds at 15, 30 and 45 DAS, kg ha^{-1}

Treatment	K removal by weeds		
	15 DAS	30 DAS	45 DAS
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	0.02 ± 0.03^{b}	0.01 ± 0.00^{c}	0.05 ± 0.03^{c}
T_2- T_1 *fb* HW at 30 DAS	0.02 ± 0.01^{b}	0.01 ± 0.00^{c}	0.01 ± 0.00^{c}
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	0.32 ± 0.24^{b}	0.41 ± 0.28^{bc}	0.50 ± 0.36^{bc}
T_4- T_3 *fb* HW at 40 DAS	0.31 ± 0.08^{b}	0.41 ± 0.13^{bc}	0.25 ± 0.12^{bc}
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	0.31 ± 0.20^{b}	0.72 ± 0.65^{b}	0.05 ± 0.04^{c}
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	0.12 ± 0.06^{b}	0.06 ± 0.04^{bc}	0.13 ± 0.08^{bc}
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	0.32 ± 0.10^{b}	0.23 ± 0.18^{bc}	0.32 ± 0.50^{bc}
T_8- HW at 15 and 30 DAS	1.46 ± 0.91^{a}	0.28 ± 0.12^{bc}	1.25 ± 0.43^{b}
T_9- Weedy check	1.30 ± 0.97^{a}	4.22 ± 1.04^{a}	6.90 ± 1.94^{a}
SEm (±)	0.26	0.23	0.40
CD (0.05)	0.776	0.675	1.196

4.6 SOIL ANALYSIS

The effect of weed management practices on pH, electrical conductivity (EC), and organic carbon (OC) status of the soil after the experiment are presented in Table 35.

4.6.1 Soil pH

The results indicated that the effect of weed management practices on soil pH was not significant. However, an increase in pH value was observed compared to the initial level.

4.6.2 Electrical Conductivity

The results revealed that weed management practices have significant effect on the EC of soil.

A significantly lower EC was recorded in T_7 (0.117 d S m^{-1}) and it was comparable with T_4 (0.121 d S m^{-1}), T_2 (0.124 d S m^{-1}), T_3 (0.128 d S m^{-1}), T_6 (0.128 d S m^{-1}), and T_8 (0.129 d S m^{-1}). However, a significantly higher value of EC was recorded in T_1 (1.143 d S m^{-1}) which was on par with T_5 (0.133 d S m^{-1}) and T_9 (0.13 d S m^{-1}).

4.6.3 Organic Carbon

A significant variation was observed in organic carbon content of post experiment soil with respect to weed management. Pre-emergence pendimethalin 1kg ha^{-1} followed by imazethapyr 50g ha^{-1} resulted in the highest organic carbon content (1.04 %) and was followed by T_5 (0.99 %), T_9 (0.94 %), T_2 (0.92 %), T_1 (0.91 %) and T_8 (0.90 %). A lower organic carbon content was recorded in T_7 (0.87 %) and was comparable with T_3 (0.90 %) and T_4 (0.90 %).

Table 35. Effect of weed management practices on pH, EC and OC of soil after the experiment

Treatment	pH	EC ($dS\ m^{-1}$)	Organic carbon (%)
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	6.03 ± 0.02	0.143 ± 0.003^{a}	0.91 ± 0.006^{cd}
T_2- T_1 *fb* HW at 30 DAS	6.02 ± 0.07	0.124 ± 0.009^{bc}	0.92 ± 0.012^{cd}
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	6.05 ± 0.05	0.128 ± 0.014^{bc}	0.90 ± 0.013^{de}
T_4- T_3 *fb* HW at 40 DAS	6.00 ± 0.01	0.121 ± 0.012^{bc}	0.90 ± 0.012^{de}
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	5.98 ± 0.01	0.133 ± 0.002^{ab}	0.99 ± 0.006^{b}
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	5.99 ± 0.02	0.128 ± 0.010^{bc}	1.04 ± 0.046^{a}
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	6.03 ± 0.01	0.117 ± 0.006^{c}	0.87 ± 0.010^{e}
T_8- HW at 15 and 30 DAS	5.97 ± 0.02	0.129 ± 0.003^{bc}	0.90 ± 0.010^{de}
T_9- Weedy check	6.03 ± 0.02	0.131 ± 0.006^{ab}	0.94 ± 0.046^{c}
SEm (±)	0.018	0.004	0.014
CD (0.05)	NS	0.013	0.043

4.6.4 Available Nitrogen

The results on the effect of weed management practices on the soil available nitrogen status of the post-harvest soil are presented in the Table 36.

Perusal of the data revealed that there is a significant variation in the available nitrogen status of soil due to the weed management practices. The highest available nitrogen was recorded in T_7 (282.90 kg ha^{-1}) followed by T_6 (249.13 kg ha^{-1}), T_1 (236.23 kg ha^{-1}), T_2 (233.73 kg ha^{-1}) and T_4 (233.73 kg ha^{-1}). The lowest value of available soil nitrogen was recorded in unweeded control (140.13 kg ha^{-1}) which was followed by hand weeding twice (157.10 kg ha^{-1}).

4.6.5 Available Phosphorus

The results on the effect of weed management practices on available phosphorus status in postharvest soil are presented in the Table 36.

The data revealed a significant variation in the available phosphorus status across the different weed management practices adopted. The highest value of available P was recorded in T_4 (52.10 kg ha^{-1}) followed by T_7 (47.67 kg ha^{-1}), T_2 (47.13 kg ha^{-1}), T_1 (45.80 kg ha^{-1}), T_6 (44.03 kg ha^{-1}) and T_5 (43.23 kg ha^{-1}). The lowest available phosphorus in post experiment soil was recorded in weedy check (28.05 kg ha^{-1}) followed by T_8 (35.07 kg ha^{-1}) and T_3 (40.24 kg ha^{-1}).

4.6.6 Available Potassium

The results on the effect of weed management practices on available potassium status in postharvest soil are presented in the Table 36.

The data indicated a significant variation in the available potassium status among the weed management practices employed. A higher value of soil available potassium was recorded in T_7 (219.33 kg ha^{-1}) and was on par with T_3 (218.60 kg ha^{-1}). The lowest value of available soil potassium was recorded in T_8 (114.10 kg ha^{-1}) followed by T_9 (124.13kg ha^{-1}) and T_5 (195.76 kg ha^{-1}).

Table 36. Effect of weed management practices on post-harvest nutrient status of soil, kg ha^{-1}

Treatment	Post-harvest soil nutrient status		
	Available N	Available P	Available K
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	236.23 ± 0.86^{c}	45.80 ± 0.53^{c}	212.20 ± 1.11^{b}
T_2- T_1 *fb* HW at 30 DAS	233.73 ± 0.46^{cd}	47.13 ± 0.32^{b}	213.06 ± 1.88^{b}
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	224.07 ± 1.10^{e}	40.24 ± 0.24^{e}	218.60 ± 0.81^{a}
T_4- T_3 *fb* HW at 40 DAS	233.17 ± 1.04^{d}	52.10 ± 0.60^{a}	209.67 ± 0.40^{c}
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	224.10 ± 1.15^{e}	43.23 ± 0.87^{d}	195.77 ± 0.80^{e}
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	249.13 ± 1.20^{b}	44.03 ± 0.95^{d}	203.93 ± 1.90^{d}
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	282.90 ± 3.95^{a}	47.67 ± 0.46^{b}	219.33 ± 0.83^{a}
T_8- HW at 15 and 30 DAS	157.10 ± 1.10^{f}	35.07 ± 1.00^{f}	114.10 ± 0.85^{g}
T_9- Weedy check	140.13 ± 2.01^{g}	28.05 ± 0.61^{g}	124.13 ± 0.80^{f}
SEm (±)	0.92	0.34	0.51
CD (0.05)	2.76	1.009	1.527

4.8. MICROBIAL POPULATION IN SOIL

Effect of weed management practices on population of beneficial rhizospheric soil microorganisms including bacteria, fungi and actinomycetes are presented in the Table 37- 38.

4.8.1. Population of *Rhizobium*

The effect of weed management practices on the *Rhizobium* population in rhizospheric soil is presented in Table 37. The population of *Rhizobium* population did not vary significantly either before herbicide application or 15 days after herbicide application and the population remained relatively stable across the treatments.

However, at 30 days after herbicide application, the effect of herbicide application on the rhizobium population was found to be significant. At this stage, the population of *Rhizobium* was higher in T_2 (7.48 log_{10} CFU g^{-1}) and was on par with T_1 (7.45 log_{10} CFU g^{-1}). A significantly lower population of *Rhizobium* was observed in T_4 (6.24 log_{10} CFU g^{-1}), T_5 (6.24 log_{10} CFU g^{-1}) that was on par with T_8 (6.48 log_{10} CFU g^{-1}).

4.8.2 Population of PSB

The effect of weed management practices on the population of phosphorus solubilising bacteria are presented in the Table 37.

Across all time points (before, 15, and 30 days after herbicide application), no significant differences were noted in the population of phosphorus solubilising bacteria and it remained consistent at approximately 3.0–3.2 log_{10} CFU g^{-1} soil across the treatments. The herbicide application had no significant effect on PSB population throughout the observation period.

4.8.3 Population of N-fixers

The impact of weed management practices on the population of nitrogen-fixing bacteria is detailed in Table 37.

Analysis of the data on the effect of herbicide application on the population of nitrogen fixers in soil, measured before, 15 days, and 30 days after herbicide application, showed a significant influence of weed management practices on the nitrogen fixer population before and 30 days after herbicide application.

At 30 days after herbicide application, T_3 resulted in higher population of nitrogen fixers (4.68 log_{10} CFU g^{-1}) and was on par with T_9 (4.67 log_{10} CFU g^{-1}), T_7 (4.49 log_{10} CFU g^{-1}), T_4 (4.48 log_{10} CFU g^{-1}) and T_1 (4.24 log_{10} CFU g^{-1}). However, a significantly lower population was recorded in T_5 (3.10 log_{10} CFU g^{-1}) that was on par with T_2 (3.52 log_{10} CFU g^{-1}).

4.8.4 Population of fungi

The effect of weed management practices on population of fungi in rhizospheric soil is presented in Table 38.

The data on fungal population in soil with respect to weed management practices revealed that fungal population varied significantly initially and at 30 DAS. However, their population showed no significant difference at 15 DAS.

At 30 DAS, T_1 resulted in a higher population of soil fungi (6.20 log_{10} CFU g^{-1}) and was on par with T_9 (5.56 log_{10} CFU g^{-1}). However, a significantly lower fungal population was recorded in T_2 (4.00 log_{10} CFU g^{-1}) which was comparable with T_3 (4.39 log_{10} CFU g^{-1}), T_4 (4.50 log_{10} CFU g^{-1}), T_7 (4.50 log_{10} CFU g^{-1}), T_6 (4.59 log_{10} CFU g^{-1}) and T_8 (4.65 log_{10} CFU g^{-1}).

4.8.5 Population of actinomycetes

The effect of weed management practices on the population of actinomycetes in rhizospheric soil is presented in Table 38.

The impact of weed management practices on the actinomycetes population in the soil initially and at 15 DAS, and 30 DAS showed significant variation. Before herbicide application, the actinomycetes population varied significantly, ranging from 3.00 log_{10} CFU g^{-1} to 3.39 log_{10} CFU g^{-1}.

At 15 DAS, weedy check recorded a significantly higher population and was on par with T_8 (3.00 log_{10} CFU g^{-1}), T_2 (3.00 log_{10} CFU g^{-1}), T_1 (3.00 log_{10} CFU g^{-1}). Among the weed management practices, a significantly lower population of actinomycetes was recorded in T_3 (2.00 log_{10} CFU g^{-1}) and was on par with T_4 (2.15 log_{10} CFU g^{-1}), T_5 (2.15 log_{10} CFU g^{-1}), T_6 (2.15 log_{10} CFU g^{-1}) and T_7 (2.50 log_{10} CFU g^{-1}).

At 30 DAS, among the weed management practices T_1 recorded higher population of actinomycets (3.00 log_{10} CFU g^{-1}) and was comparable with T_2 (3.00 log_{10} CFU g^{-1}) and T_3 (3.00 log_{10} CFU g^{-1}), T_9 (3.00 log_{10} CFU g^{-1}) and T_8 (2.50 log_{10} CFU g^{-1}). The treatments T_4, T_5, T_6, T_7 recorded lower population of actinomycetes (2.15 log_{10} CFU g^{-1}.

4.9 *IN VITRO* SENSITIVITY of *Bradyrhizobium* to HERBICIDE MIXTURES

4.9.1 *in vitro* sensitivity of *Bradyrhizobium* to pendimethalin+imazethapyr

The results revealed that *Bradyrhizobium* was not significantly affected by the herbicide mixture of pendimethalin + imazethapyr used. At all the concentrations tested *viz*., 800, 1000, 1200, 1400, 1600, 1800 and 2000 ppm, no inhibition zone occured around the sterile disc containing herbicide mixture placed on a lawn of *Bradyrhizobium* in the medium and positive growth was observed.

4.9.2 *in vitro* sensitivity of *Bradyrhizobium* to propaquizafop + imazethapyr

The results revealed that the pure culture of *Bradyrhizobium* was not significantly affected by the herbicide mixture of propaquizafop + imazethapyr. At all concentrations tested (175, 200, 225, 250, 275, 300, and 325 ppm), no inhibition zone occured around the sterile disc containing herbicide mixture placed on a lawn of *Bradyrhizobium* in the medium and positive growth was observed.

Table 37. Rhizospheric population of beneficial bacteria in the soil just before, 15 and 30 days after spraying of herbicide

	Microbial population in $\log_{10}$ CFU g^{-1} soil								
	Rhizobium			Phosphorus solubilising bacteria			Nitrogen fixers		
Treatments	Before herbicide application	15 days after herbicide application	30 days after herbicide application	Before herbicide application	15 days after herbicide application	30 days after herbicide application	Before herbicide application	15 days after herbicide application	30 days after herbicide application
T_1	7.48 ± 0.00	6.56 ± 0.14	7.45 ± 0.12^{ab}	3.10 ± 0.17	3.10 ± 0.17	3.00 ± 0.00	4.50 ± 0.08^{b}	4.67 ± 0.23	4.24 ± 0.24^{ab}
T_2	7.48 ± 0.00	6.56 ± 0.14	7.48 ± 0.00^{a}	3.00 ± 0.00	3.10 ± 0.17	3.00 ± 0.00	4.72 ± 0.27^{a}	4.12 ± 0.62	3.52 ± 0.66^{cd}
T_3	7.45 ± 0.12	7.16 ± 0.22	6.90 ± 0.07^{c}	3.00 ± 0.00	3.00 ± 0.00	3.10 ± 0.17	4.68 ± 0.23^{a}	4.24 ± 0.24	4.68 ± 0.01^{a}
T_4	7.45 ± 0.12	6.60 ± 0.00	6.24 ± 0.34^{d}	3.10 ± 0.17	3.00 ± 0.00	3.00 ± 0.00	3.90 ± 0.37^{b}	4.24 ± 0.24	4.48 ± 0.06^{a}
T_5	7.16 ± 0.22	6.69 ± 0.07	6.24 ± 0.34^{d}	3.00 ± 0.00	3.00 ± 0.00	3.00 ± 0.00	4.66 ± 0.30^{a}	4.52 ± 0.48	3.10 ± 0.17^{d}
T_6	7.24 ± 0.33	6.98 ± 0.04	7.08 ± 0.11^{bc}	3.10 ± 0.17	3.00 ± 0.00	3.00 ± 0.00	4.67 ± 0.23^{a}	4.67 ± 0.23	3.56 ± 0.07^{cd}
T_7	7.01 ± 0.15	7.07 ± 0.10	6.98 ± 0.04^{c}	3.00 ± 0.00	3.00 ± 0.00	3.20 ± 0.17	4.70 ± 0.29^{a}	4.12 ± 0.61	4.49 ± 0.19^{a}
T_8	6.95 ± 6.95	6.60 ± 0.00	6.48 ± 0.00^{d}	3.10 ± 0.17	3.00 ± 0.00	3.00 ± 0.00	3.10 ± 0.17^{c}	4.35 ± 0.26	3.90 ± 0.37^{bc}
T_9	7.35 ± 0.49	6.98 ± 0.47	7.01 ± 0.15^{c}	3.00 ± 0.00	3.00 ± 0.00	3.00 ± 0.00	3.10 ± 0.17^{c}	4.91 ± 0.10	4.67 ± 0.23^{a}
SEm (±)	0.16	0.14	0.13	0.07	0.05	0.05	0.14	0.22	0.17
CD (0.05)	NS	NS	0.402	NS	NS	NS	0.427	NS	0.496

Table 38. Rhizospheric population of fungi and actinomycetes in the soil just before, 15 and 30 days after spraying of herbicide

	Population of fungi and actinomycetes in $\log_{10}$ CFU g^{-1} soil					
	Fungi			Actinomycetes		
Treatments	Before herbicide application	15 days after herbicide application	30 days after herbicide application	Before herbicide application	15 days after herbicide application	30 days after herbicide application
T_1	4.43 ± 0.60^{bc}	4.50 ± 0.28	6.20 ± 0.11^{a}	3.00 ± 0.00^{b}	3.00 ± 0.00^{ab}	3.00 ± 0.00^{a}
T_2	4.54 ± 0.09^{bc}	4.67 ± 0.26	4.00 ± 0.00^{d}	3.39 ± 0.13^{a}	3.00 ± 0.00^{ab}	3.00 ± 0.00^{a}
T_3	6.20 ± 0.11^{a}	4.89 ± 0.16	4.39 ± 0.13^{cd}	3.00 ± 0.00^{b}	2.00 ± 0.00^{c}	3.00 ± 0.00^{a}
T_4	4.00 ± 0.00^{c}	5.24 ± 0.34	4.50 ± 0.28^{cd}	3.00 ± 0.00^{b}	2.15 ± 0.21^{c}	2.15 ± 0.21^{b}
T_5	4.39 ± 0.13^{c}	6.16 ± 1.63	5.06 ± 0.03^{bc}	3.15 ± 0.21^{b}	2.15 ± 0.21^{c}	2.15 ± 0.21^{b}
T_6	4.50 ± 0.28^{bc}	6.11 ± 1.57	4.59 ± 0.16^{cd}	3.00 ± 0.00^{b}	2.15 ± 0.21^{c}	2.15 ± 0.21^{b}
T_7	5.06 ± 0.03^{b}	5.15 ± 0.21	4.50 ± 0.28^{cd}	3.00 ± 0.00^{b}	2.50 ± 0.70^{bc}	2.15 ± 0.21^{b}
T_8	4.59 ± 0.16^{bc}	5.15 ± 0.21	4.65 ± 0.07^{cd}	3.00 ± 0.00^{b}	3.00 ± 0.00^{ab}	2.50 ± 0.70^{ab}
T_9	4.35 ± 0.50^{c}	5.39 ± 0.13	5.56 ± 0.79^{ab}	3.00 ± 0.00^{b}	3.15 ± 0.21^{a}	3.00 ± 0.00^{a}
SEm (±)	0.20	0.55	0.22	0.06	0.20	0.20
CD (0.05)	0.652	NS	0.694	0.186	0.622	0.622

Table 39. *In vitro* sensitivity of *Bradyrhizobium* to pendimethalin + imazethapyr

pendimethalin + imazethapyr concentration (µL L^{-1})	Growth of *Bradyhizobium*	
	Inhibition zone at 3 DAI (mm)	Growth
800	Nil	+
1000	Nil	+
1200	Nil	+
1400	Nil	+
1600	Nil	+
1800	Nil	+
2000	Nil	+
0 (control)	Nil	+

+: positive growth around the sterile disc

DAI- Days after incubation

Table 40. *In vitro* sensitivity of *Bradyhizobium* to propaquizafop + imazethapyr

propaquizafop + imazethapyr concentration (µL L^{-1})	Growth of *Bradyhizobium*	
	Inhibition zone at 3 DAI (mm)	Growth
175	Nil	+
200	Nil	+
225	Nil	+
250	Nil	+
275	Nil	+
300	Nil	+
375	Nil	+
0 (control)	Nil	+

+: positive growth around the sterile disc

DAI- Days after incubation

4.10 ECONOMIC ANALYSIS

4.10.1 Net income

The effect of weed management practices on the net income of blackgram cultivation is presented in Table 41.

A review of the data revealed that weed management practices had a significant impact on the net income of the crop. Among the practices, T_4 generated the highest net income (₹ 87,158 ha^{-1}), which was comparable to T_7 (₹ 83,094 ha^{-1}). In contrast, the weedy check resulted in the lowest net income, while hand weeding twice led to a significantly lower net income of ₹ 5,039 ha^{-1}.

4.10.2 Benefit Cost Ratio (BCR)

The influence of weed management practices on benefit cost ratio of blackgram cultivation is presented in Table 41.

The BC ratio varied among the weed management practices, with T_4 recording the highest BC ratio of 1.95, followed by T_7 (1.94), T_3 (1.80), T_6 (1.74), and T_1 (1.67). However, hand weeding twice resulted in a lower BC ratio of 1.05, while the weedy check recorded the lowest BC ratio of 0.82.

Table 41. Effect of weed management practices on net income and benefit cost ratio.

Treatment	Gross income (₹ ha^{-1})	Net income (₹ ha^{-1})	B:C ratio
T_1- PE pendimethalin + imazethapyr 800 g ha^{-1}	141285	56585 ± 19448^{c}	1.67
T_2- T_1 *fb* HW at 30 DAS	142341	50141 ± 14058^{c}	1.54
T_3- PoE propaquizafop+ imazethapyr 125 g ha^{-1}	152626	67926 ± 15857^{abc}	1.80
T_4- T_3 *fb* HW at 40 DAS	179358	87158 ± 16900^{a}	1.95
T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS	154464	62265 ± 11695^{c}	1.68
T_6 - PE pendimethalin 1kg ha^{-1} *fb* imazethapyr 50g ha^{-1}	155684	66284 ± 24213^{bc}	1.74
T_7- PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100g ha^{-1}	173194	83794 ± 9412^{ab}	1.94
T_8- HW at 15 and 30 DAS	115039	5039 ± 17111^{d}	1.05
T_9- Weedy check	65866	-14133 ± 4669^{d}	0.82
SEm (±)	--	6885	--
CD (0.05)	--	20641	--

DISCUSSION

5. DISCUSSION

Weeds are one of the major constraints in blackgram cultivation and effective weed management is therefore essential to optimize crop performance and yield. Among the chemical methods, premix herbicides have gained prominence due to their ability to target a broader spectrum of weed species with a single application, reducing labour costs and time. The present study was conducted to evaluate the efficacy of premix herbicides as part of an integrated weed management strategy for blackgram intercropped in coconut garden. A detailed analysis of the experimental findings and their significance in formulating efficient weed management strategies is presented below.

5.1 INFLUENCE OF WEED MANAGEMENT PRACTICES ON GROWTH AND GROWTH ATTRIBUTES OF BLACKGRAM INTERCROPPED IN COCONUT GARDEN

The findings of the study indicated that weed management practices had no significant influence on the growth attributes of blackgram like plant height, number of trifoliate leaves per plant, number of branches per plant and leaf area index at all stages of observation. The lack of significant variation suggested that the weed management practices adopted did not interfere with the basic vegetative growth parameters of the crop. It is possible that the competition for resources such as light, water, and nutrients between weeds and the crop was minimized to a threshold level that did not adversely affect these growth parameters. On the other hand, the inherent genetic potential of the blackgram variety used *viz*; DBGV-5 and its suitability to partial shade might have enabled it to maintain its growth irrespective of variations in weed management practices (Pooja *et al*., 2023)

The uniformity in vegetative growth metrics across different weed management treatments also implied that the adopted practices may have provided an equivalent level of weed control efficacy, ensuring the sufficient resources to crop for optimal growth. However, it is essential to note that while weed management practices may not significantly affect vegetative growth parameters, they could still play a critical role in influencing reproductive parameters and yield. These results indicated that blackgram exhibited a degree of resilience to weed interference under partial shade in coconut garden in terms of its vegetative growth parameters during the initial stage. Subramanian *et al*. (2006) observed that blackgram demonstrates resilience to weed interference in vegetative growth through effective weed control measures.

However, the phytotoxicity assessment of crop revealed that mild stunting symptoms were observed in blackgram plants treated with the premix herbicide combination of pendimethalin + imazethapyr sprayed on the next day of sowing onto the soil, as per the scoring scale of Thomas and Abraham (2007). These symptoms appeared seven days after herbicide application and persisted upto 10 days after application. However, the crop exhibited complete recovery by 15 days after application, indicating the transient nature of the phytotoxic effects. In contrast, Reddy *et al*. (2023) reported that ready-mix combination of pendimethalin + imazethapyr at 1000 g ha^{-1} applied as pre-emergence resulted in higher plant height and seed yield, without significant phytotoxicity.

The observed mild stunting may be attributed due to the residual activity of the herbicide combination, which could have temporarily affected the metabolic processes of the crop. Such transient symptoms are not uncommon with premix herbicides, especially under intercropping situation in partial shade where environmental and soil conditions can influence herbicide behaviour and crop tolerance. In a field experiment conducted during the *kharif* (rainy) season of 2019, the post-emergence application of imazethapyr at 75 g ha^{-1} resulted in a phytotoxicity rating of '1' on a 0-10 scale in blackgram, observed 5 days after herbicide application (Reddy *et al*., 2023). Nayak and Singh (2023) observed phytotoxic effect of pendimethalin on crop emergence relative to other treatments in blackgram. In contrast, no phytotoxicity symptoms were observed in the plots treated with other herbicide sprays either pre or post emergence, suggesting their compatibility and safety for pure crop of blackgram as well as intercropped in coconut garden.

The study revealed significant differences among treatments in the number of effective nodules per plant, indicating that weed management practices have a notable impact on nodule formation in blackgram. The pre-emergence application of

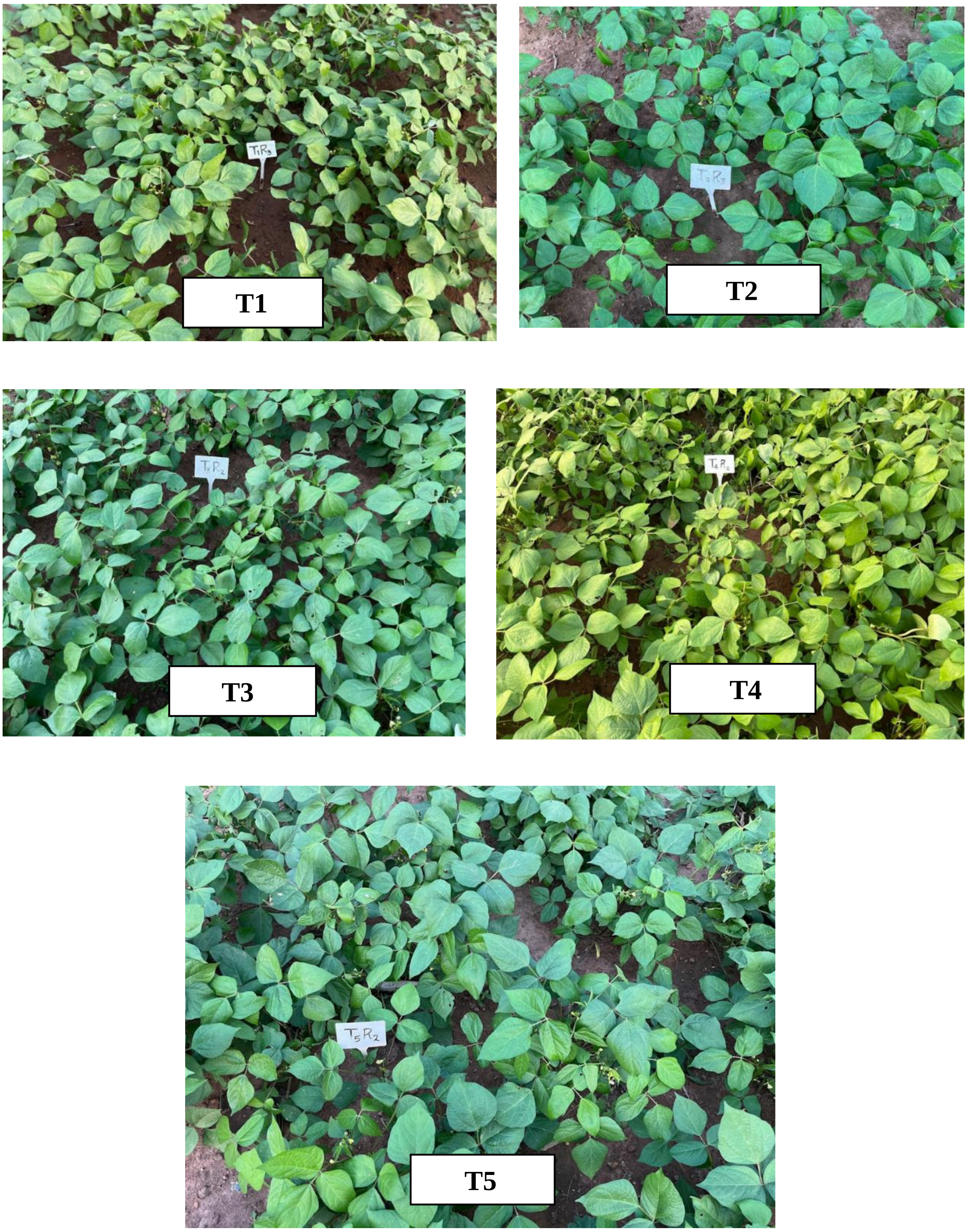


Plate 4a. Effect of weed management practices on crop growth at 30 DAS

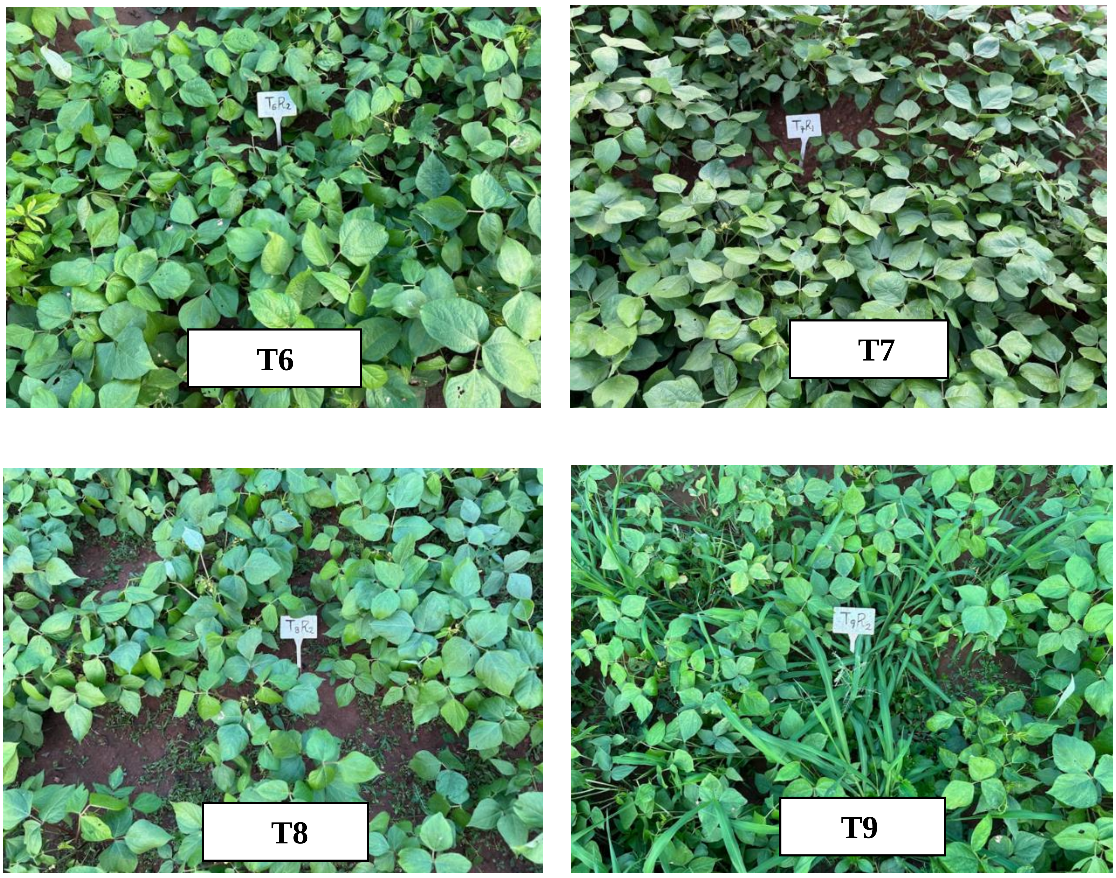


Plate 4b. Effect of weed management practices on crop growth at 30 DAS

T1

T2

Plate 5. Visual symptoms of phytotoxicity in blackgram 7 days after herbicide application

pendimethalin at 1 kg ha^{-1} followed by propaquizafop at 100 g ha^{-1} and post emergence propaquizafop + imazethapyr 125 g ha^{-1} with hand weeding produced higher number of effective nodules per plant (31.67 and 29.67). This could be attributed to effective weed suppression during critical growth stages, which likely minimized competition for nutrients and provided favourable conditions for *Rhizobium* activity and nodule formation. Suryavanshi (2013) also reported significantly higher root nodules per plant in propaquizafop + imazethapyr at 127 and 134 g ha^{-1} applied at 30 DAS in blackgram.

According to Aggarwal *et al.* (2014a), application of imazethapyr at 75 g ha^{-1} at 15 DAS in blackgram resulted in a greater number of nodules and an increase in nodule dry weight. Choudhary *et al*., (2012) reported that effective weed management significantly enhanced nodulation by promoting better growth attributes, which increased the accumulation and translocation of photosynthates to support nodule development. However, Singh *et al*. (2015b) reported that the application of imazethapyr at 25, 40, and 75 g ha^{-1} adversely impacted several symbiotic parameters, such as nodule number, nodule dry weight, and leghaemoglobin content in green gram.

In contrast, a significantly lower number of effective nodules per plant was recorded in T_2 (15.33), T_5 (17.33), T_6 (18.33), T_1, and T_8 (18.67). The reduced nodule numbers in these treatments might be due to suboptimal weed control, leading to greater competition for resources and potentially inhibiting the symbiotic relationship between the crop and rhizobia. Khaffagy and Kasem (2016) noted that pendimethalin reduced nodule numbers and dry weight, indicating a detrimental impact on the symbiotic relationship in pea. Studies indicated that poor weed control can lead to significant yield losses, with competition potentially reducing nodule formation and function (Tilgam and Shyam, 2019). However, the fresh weight of nodules was not significantly influenced by the weed management practices.

The data indicated a significant variation in the number of days required to reach 50 per cent flowering in blackgram grown as intercrop in coconut garden, highlighting the influence of weed management practices on crop phenology. Across the treatments, the flowering duration ranged between 39.67 and 43 days. The early flowering observed in T_3 (propaquizafop+ imazethapyr 125 g ha^{-1} at 15 DAS alone), T_4 (premix followed by hand weeding) and T_7 (pendimethalin 1kg ha^{-1} on next day of sowing followed by propaquizafop 100g ha^{-1} at 15 DAS) could be attributed to efficient weed control during the early growth stages, which minimized resource competition and allowed the crop to progress to the reproductive stage more quickly. Mishra *et al*. (2019) opined that combination of propaquizafop and imazethapyr was effective in controlling weeds in black gram. In contrast, the application of pendimethalin + imazethapyr delayed flowering, requiring more days to reach 50 per cent flowering (43 days), which was on par with T_2 (42.67 days), T_9 (42 days), and T_6 (41.67 days). This delay could be associated with transient crop stress or phytotoxic effects from the herbicide combination, as noted in previous observation, which may have temporarily hindered plant physiological processes. While the application of pendimethalin + imazethapyr can enhance weed control and improve growth in black gram, there is a possibility that these herbicides may also induce stress or phytotoxic effects that could delay flowering.

5.2 INFLUENCE OF WEED MANAGEMENT PRACTICES ON YIELD AND YIELD ATTRIBUTES OF BLACKGRAM INTERCROPPED IN COCONUT GARDEN

The results demonstrated a significant effect of weed management practices on the number of pods produced per plant in blackgram. Post emergence application of propaquizafop+ imazethapyr 125 g ha^{-1} at 15 DAS followed by hand weeding at 40 DAS (T_4) recorded higher number of pods (36.00) and was statistically comparable to pre emergence application of pendimethalin 1kg ha^{-1} followed by propaquizafop 100g ha^{-1} at 15 DAS (35.83), highlighting its effectiveness in managing weeds and optimizing pod production. Hundred seed weight was also found to be higher in these treatments. The highest seed yield per plant (9.60 g) was also recorded in the same treatment involving the post-emergence application of propaquizafop + imazethapyr at 125 g ha^{-1} at 15 DAS followed by hand weeding at 40 DAS. This superior performance could be attributed to efficient weed control during the critical stages of crop growth, particularly with hand weeding at 40 DAS. This practice ensured a weed-free environment during the initial period from 15 DAS till 50 DAS coinciding with flowering stage, minimizing resource competition and providing optimal conditions for seed development. Vivek *et al*. (2008) opined that maintaining a weed-free period beyond 30 DAS improved yield, while weed persistence beyond this period reduced it, highlighting that 30 to 45 DAS window is crucial for managing crop-weed competition. This was closely followed by T_7 (9.23 g), T_6 (8.3 g), T_5 (8.23 g), and T_3 (8.14 g) per plant, which also demonstrated significant yield benefits, further validating the importance of integrated weed management practices in enhancing productivity.

The combination of chemical and manual weed management approaches, such as the post-emergence application of a broad spectrum premix (propaquizafop + imazethapyr) followed by hand weeding, helped in maximizing seed yield and haulm yield per plant in blackgram. This integrated approach not only enhanced weed control but also optimized resource availability for the crop, promoting better seed development and ultimately increasing seed yield per plant. In contrast, the lowest seed yield per plant (3.54 g) was recorded in the weedy check, where unchecked weed growth severely affected resource availability for the crop. Hand weeding at 15 and 30 DAS also resulted in comparatively lower yield (6.16 g), possibly due to incomplete or delayed weed removal leading to residual competition.

The data revealed significant variation in seed and haulm yield per ha across different weed management practices. The post-emergence application of propaquizafop + imazethapyr at 125 g ha^{-1} followed by hand weeding resulted in higher seed yield (1793.58 kg ha^{-1}) and was comparable with T_7 (1731.94 kg ha^{-1}). This weed free treatment recorded 92.61 per cent higher seed yield and 61.36 per cent higher haulm yield over weedy check. In contrast, the weedy check recorded the lowest seed yield (658.67 kg ha^{-1}), highlighting the negative impact of unchecked weeds. Regarding haulm yield, T_5 produced higher yield (3658.2 kg ha^{-1}) and was on par with T_4 (3616 kg ha^{-1}), T_6 (3581.93 kg ha^{-1}), and T_7 (3485.73 kg ha^{-1}), with the weedy check and hand weeding yielding lower haulm yield (1917.5 kg ha^{-1}). These results emphasized the effectiveness of integrated weed management strategies in enhancing both seed and haulm yields. Consistent with these findings, Sanbagavalli *et al.* (2016) and Kumari *et al.* (2023) reported the effectiveness of integrated weed management practices in blackgram.

The weed index varied significantly among the weed management practices, indicating the impact of weed control on yield reduction. The highest yield reduction was observed in the unweeded control (54.44%), highlighting the adverse effects of unchecked weed growth. Among the treatments, post emergence application of propaquizafop + imazethapyr 125 g ha^{-1} at 15 DAS followed by hand weeding at 40 DAS (T_4) recorded the lowest yield reduction due to weeds (2.45%), on par with T_7 (5.35%), indicating superior weed suppression. Hand weeding twice, despite its labour-intensive nature also resulted in a high weed index (54.43%), emphasizing its ineffectiveness for controlling deep rooted weeds and need for integrated approaches to minimize yield losses.

5.3 INFLUENCE OF WEED MANAGEMENT PRACTICES ON WEED FLORA AND WEED CONTROL PARAMETRS IN BLACKGRAM INTERCROPPED IN COCONUT GARDEN

Results of predominant species of weeds observed in the experimental field showed the dominance of grasses as major weed flora in terms of weed dry weight. However, more diversity was observed in broad leaf weeds. *Phyllanthus niruri, Mollugo pentaphylla, Spermacoce latifolia, Richardia scabra, Euphorbia hirta, Commelina diffusa, Synedrella nodiflora, Trianthema portulacastrum* and *Odenlandia umbellata* were the major broad leaf weeds observed. Diversity of sedges was low and *Cyperus rotundus* L. was the only sedge observed in the experimental field. Punia *et al.* (2013), Sanbagavalli *et al*. (2016), Pankaj and Dewangan (2017) also reported increased diversity of broadleaf weeds in blackgram.

Weed management practices significantly influenced both weed density and dry weight at all growth stages of blackgram. T_2 (PE pendimethalin + imazethapyr 800 g ha^{-1} *fb* HW at 30 DAS) consistently recorded lower weed density (1.00 to1.33 m^{-2}) and dry weight (0.13 to 0.27 g m^{-2}) across all stages and was on par with all treatments highlighting the efficacy of integrating chemical and mechanical weed control to suppress early and persistent weed growth effectively. An early pre or post emergence herbicide combined with a late hand weeding effectively reduced weed competition and biomass. Smith *et al*. (2009) demonstrated that pendimethalin-based weed management methods are effective for providing season-long weed control. Pre-emergence herbicides help maintain weed populations below the economic threshold during the early stages of crop growth, while subsequent hand weeding ensures effective control during later stages (Shivalingappa *et al*., 2014). Weed dry weight, a key indicator of

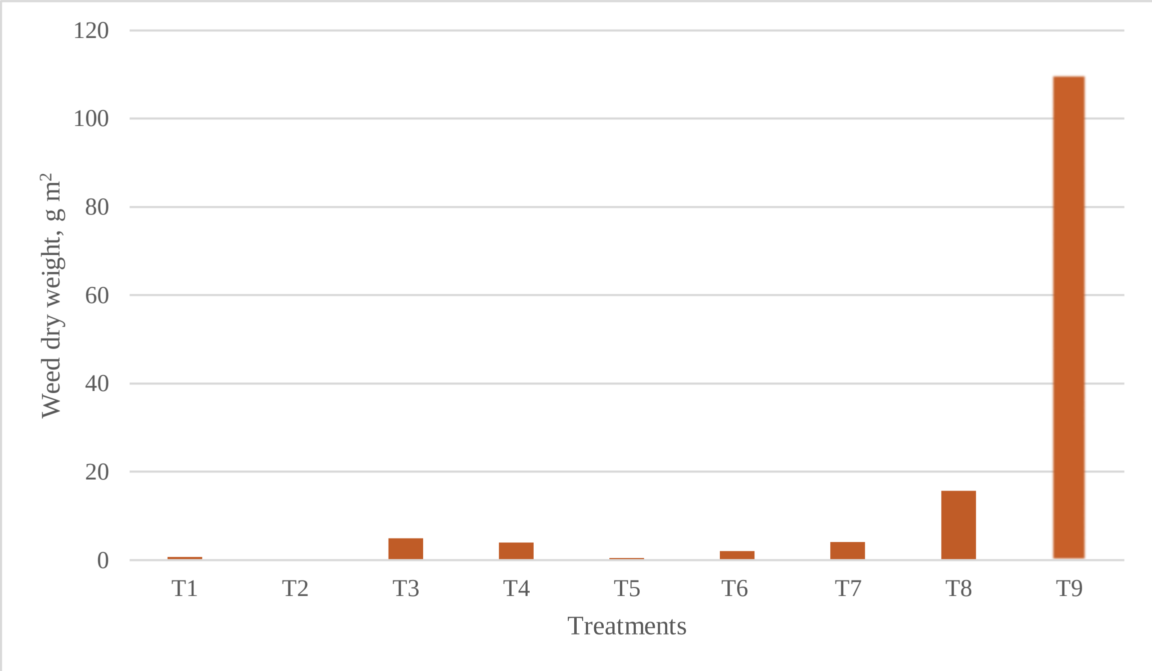


Fig. 3. Effect of weed management practices on weed dry weight at 45 DAS, g m^{-2}

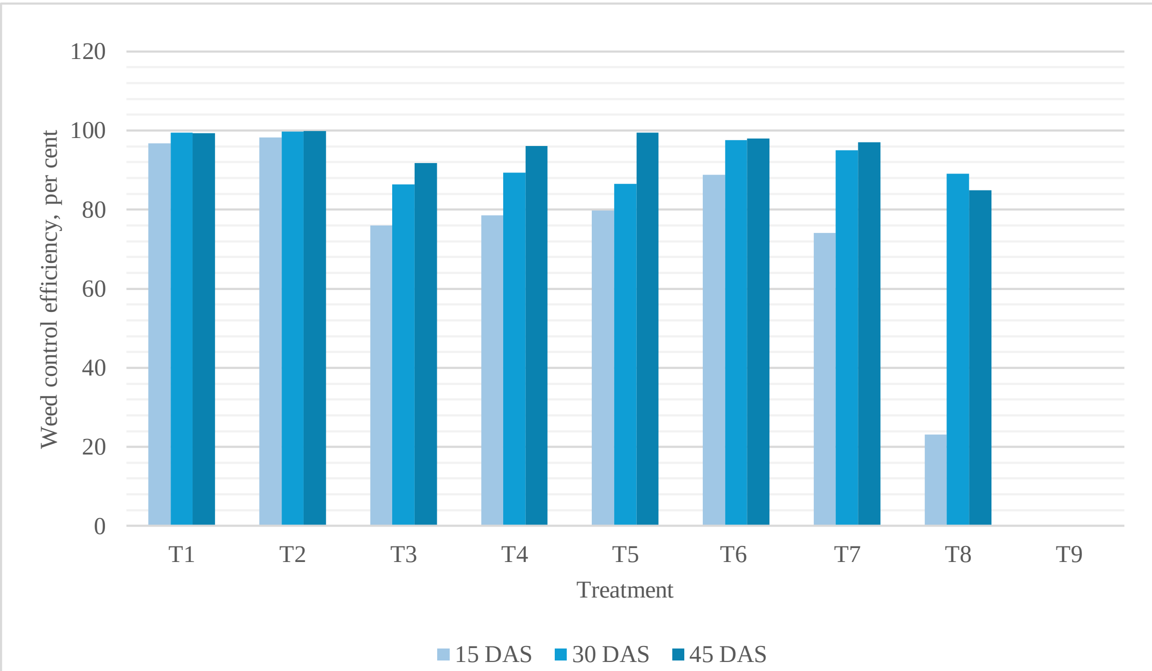


Fig.4. Effect of weed management practices on weed control efficiency, per cent

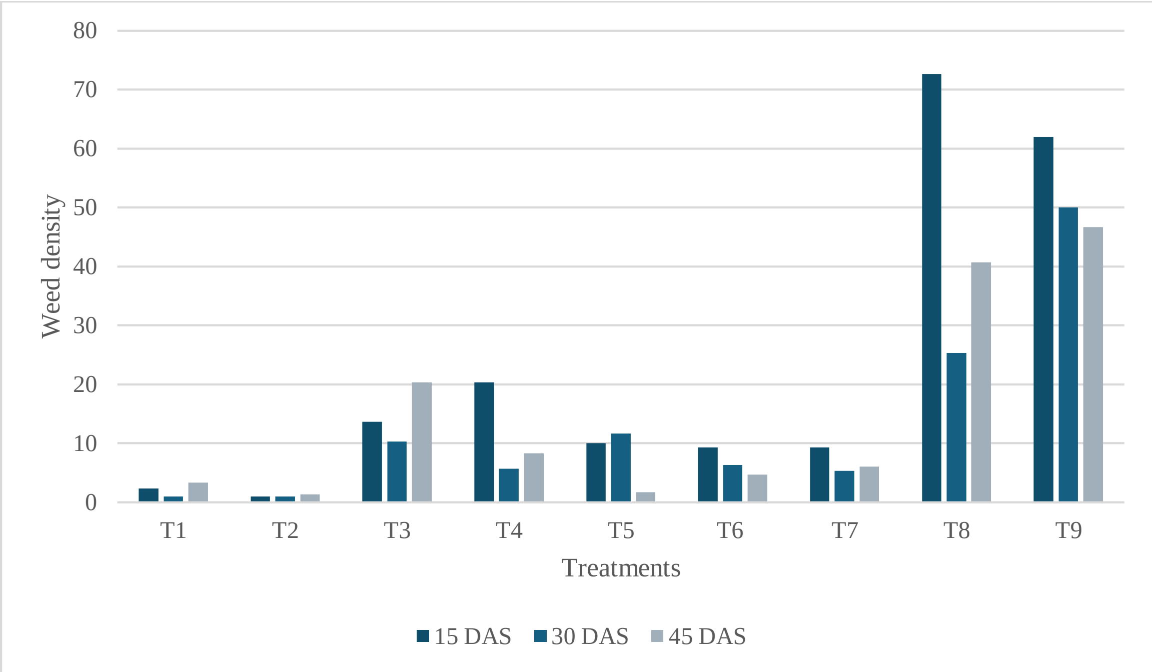


Fig.5. Effect of weed management practices on weed density

weed competitiveness, followed a pattern similar to weed density, with the highest dry weight observed in the weedy check. Sequential treatments outperformed individual herbicide applications (Rao *et al.,* 2010a). Combining herbicides with hand weeding is a labour-saving, cost-effective, and promising alternative in performing hand weeding twice (Imoloame and Usman, 2018). The results align with previous studies (Kumari *et al*. (2023); Reddy *et al*. (2023) reaffirming the effectiveness of integrated weed management in optimizing blackgram productivity.

Weed control efficiency (WCE) quantifies the ability of a treatment to reduce weed growth and competition with the crop, thereby improving crop yield and minimizing the impact of weeds on crop performance. WCE varied significantly across different weed management practices at all stages of observation. Pre-emergence pendimethalin, along with post-emergence imazethapyr or propaquizafop, effectively maintained weed suppression throughout the crop growth stages. Shashidhar *et al*., (2020a) also reported that pre emergence pendimethalin mixed with imazethapyr at 1 kg ha^{-1} followed by hand weeding at 30 DAS significantly reduced weed biomass in black gram, under acidic soils of Manipur.

The data on relative density and biomass of weeds indicated that the weed management practices involving pre-emergence pendimethalin (T_1, T_5, T_6) along with combinations of post-emergence herbicides (T_2, T_7) effectively suppressed grass weeds across all growth stages. These treatments showed consistently low relative density of grasses (0%) compared to the weedy check, which had significantly higher grass density at all stages. This suggested that the combination of pendimethalin with imazethapyr or propaquizafop provided effective and sustained control of grass weeds in blackgram (Nain *et al*., 2024). Hand weeding twice recorded poor weed control efficiency due to the dominance of grass flora where hand weeding stimulated its regrowth. However, the lower relative biomass of BLW was recorded in hand weeded plots due to the absence of its underground propagules.

5.4 INFLUENCE OF WEED MANAGEMENT PRACTICES ON SOIL ENZYME ACTIVITY IN BLACKGRAM INTERCROPPED IN COCONUT GARDEN

Dehydrogenase enzyme activity is a key indicator of soil microbial activity and health. The results indicated that weed management practices significantly influenced dehydrogenase enzyme activity across all growth stages. Munoz-Leoz *et al.* (2011) stated that pesticides applied to the soil influence the microbial population, as only 0.3 per cent reaches the target pest while the remaining 97 per cent is dispersed into the environment. At 30 DAS, pre emergence pendimethalin application (T_7 and T_6) resulted in higher enzyme activity. The rise in dehydrogenase activity could be attributed to an increased carbon source available for microbial activity. Sireesha *et al*. (2012) reported that pre-emergence application of pendimethalin, especially at lower doses, increased dehydrogenase activity relative to the control. However, at 45 DAS, post-emergence propaquizafop + imazethapyr followed by hand weeding (T_4) showed higher dehydrogenase enzyme activity suggesting that it favoured microbial activity. Saha *et al*. (2016) observed an initial inhibition in dehydrogenase activity which returned to control levels after 30 days, suggesting resilience in soil microbial communities. The weed-free conditions created through effective weed management with premix herbicides, along with enhanced plant growth due to improved soil aeration from hand weeding, contributed to better root proliferation and exudation. Dehydrogenase activity depends on oxidation-reduction reactions and microbial respiration in the soil. These factors likely stimulated microbial activity, leading to increased dehydrogenase activity in the soil. However, weedy check and hand weeding twice showed lower enzyme activity. Arya and Ameena (2016) concluded that herbicides, whether applied as pre-emergence or post-emergence, persist in the topsoil and influence soil enzyme activities during initial stages; however, none exhibited a significantly adverse impact on soil enzyme activity under dry sowing conditions at active growth stage of the crop.

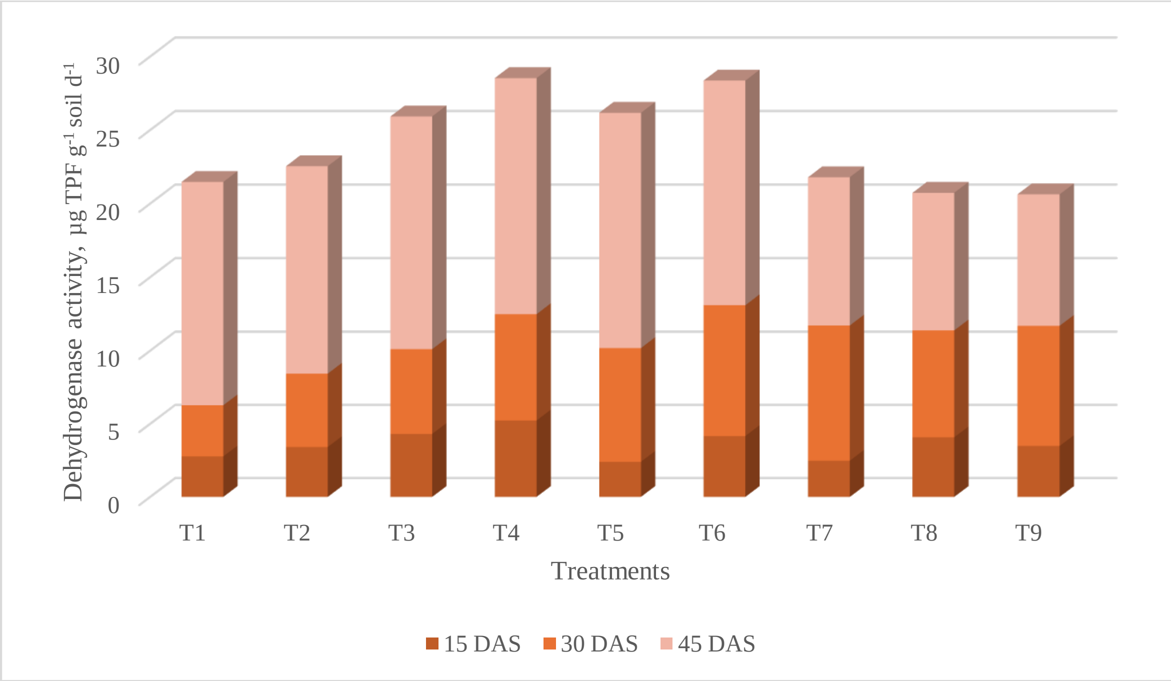


Fig. 6. Effect of weed management practices on dehydrogenase enzyme activity, µg TPF g^{-1} soil d^{-1}

5.5 INFLUENCE OF WEED MANAGEMENT PRACTICES ON PLANT NUTRIENT UPTAKE, WEED REMOVAL AND AVAILABLE NUTRIENT STATUS IN BLACKGRAM INTERCROPPED IN COCONUT GARDEN

From the results of the study, it was evident that weed management practices have a significant influence on nitrogen uptake by plants. Pre-emergent pendimethalin *fb* propaquizafop 100g ha^{-1} enhanced the total N uptake by 102.21 per cent over weedy check while hand weeding recorded a 10.35 per cent improvement. The increased uptake could be attributed to a higher dry matter production and weed control efficiency. PoE propaquizafop + imazethapyr 125 g ha^{-1} *fb* hand weeding at 40 DAS recorded the highest P uptake (42.97 kg ha^{-1}), which was statistically similar to T_7 (38.60 kg ha^{-1}) and T_2 (38.22 kg ha^{-1}) while K uptake was higher in PoE propaquizafop+ imazethapyr 125 g ha^{-1} (169.63 kg ha^{-1}). According to Reddy and Ameena (2021), implementing weed control measures enhanced crop uptake of nitrogen, phosphorus, and potassium by 49.42, 60.07 and 51.73 per cent , respectively, relative to untreated weedy plots. Weedy check which represents the presence of weeds without any management, showed the lowest total NPK uptake of 199.26, 21.18 and 95.79 kg ha^{-1}.

Weed management practices significantly influenced N, P, and K removal by weeds. Herbicide application and its combination with hand weeding showed lower weed nutrient removal, while the highest nutrient removal occurred in the weedy check plot. These findings highlighted the importance of weed control from 15 DAS upto 45 days, as delayed management allows weeds to deplete nutrients, depriving the crop of essential resources. The present study suggests that weeds should be effectively controlled from the early stages up to completion of flowering in blackgram to minimize competition. Two hand weeding at 15 and 30 DAS proved ineffective and uneconomical as perennial grass weeds dominated the flora. While pre-emergence herbicides control early-stage weeds, they are less effective against late-emerging weeds. Therefore, an integrated approach combining herbicides with one hand weeding could be recommended for optimal weed management and higher blackgram yield. Reddy and Ameena (2021) observed that combining pre-emergent herbicide application with hand weeding extended the duration of effective weed suppression, allowing the crop to utilize resources more efficiently for enhanced growth and dry matter accumulation.

The post-harvest availability of N, P and K in the soil was significantly affected by weed management practices. The availability of N, P and K in the soil was observed to show improvement compared to the weedy check plot. This could be attributed to the improved weed control, leading to a decrease in the amount of nutrients taken away by weeds. Reddy *et al*. (2020) reported a decrease of 40.0, 13.2, and 28.4 per cent respectively, in available N, P and K levels in the soil, when compared to the initial levels.

5.6 INFLUENCE OF WEED MANAGEMENT PRACTICES ON SOIL MICROBIAL HEALTH

The microbial population in the soil was not influenced by the weed management practices undertaken in the current study during the initial phase of herbicide application upto 15 days. However, herbicide application or its combination with hand weeding had a significant impact on the population of *Rhizobium*, nitrogen fixers, fungi, and actinomycetes in the rhizosphere after 30 days of herbicide application, especially in plots that received pendimethalin + imazethapyr application which exhibited a higher population count. As a pre-emergence herbicide, pendimethalin could create a favourable environment for microbial growth by suppressing early weed emergence, thereby reducing competition for nutrients and improving their availability, while minimizing disturbance to the soil microbiome (Pankaj and Dewangan, 2017). Barman *et al*. (2008) observed that over time, certain bacteria, fungi, and actinomycetes multiply in higher numbers by metabolizing pendimethalin, leading to their population buildup. On the contrary, Singh and Singh (2020) reported that the combination of pendimethalin with imazethapyr does not significantly affect fungal and actinomycete population in mungbean rhizosphere.

The *Rhizobium* population in rhizospheric soil remained stable across all treatments upto 15 days of herbicide application indicating no immediate adverse effects of the applied herbicides. Anusha *et al*. (2024) opined that the careful selection and timing of herbicide application are crucial, as certain herbicides can effectively control weeds without significantly hindering nodulation, thereby preserving the host-rhizobia symbiosis. On the contrary, Iriart *et al*. (2024) reported that herbicide stress

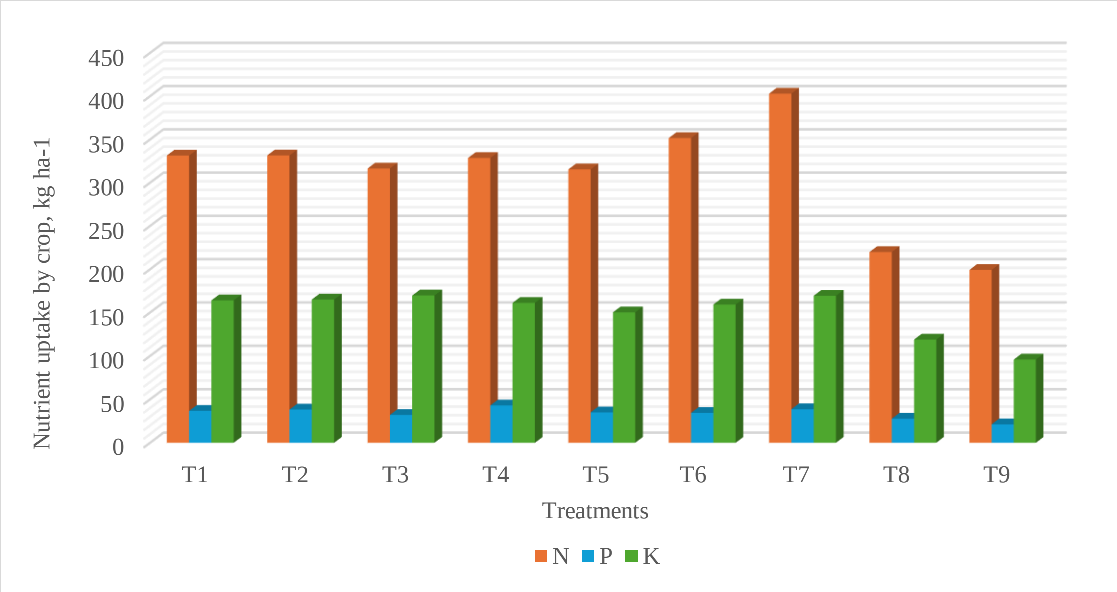


Fig. 7. Effect of weed management practices on NPK uptake by crop at 45 DAS, kg ha^{-1}

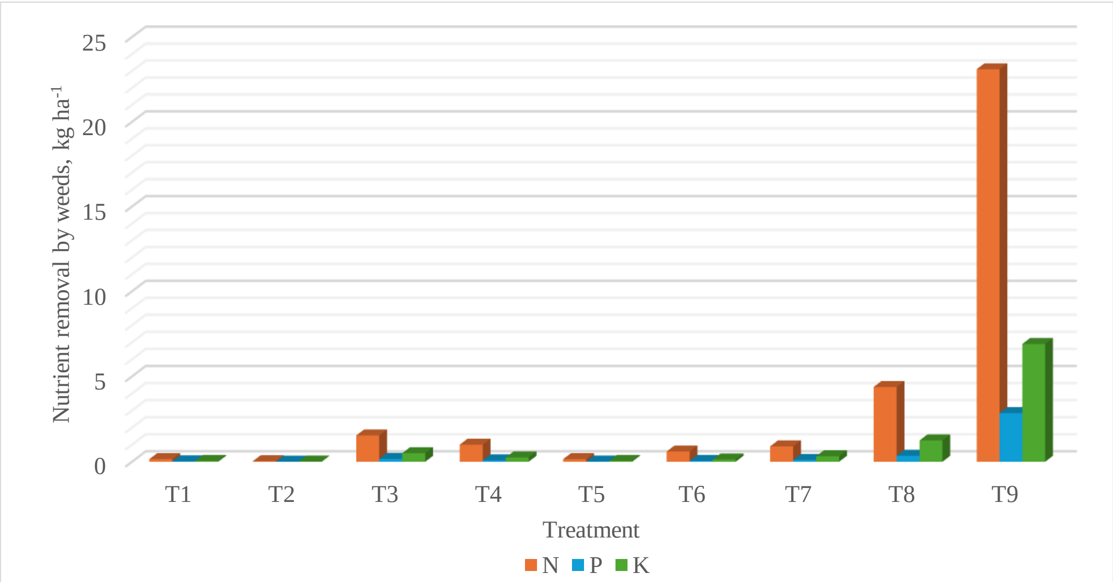


Fig. 8. Effect of weed management practices on NPK removal by weeds at 45 DAS, kg ha^{-1}

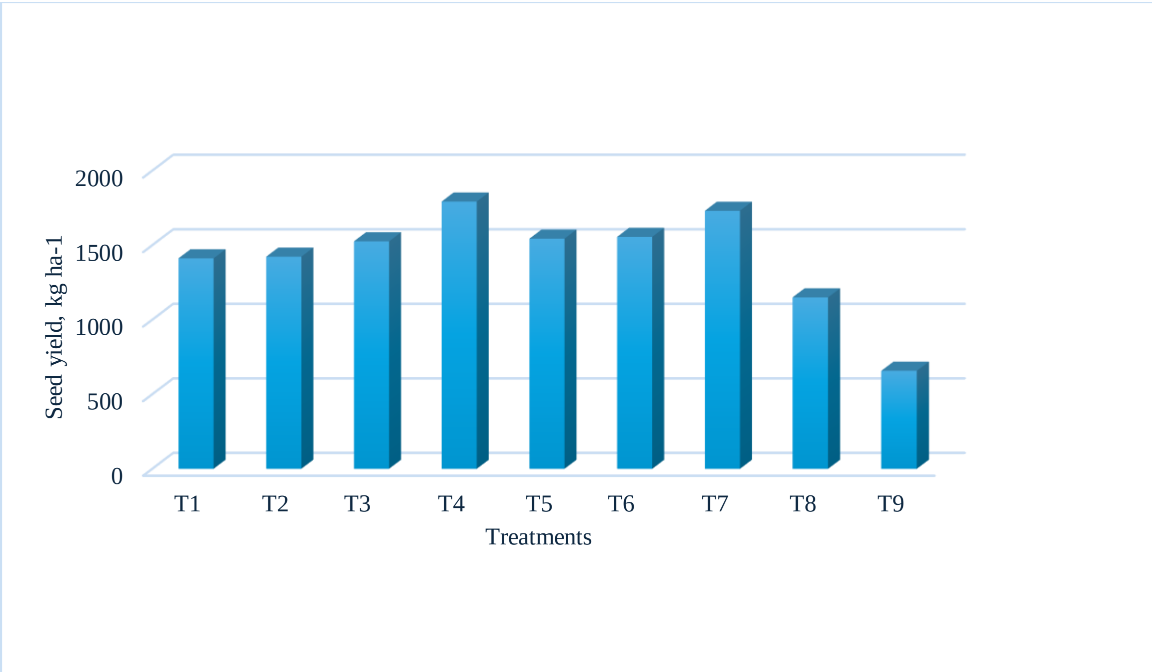


Fig. 9. Effect of weed management practices on seed yield, kg ha^{-1}

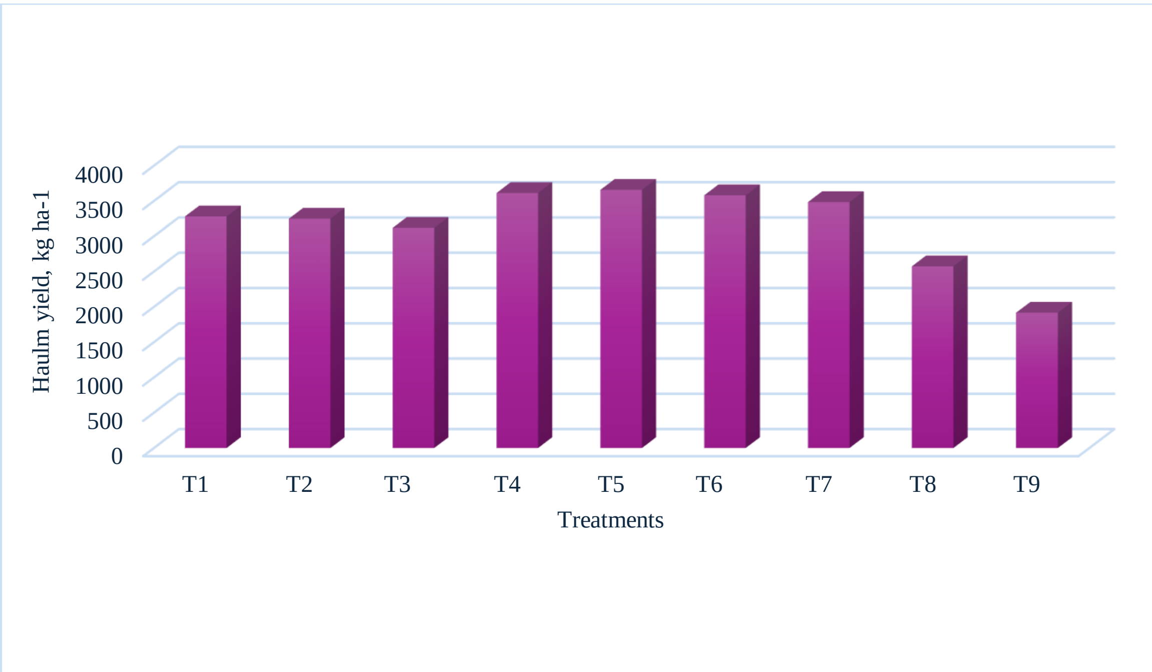
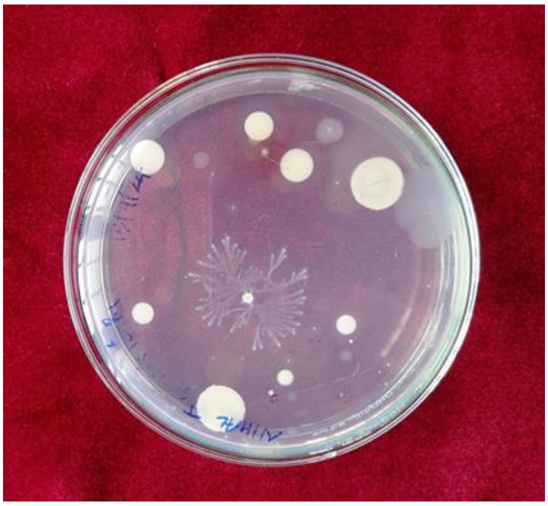
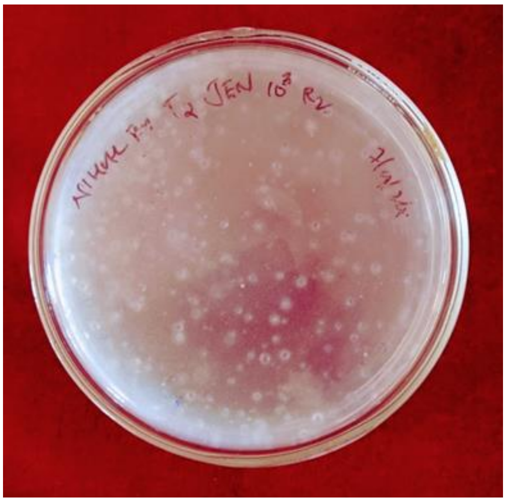


Fig. 10. Effect of weed management practices on haulm yield, kg ha^{-1}



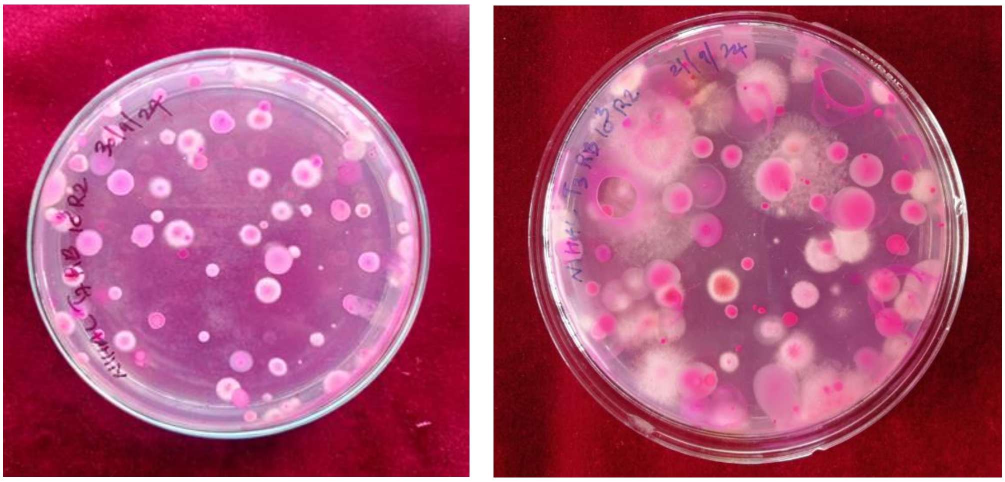
Rhizobium

Phosphorus solubilizing bacteria (PSB)



N-fixers

Plate 6a. Microbial colonies



Fungi

Actinomycetes

Plate 6b. Microbial colonies

can impact the performance of rhizobial strains, in red clover affecting nodule formation and overall plant health.

Phosphorus-solubilizing bacterial population showed no notable variations across different time points after the application of weed management practices. The bacterial count remained consistent at approximately 3.0–3.2 $\log_{10}$ CFU g^{-1} soil across the treatments. Since the activity of phosphorus-solubilizing bacteria is driven by soil phosphorus levels, a stable phosphorus supply with a higher P status in soil could have helped in maintaining stable population dynamics. The population of soil nitrogen-fixing bacteria was significantly influenced by weed management practices after 30 days of application. A higher population of nitrogen fixers was recorded in plots applied with propaquizafop + imazethapyr, which might have provided a favourable soil environment for microbial activity, either by minimizing weed competition or through indirect effects on soil properties. Malviya and Saini (2023) reported that propaquizafop and imazethapyr together improved weed control efficiency (>85%) without adding microbial stress. Zhang *et al*. (2010) observed that application of imazethapyr temporarily altered soil microbial community structures by reducing microbial biomass and shifting compositions with recovery occurring after 60 days of incubation.

The fungal population in soil varied significantly at the beginning and at 30 DAS but showed no difference at 15 DAS. At 30 DAS, soil that received pendimethalin + imazethapyr application recorded a higher fungal population (6.20 $\log_{10}$ CFU g^{-1}) which was comparable to weedy check (5.56 $\log_{10}$ CFU g^{-1}). It can be inferred that the premix application has no adverse impact on fungal population in soil. The root exudates and enhanced rhizodeposition in weedy check plots might have supported fungal proliferation. However, weed management practices significantly influenced the actinomycetes population at all-time points. The weedy check plots recorded higher microbial population of N fixers, fungi and actinomycetes at 30 days after herbicide application. This could be attributed to the absence of herbicide stress, the release of diverse root exudates from weeds, reduced soil disturbance, and the ability of weed cover to retain soil moisture, collectively creating favourable conditions for microbial proliferation.

The *in vitro* sensitivity analysis revealed that growth of *Bradyrhizobium* was not inhibited when exposed to pendimethalin + imazethapyr (800 to 2000 ppm) or propaquizafop + imazethapyr (175 to 325 ppm), at all tested concentrations. The absence of inhibition zones and the positive growth confirmed that these herbicide mixtures did not adversely affect the survival of *Bradyrhizobium* in pure culture. The results suggest that the combination of pendimethalin + imazethapyr can safely be integrated into weed management programs without adversely affecting *Bradyrhizobium* population, supporting both weed control and soil microbial health. This finding is crucial for sustainable weed management in legume-based systems, as the application of these herbicides is unlikely to interfere with biological nitrogen fixation. Maintaining a stable *Bradyrhizobium* population ensures effective nitrogen fixation and assimilation, promoting soil fertility and crop productivity. However, further studies under field conditions are necessary to assess long-term interactions between these herbicides and soil microbial communities.

Overall, the results indicated that weed management strategies with herbicides such as pendimethalin, pendimethalin+imazethapyr, propaquizafop+imazethapyr, propaquizafop are effective in maintaining soil microbial health, as they control weeds efficiently while minimizing soil disturbance and chemical stress to beneficial microbes. These findings are consistent with previous studies that emphasize the importance of using safer herbicides for weed management to preserve and sustain soil biological activity (Trimurtulu *et al*., 2015).

5.7 INFLUENCE OF WEED MANAGEMENT PRACTICES ON ECONOMICS OF BLACKGRAM INTERCROPPED IN COCONUT GARDEN

Weed management practices significantly influenced the economic returns and benefit-cost ratio (BCR) in the crop. Post emergent propaquizafop + imazethapyr *fb* HW at 40 DAS (T_4) generated the highest net income (Rs 87,158 ha^{-1}), followed by T_7 (PE pendimethalin 1kg ha^{-1} *fb* propaquizafop 100 g ha^{-1}) with Rs 83,094 ha^{-1}, indicating their efficacy in balancing weed control costs and yield gains. Umkhulzum and Ameena (2019) opined that herbicide application proved to be a more convenient, time-efficient, labour-saving, and cost-effective alternative. In contrast, the weedy check resulted in the lowest net income, while hand weeding twice (T_8) led to a significantly lower net

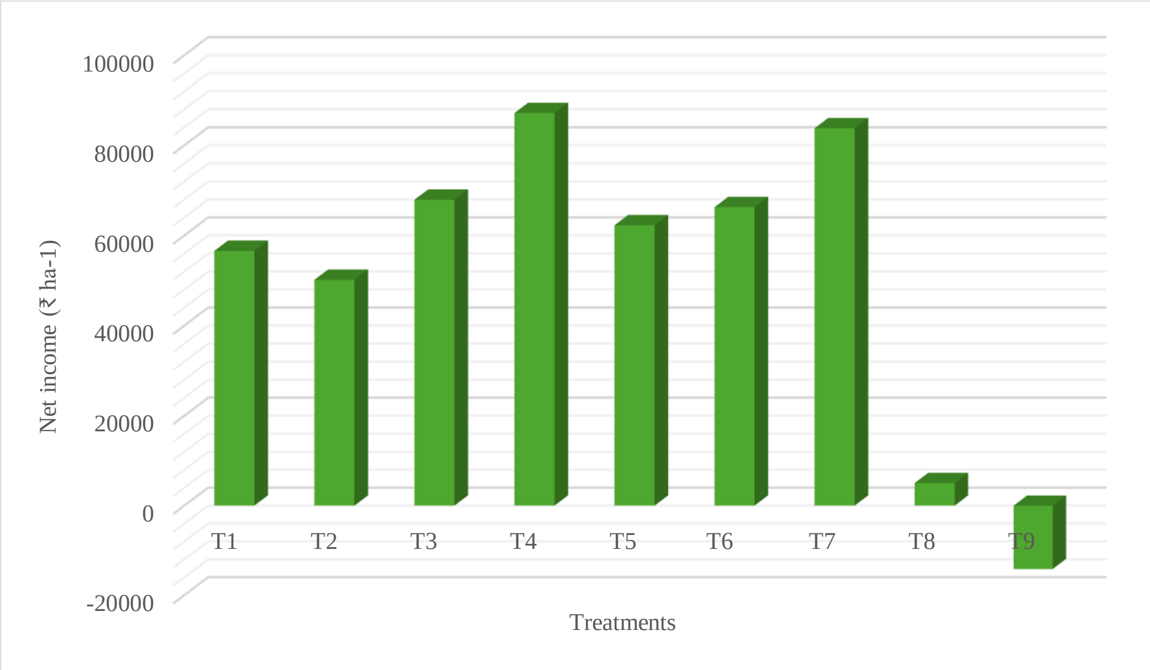


Fig. 11. Effect of weed management practices on net income (₹ ha^{-1})

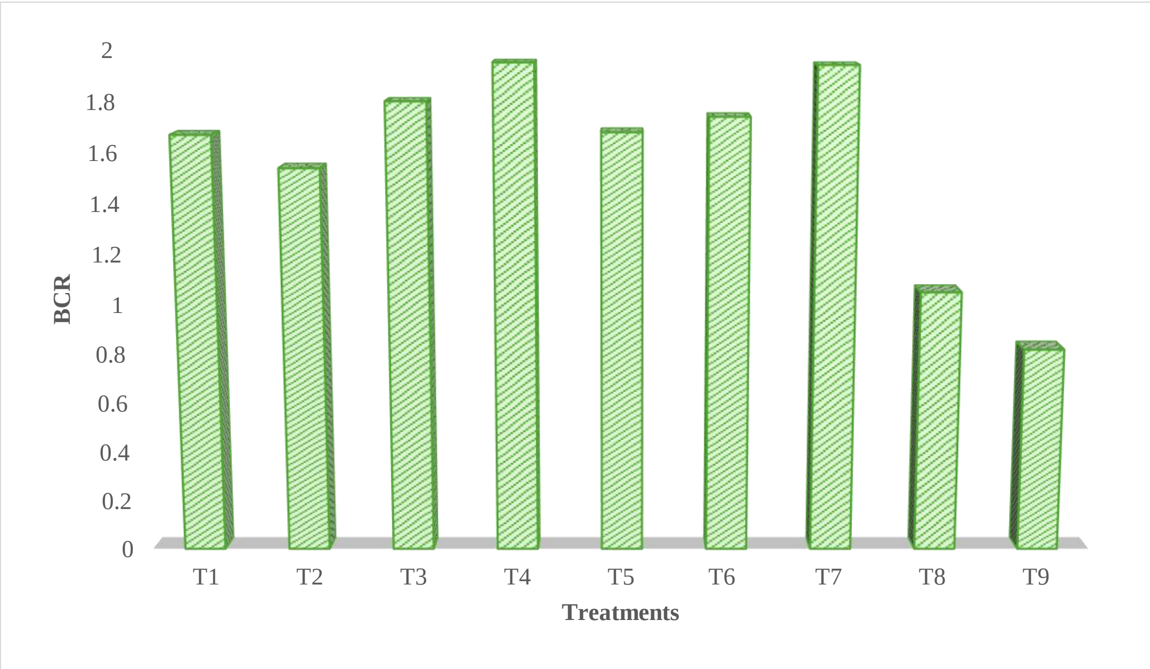
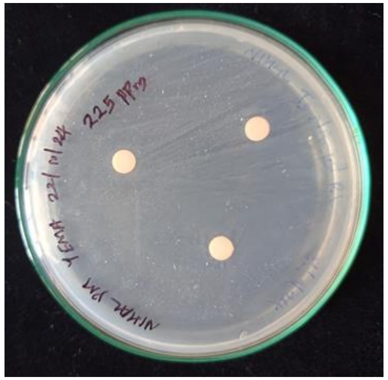


Fig. 12. Effect of weed management practices on B:C ratio

175 ppm

200 ppm



225 ppm

250 ppm

275 ppm

300 ppm

325 ppm

Control

Plate 7. *In vitro* sensitivity of *Bradyrhizobium* to Propaquizafop + imazethapyr

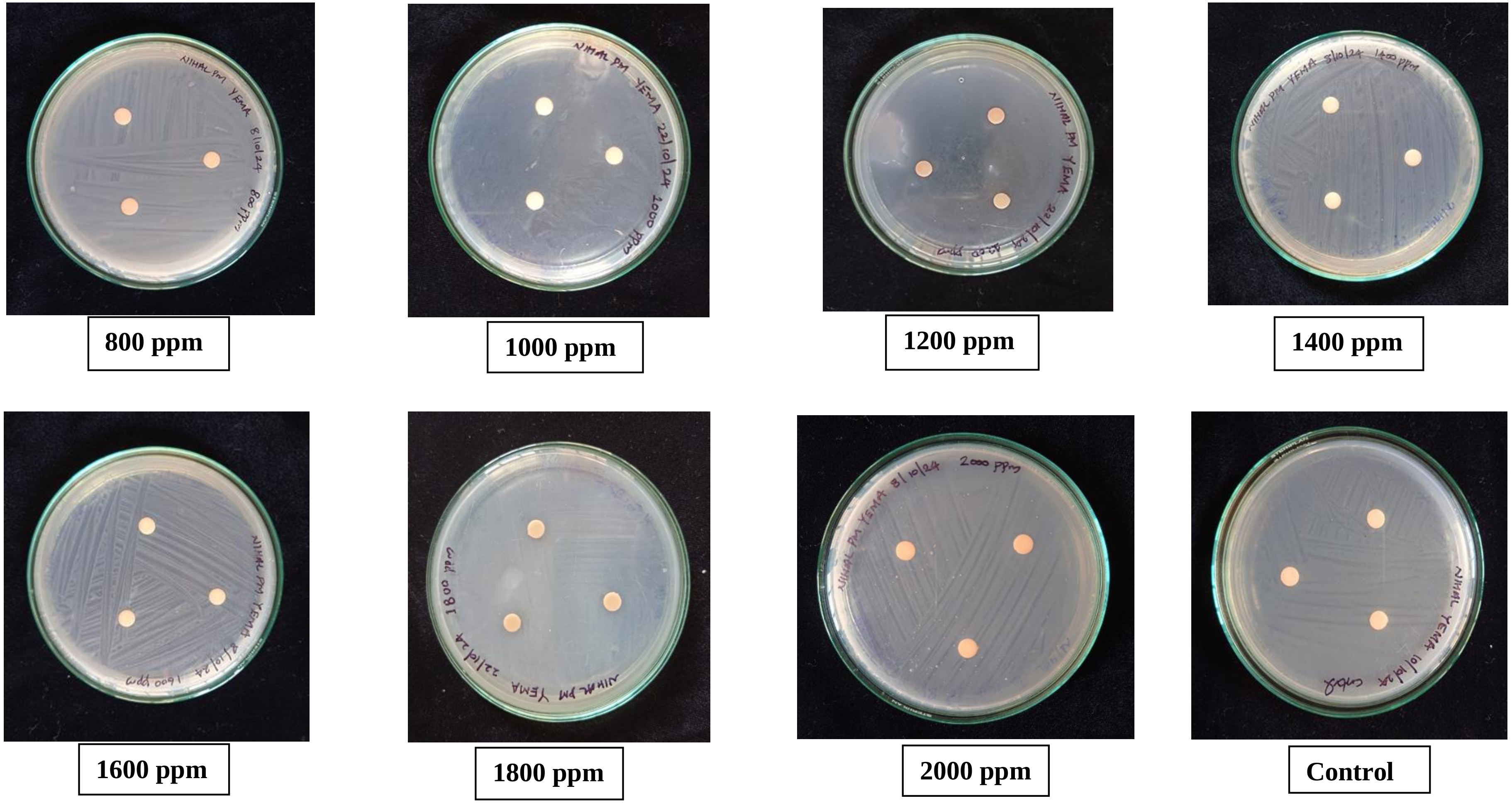


Plate 8. *In vitro* sensitivity of *Bradyrhizobium* to pendimethalin+ imazethapyr

income of Rs. 5,039 ha^{-1} due to high labour costs and suboptimal weed control. The highest BCR (1.95) was recorded in T_4 followed by T_7 (1.94) and T_3 (1.80), showcasing the economic advantage of integrating herbicides with hand weeding. Hand weeding twice (T_8) and the weedy check recorded lower BCR of 1.05 and 0.82, respectively, emphasizing their limited economic viability.

The study revealed that the premix combination, pendimethalin + imazethapyr 800 g ha^{-1}could cause phytotoxicity in blackgram when applied on the next day of sowing and the symptoms persisted upto 10 days after herbicide application. The present investigation also revealed the need for adopting integrated weed management practices especially at the critical stages of crop-weed competition for realizing better yield from blackgram intercropped in coconut garden. Uncontrolled weed growth could result in a yield reduction of 54.44 per cent in blackgram. The weeds could be effectively controlled by propaquizafop + imazethapyr 125 g ha^{-1} at 15 DAS *fb* HW at 40 DAS; and application of pendimethalin 1kg ha^{-1} on the next day of sowing *fb* propaquizafop 100g ha^{-1} at 15 DAS. From an economic perspective, application of propaquizafop + imazethapyr at 15 DAS followed by hand weeding at 40 DAS emerged as the promising integrated weed management approach for maximizing seed yield in blackgram intercropped in coconut garden.

SUMMARY

6. SUMMARY

An investigation entitled 'Integrated weed management in blackgram [*Vigna mungo* (L.) Hepper] with pre-mix herbicides' was conducted at College of Agriculture, Vellayani, Thiruvananthapuram during 2022-2024. The major objective of the study was to formulate an integrated weed management strategy using pre-mix herbicides for black gram intercropped in coconut garden.

The field experiment was conducted at the Instructional Farm, Vellayani during February to April 2024 (summer season) in a coconut garden with palms above 40 years of age, planted at a spacing of 7.5 m x 7.5 m and permitting 60 per cent of the solar radiation to filter through the canopy. The experiment was laid out in randomized block design with nine treatments replicated thrice. The weed management practices tested were: T_1- pre emergence (PE) pendimethalin + imazethapyr (premix 1) 800 g ha^{-1}; T_2 - T_1 followed by (*fb*) hand weeding (HW) at 30 days after sowing (DAS); T_3- post emergence (PoE) propaquizafop + imazethapyr (premix 2) 125 g ha^{-1}; T_4- T_3 *fb* HW at 40 DAS; T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS; T_6- PE pendimethalin 1kg ha^{-1}*fb* PoE imazethapyr 50g ha^{-1}; T_7- PE pendimethalin 1kg ha^{-1} *fb* PoE propaquizafop 100g ha^{-1}; T_8- HW at 15 and 30 DAS; T_9- weedy check. The blackgram variety DBGV-5 treated with *Bradyrhizobium* inoculant BMBS 47 was dibbled in the interspaces of coconut and managed as per the KAU Package of Practices. Pre emergence herbicide was applied on the next day of sowing and post emergence applied at 15 DAS. The salient findings of the experiment are summarised here.

Among the different treatments of herbicides tested, symptoms of phytotoxicity were observed in crop as mild stunting in plots sprayed with premix combination, pendimethalin + imazethapyr which persisted upto 10 days after herbicide application and recovered by 15 days after application.

The results of the study revealed that weed management practices had no significant influence on the growth attributes of blackgram.

A significant variation among the treatments was observed with respect to the number of effective nodules produced per plant. Pre-emergence application of pendimethalin 1kg ha^{-1} followed by propaquizafop 100g ha^{-1} resulted in higher effective nodules per plant (31.67) and was on par with T_4 (29.67), T_3 (25.33) and T_9 (24.67). A significantly lower number of effective nodules per plant was observed in T_2 (15.33) and was on par with T_5 (17.33), T_6 (18.33), T_1 and T_8 (18.67).

The data revealed that fresh weight of nodules was not significantly influenced by weed management practices. However, the nodule fresh weight ranged between 111.67 mg to 182.03 mg per plant.

Perusal of the data revealed a significant variation in the number of days required to reach 50 per cent flowering in black gram raised as intercrop in coconut garden. In general, the number of days to attain 50 per cent flowering ranged between 39.67 to 43.

Among the weed management practices. T_3 resulted in early flowering (39.67 days) and was comparable with T_4 (40.67 days) and T_7 (40. 67 days). Application of pendimethalin + imazethapyr resulted in more number of days (43.00) to reach flowering and was on par with T_2 (42.67), T_9 (42) and T_6 (41.67 days).

However, the yield and yield attributes were significantly influenced by the weed management practices. Higher pods per plant was recorded in T_4 (36.00) and was comparable with T_7 (35.83) while weedy check recorded the lowest number of pods (14.24). Hundred seed weight was recorded higher in T_2 (5.33 g) and was on par with T_4 (5.17 g) and T_1 (5.13 g).

The highest seed yield per plant was recorded in T_4 (9.60 g) followed by T_7 (9.23g), T_6 (8.3g) and T_5 (8.23g). Post emergence application of premix 2 *fb* HW at 40 DAS resulted in higher seed yield per ha (1793 kg) and was comparable with T_7 (1731 kg).

Higher haulm yield per ha was recorded in T_5 (3658 kg) and was comparable with T_4 (3616 kg), T_6 (3581 kg) and T_7 (3485 kg).

The study observed that absence of weeding led to the highest yield reduction in blackgram, with a weed index of 54.44 per cent while yield reduction was lower in T_4 (2.45%) and on par with T_7 (5.35%).

The predominant weed flora in the experimental field was grasses. However, more diversity was observed in the flora of broad leaf weeds. *Megathyrsus maximus* and *Eleusine indica* were the grass species present in the experimental field.

The major BLW species observed were *Phyllanthus niruri, Mollugo pentaphylla, Spermacoce latifolia, Richardia scabra, Euphorbia hirta, Commelina diffusa, Synedrella nodiflora, Trianthema portulacastrum* and *Odenlandia umbellata. Cyperus rotundus* was the only sedge present in the field.

Pre emergence application of premix 1 *fb* HW at 30 DAS resulted in significantly lower weed density and weed dry weight and higher weed control efficiency at all stages of observation and was comparable with T_7, T_4 and T_6. At 30 and 45 DAS, T_1, T_2, T_5, T_6 and T_7 resulted in lower relative biomass of grasses that was comparable with T_4 and the highest relative biomass of grasses was recorded in weedy check (85.92 %).

Treatments involving both pre- and post-emergence herbicide applications (T_7 and T_6) resulted in higher dehydrogenase enzyme activity at 30 DAS, while their combination with hand weeding (T_4, T_5) showed increased activity at 45 DAS.

Weed management practices significantly influenced nutrient uptake, with T_7 and T_1 exhibiting higher N, P and K uptake. The integration of premix herbicides with hand weeding and use of pre and post-emergence herbicides, significantly reduced N, P, and K removal by weeds throughout the growth period.

The BC ratio varied significantly among the weed management practices with the highest in T_4 (1.95), followed by T_7 (1.94), with the lowest ratios in hand weeding twice (1.05) and weedy check (0.82).

Effect of weed management practices on population of beneficial rhizospheric soil microorganisms including bacteria, fungi and actinomycetes were assessed from soil samples collected from root zone using serial dilution followed by plating on appropriate microbial media under *in vitro* condition. The microbial count was estimated at different time points *viz.*, before spraying, at 15 and 30 days after spraying.

Weed management practices significantly influenced the population of *Bradyrhizobium*, fungi and actinomycetes in rhizospheric soil at 30 DAS with T_2 showing higher count and on par with T_1. However, no significant differences were noted in the population of phosphorus solubilising bacteria across all time points.

Laboratory experiments were undertaken separately to examine the *in vitro* sensitivity of *Bradyrhizobium* to two premix herbicides following standard procedures (disc diffusion method). The *in vitro* sensitivity test of *Bradyrhizobium* to premix 1 (pendimethalin + imazethapyr) and 2 (propaquizafop + imazethapyr) at concentrations of 800 to 2000 ppm and 175 to 325 ppm respectively showed positive growth with no inhibition zones around the sterile disc containing herbicide mixture placed on a lawn of *Bradyrhizobium* in the medium. The results revealed the compatibility of premix 1 and 2 with *Bradyrhizobium.*

The study identified application of propaquizafop + imazethapyr 125 g ha^{-1} at 15 DAS *fb* HW at 40 DAS; and application of pendimethalin 1kg ha^{-1} on the next day of sowing *fb* propaquizafop 100g ha^{-1} at 15 DAS as the most effective weed management strategies in terms of yield, weed control efficiency and gross return in blackgram.

Considering economics, hand weeding twice resulted in a lower BC ratio of 1.05, while the weedy check recorded the lowest BC ratio of 0.82.

Application of propaquizafop + imazethapyr at 15 DAS *fb* HW at 40 DAS could be adjudged as the most effective integrated weed management strategy for achieving higher seed yield (1793 kg ha^{-1}) with a mean BC ratio of 1.95 in blackgram intercropped in coconut garden.

Future line of work

- The application window of the ready mix herbicides with molecules having both pre and post action can be standardised
- Still lower doses of propaquizafop + imazethapyr can be tested for its efficacy in coconut garden

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APPENDICES

APPENDIX I

Weather data during the cropping period

(February to April, 2024)

Standard week	Temperature (^{o} C)		Relative humidity (%)		Mean bright sunshine hours	Total rainfall (mm)	Evaporation (mm per day)
	Maximum	Minimum	RH I	RH II			
6	32.73	21.41	94.43	73.29	7.3	0	4.17
7	33.17	21.4	94	74.14	7.9	0	4.16
8	33.21	21.53	93.29	75.43	9.41	0	4.49
9	33.84	23.01	90.43	74.43	9.74	0	4.06
10	33.63	22.16	90.43	74.43	9.54	0	4.56
11	33.86	23.69	87.57	76	7.87	0	4.77
12	33.94	24.23	86.43	67.43	8.5	0.59	4.97
13	34.33	24.64	86.86	64.71	9.04	0.26	5.23
14	34.25	25.94	89.29	69.71	8.95	5.03	4.63
15	33.45	24.79	89.57	77	7.25	10.46	4.07
16	33.99	26.09	88.57	68	7.42	0.63	4.41
17	34.34	25.61	86.71	68.86	7.44	5.34	4.57

APPENDIX II

Average input cost and market price of produce

Sl. No	Items	Cost (₹)
I	**INPUT**	
A	Seed	
	Black gram seed	180 kg^{-1}
B	Labour	
	Man	800 day^{-1}
	Woman	600 day^{-1}
C	Manures, fertilizers, biofertilizer and herbicide	
	FYM	1 kg^{-1}
	Lime	20 kg^{-1}
	Urea	7 kg^{-1}
	Rajphos	17 kg^{-1}
	Muriate of Potash	40 kg^{-1}
	Rhizobium	90 kg^{-1}
	Pendimethalin (Dost Super)	535 for 700 mL
	Imazethapyr (Pursuit ®)	714 for 500 mL
	Propaquizafop (Agil)	710 for 250 mL
	Pendimethalin (30%) + imazethapyr (2%) (Penza)	850 for1000 mL
	Propaquizafop (2.5%) + Imazethapyr (3.75%) (Shaked)	880 for 400 mL
II	**OUTPUT**	
	Market price of unprocessed blackgram	100 per kg^{-1}

ABSTRACT

INTEGRATED WEED MANAGEMENT IN BLACKGRAM [*Vigna mungo* (L.) Hepper] WITH PRE-MIX HERBICIDES

by

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ABSTRACT

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ABSTRACT

An investigation entitled 'Integrated weed management in blackgram [*Vigna mungo* (L.) Hepper] with pre-mix herbicides' was conducted at College of Agriculture, Vellayani during 2022-2024. The major objective was to formulate an integrated weed management strategy using pre-mix herbicides for black gram intercropped in coconut garden. The field experiment was conducted at the Instructional Farm, Vellayani during the summer season from February to April 2024 in a coconut garden with palms above 40 years of age.

The experiment was laid out in randomized block design with nine treatments replicated thrice. The weed management practices tested were: T_1- pre emergence (PE) pendimethalin + imazethapyr (premix 1) 800 g ha^{-1}; T_2 - T_1 followed by (*fb*) hand weeding (HW) at 30 days after sowing (DAS); T_3- post emergence (PoE) propaquizafop + imazethapyr (premix 2) 125 g ha^{-1}; T_4- T_3 *fb* HW at 40 DAS; T_5- PE pendimethalin 1kg ha^{-1} *fb* HW at 30 DAS; T_6- PE pendimethalin 1kg ha^{-1}*fb* PoE imazethapyr 50g ha^{-1}; T_7- PE pendimethalin 1kg ha^{-1} *fb* PoE propaquizafop 100g ha^{-1}; T_8- HW at 15 and 30 DAS; T_9- weedy check. The blackgram variety DBGV-5 treated with *Bradyrhizobium* inoculant BMBS 47 was dibbled in the interspaces of coconut and managed as per the KAU Package of Practices. Pre emergence herbicide was applied on the next day of sowing and post emergence applied at 15 DAS. Symptoms of phytotoxicity were observed in crop as mild stunting in plots sprayed with premix combination, pendimethalin + imazethapyr which persisted upto 10 days after herbicide application.

The results of the study revealed that weed management practices had no significant influence on the growth attributes of blackgram. However, the yield and yield attributes were significantly influenced by the weed management practices. Higher pods per plant was recorded in T_4 (36.00) and was comparable with T_7 (35.83) while weedy check recorded the lowest number of pods (14.24). Hundred seed weight was recorded higher in T_2 (5.33 g) and was on par with T_4 (5.17 g) and T_1 (5.13 g).

The highest seed yield per plant was recorded in T_4 (9.60 g) followed by T_7 (9.23g), T_6 (8.3g) and T_5 (8.23g). Post emergence application of premix 2 *fb* HW at 40 DAS resulted in higher seed yield per ha (1793 kg) and was comparable with T_7 (1731

kg). Higher haulm yield per ha was recorded in T_5 (3658 kg) and was comparable with T_4 (3616 kg), T_6 (3581 kg) and T_7 (3485 kg). The study observed that absence of weeding led to the highest yield reduction in blackgram, with a weed index of 54.44 per cent while yield reduction was lower in T_4 (2.45%) and on par with T_7 (5.35%).

The predominant weed flora in the experimental field was grasses. However, more diversity was observed in the flora of broad leaf weeds. Pre emergence application of premix 1 *fb* HW at 30 DAS resulted in significantly lower weed density and weed dry weight and higher weed control efficiency at all stages of observation and was comparable with T_7, T_4 and T_6. At 30 and 45 DAS, T_1, T_2, T_5, T_6 and T_7 resulted in lower relative biomass of grasses that was comparable with T_4 and the highest relative biomass of grasses was recorded in weedy check (85.92 %).

Treatments involving both pre- and post-emergence herbicide applications (T_7 and T_6) resulted in higher dehydrogenase enzyme activity at 30 DAS, while their combination with hand weeding (T_4, T_5) showed increased activity at 45 DAS. Weed management practices significantly influenced nutrient uptake, with T_7 and T_1 exhibiting higher N, P and K uptake. The integration of premix herbicides with hand weeding and use of pre and post-emergence herbicides, significantly reduced N, P, and K removal by weeds throughout the growth period. The BC ratio varied significantly among the weed management practices with the highest in T_4 (1.95), followed by T_7 (1.94), with the lowest ratios in hand weeding twice (1.05) and weedy check (0.82).

Weed management practices significantly influenced the population of *Bradyrhizobium*, fungi and actinomycetes in rhizospheric soil at 30 DAS with T_2 showing higher count and on par with $T_{1.}$ However, no significant differences were noted in the population of phosphorus solubilising bacteria across all time points. The *in vitro* sensitivity test of *Bradyrhizobium* to premix 1 and 2 at concentrations of 800 to 2000 ppm and 175 to 325 ppm respectively showed positive growth with no inhibition zones around the sterile disc containing herbicide mixture placed on a lawn of *Bradyrhizobium* in the medium.

The study identified application of propaquizafop + imazethapyr 125 g ha^{-1} at 15 DAS *fb* HW at 40 DAS; and application of pendimethalin 1kg ha^{-1} on the next day of sowing *fb* propaquizafop 100g ha^{-1} at 15 DAS as the most effective weed management strategies in terms of yield, weed control efficiency and gross return in blackgram. Considering economics, application of propaquizafop + imazethapyr at 15 DAS *fb* HW at 40 DAS could be adjudged as the most effective integrated weed management strategy for achieving higher seed yield in blackgram intercropped in coconut garden.

സംഗ്രഹം

''മിശ്രിത കളനാശിനികൾ (പ്രീ മിക്സ്) ഉപയോഗിച്ച് ഉഴുന്നിലെ സംയോജിത കള നിയന്ത്രണം' എന്ന വിഷയത്തിലുള്ള പഠനം കേരള കാർഷിക സർവകലാശാലയുടെ കീഴിലുള്ള വെള്ളായണി കാർഷിക കോളേജിൽ 2022 മുതൽ 2024 വരെയുള്ള കാലയളവിൽ നടന്നു. 40 വർഷത്തിലധികം പ്രായമുള്ള തെങ്ങിൻ തോപ്പിൽ ഉഴുന്ന് ഇടവിളയായി കൃഷിചെയ്യുന്നതിനായി മിശ്രിത കളനാശിനികൾ ഉൾപ്പെടുന്ന സംയോജിത കള നിയന്ത്രണ രീതി രൂപപ്പെടുത്തുന്നതായിരുന്നു പ്രധാന ലക്ഷ്യം. 2024 ഫെബ്രുവരി മുതൽ ഏപ്രിൽ വരെയുള്ള വേനൽക്കാലത്ത് വെള്ളായണി ഇൻസ്ട്രക്ഷണൽ ഫാമിൽ ഈ ഫീൽഡ് പരീക്ഷണം നടന്നു.

റാൻഡമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈൻ അനുസരിച്ച്, ഒമ്പത് ട്രീട്മെന്റുകൾ മൂന്നുതവണ ആവർത്തിച്ച് നടത്തിയ പരീക്ഷണത്തിൽ പരിശോധിച്ച കള നിയന്ത്രണ രീതികൾ ഇപ്രകാരമാണ്: T1 – മുളക്കുന്നതിനു മുമ്പ് പെൻഡിമെഥാലിൻ + ഇമസെഥപയർ (പ്രീ മിക്സ് 1) ഹെക്ടറിന് 800 ഗ്രാം, T2 – T1 തുടർന്ന് 30 ദിവസം കഴിഞ്ഞ് കൈകൊ ുള്ള കളനീക്കം, T3 – മുളച്ചതിനു ശേഷം പ്രൊപ്പാക്വിസാഫോപ് + ഇമസെഥപയർ (പ്രീ മിക്സ് 2) ഹെക്ടറിന്125 ഗ്രാം, T4 – T3 തുടർന്ന് വിതച്ച് 40 ദിവസങ്ങൾ കഴിഞ്ഞ് കൈകൊ ുള്ള കള നീക്കം, റ്റി 5– മുളക്കുന്നതിനു മുമ്പ് പെൻഡിമെഥാലിൻ ഹെക്ടറിന് 1 കിലോ തുടർന്ന് വിതച്ച് 30 ദിവസം കഴിഞ്ഞ് കൈകൊ ുള്ള കള നീക്കംT6 – മുളക്കുന്നതിനു മുമ്പ് പെൻഡിമെഥാലിൻ ഹെക്ടറിന്1 കിലോ, തുടർന്ന് മുളച്ചതിനു ശേഷം ഇമസെഥപയർ ഹെക്ടറിന് 50 ഗ്രാം, T7 – മുളക്കുന്നതിനു മുമ്പ് പെൻഡിമെഥാലിൻ ഹെക്ടറിന്1 കിലോ, തുടർന്ന് മുളച്ചതിനു ശേഷം പ്രൊപ്പാക്വിസാഫോപ് ഹെക്ടറിന് 100 ഗ്രാം, T8 – വിതച്ച് 15, 30 ദിവസങ്ങൾക്ക് ശേഷം കൈകൊ ുള്ള കള നീക്കം, T9 – കള നീക്കം ചെയ്യാത്ത രീതി. ബ്രാഡിറൈസോബിയം ബിഎംബിസ് 47 ഉപയോഗിച്ച് വിത്തുപചാരം ചെയ്ത ഡി ബി ജി വി -5 ഉഴുന്ന് വിത്തിനം തെങ്ങിന്റെ ഇടസ്ഥലത്ത്, 25 സെ. മീ X 15 സെ. മീ അകലത്തിൽ വിതച്ചു, വിത്ത് വിതച്ച് ഒരു ദിവസം കഴിഞ്ഞ് പ്രീ എമർജൻസ് കള നാശിനി മണ്ണിലേക്ക് തളിച്ചു. പോസ്റ്റ് എമർജൻസ് കളനാശിനികൾ വിത്ത് വിതച്ച് 15 ദിവസത്തിന് ശേഷമാണ് പ്രയോഗിച്ചത്. കേരള കാർഷിക സർവ്വകലാശാലയുടെ വിള പരിപാലന നിർദേശങ്ങൾ അനുസരിച്ച് പരിപാലിച്ചു.

പ്രീ മിക്സ് കോമ്പിനേഷൻ ആയ പെൻഡിമെഥാലിൻ + ഇമസെഥപയർ ഉപയോഗിച്ച ട്രീട്മെന്റുകളിൽ (T1, T2), നേരിയതും താൽക്കാലികവുമായ വളർച്ച മുരടിപ്പ് അനുഭവപ്പെട്ടങ്കിലും, ഈ ചെടികൾ കളനാശിനി പ്രയോഗിച്ച് 10 ദിവസങ്ങൾക്കുള്ളിൽ പൂർവ്വസ്ഥിതിയിലായി.

പരീക്ഷിച്ച കള നിയന്ത്രണ രീതികൾ ഉഴുന്നിലെ വളർച്ചാ ഘടകങ്ങളിൽ കാര്യമായ സ്വാധീനം ചെലുത്തിയില്ലെന്നു പഠന ഫലം സൂചിപ്പിക്കുന്നു. എങ്കിലും, വിളവിനെയും വിളവിന്റെ ഘടകങ്ങളെയും കളനാശിനി നിയന്ത്രണ രീതികൾ സ്വാധീനിക്കുന്നതായി ക ത്തി മുളച്ചതിനു ശേഷം പ്രൊപ്പാക്വിസാഫോപ് + ഇമസെഥപയർ (പ്രീ മിക്സ് 2) ഹെക്ടറിന്125 ഗ്രാം, തുടർന്ന് വിതച്ച് 40 ദിവസങ്ങൾ കഴിഞ്ഞ് കൈകൊ ു കള നീക്കം ചെയ്ത പ്ലോട്ടിൽ ഒരു ചെടിയിലെ ഉയർന്ന കായ് ഫലം (36.00) രേഖപ്പെടുത്തി. കള നീക്കം ചെയ്യാത്ത പ്ലോട്ടുകളിൽ ഏറ്റവും കുറഞ്ഞ കായ്കളുടെ എണ്ണം (14.24) രേഖപ്പെടുത്തി.

മുളച്ചതിനു ശേഷമുള്ള പ്രി മിക്സ് 2ന്റെ പ്രയോഗവും തുടർന്ന് വിതച്ചു 40 ദിവസത്തിനു ശേഷം കൈകൊ ു കള നീക്കവും ചെയ്യുന്ന രീതിയിൽ ഒരു ചെടിയിലെ ഏറ്റവും ഉയർന്ന ഉഴുന്ന് മണി കളുടെ വിളവ് (9.60 ഗ്രാം), ഉയർന്ന വിത്തിന്റെ വിളവും (1793 കിലോ) രേഖപ്പെടുത്തി. കള നിയന്ത്രണത്തിന്റെ അഭാവം 54.44% വരെ വിളവ് കുറയുന്നതിന് കാരണമാവുന്നതായി പഠനം നിരീക്ഷിച്ചു.

മുളക്കുന്നതിനു മുൻപുള്ള പ്രി മിക്സ് 1 ന്റെ പ്രയോഗം,തുടർന്ന് വിതച്ച് 30 കഴിഞ്ഞ് കൈകൊ ു കള നീക്കത്തിന്റെ ഫലമായി എല്ലാ നിരീക്ഷണ ഘട്ടങ്ങളിലും കളകളുടെ അളവിലും ഭാരത്തിലും ഗണ്യമായ കുറവ്, ഉയർന്ന കള നിയന്ത്രണ കാര്യക്ഷമത എന്നിവ രേഖപ്പെടുത്തി.

മുളക്കുന്നതിനു മുൻപും ശേഷവുമുള്ള കളനാശിനി പ്രയോഗം (T7, T6) വിതച്ച് 30 ദിവസങ്ങൾക്കു ശേഷം മണ്ണിൽ ഉയർന്ന ഡീഹൈഡ്രോജിനേസ് എൻസൈമിന്റെ പ്രവർത്തനത്തിന് കാരണമായി. ഏറ്റവും ഉയർന്ന വരവ് ചിലവ് അനുപാതം T 4 ലും (1.95), തൊട്ടു പിന്നിലായി T7 (1.94), ഏറ്റവും കുറവ് കള നീക്കം ചെയ്യാത്തതിലും 2 തവണ കൈകൊ ു കള നീക്കം ചെയ്തതിലും ആണ് രേഖപ്പെടുത്തിയത്.

വിതച്ച് 30 ദിവസത്തിനു ശേഷം റൈസോസ്ഫിയറിക് മണ്ണിലുള്ള ബ്രാഡിറൈസോബിയം, ഫംഗൈ, ആക്ടിനോമൈസിറ്റ്സ് എന്നിവയുടെ അംഗ സംഖ്യയിൽ കള നിയന്ത്രണ രീതികൾ ഗണ്യമായ സ്വാധീനം ചെലുത്തിയതായി ക ു. റ്റി 2ൽ ഏറ്റവും ഉയർന്ന അംഗ സംഖ്യ രേഖപ്പെടുത്തി. എങ്കിലും, വിവിധ സമയങ്ങളിലുടനീളം ഫോസ്ഫറസ് ലയിപ്പിക്കുന്ന ബാക്ടീരിയയുടെ അംഗ സംഖ്യയിൽ കാര്യമായ വ്യത്യാസം കാണപ്പെട്ടില്ല.

പ്രീ മിക്സ് 1 (800 മുതൽ 2000 പി പി എം വരെ), പ്രീ മിക്സ് 2 (175 മുതൽ 325 പി പി എം വരെ) ന്റെയും വ്യത്യസ്ത വീര്യമുള്ള കളനാശിനി മിശ്രിതങ്ങൾ ഉപയോഗിച്ച് നടത്തിയ ഇൻ വിട്രോ സെൻസിറ്റിവിറ്റി ടെസ്റ്റി ൽ ബ്രാഡിറൈസോബിയം മികച്ച വളർച്ച രേഖപ്പെടുത്തി. ബ്രാഡിറൈസോബിയം വളർത്തിയ മീഡിയത്തിലേയ്ക്കു കളനാശിനിയുള്ള സ്റ്റെറൈൽ ഡിസ്ക് വെച്ചപ്പോൾ അതിന് ചുറ്റിലും ഇൻഹിബിഷൻ സോൺ പ്രകടമായില്ല.

വിതച്ച് 15 ദിവസത്തിനു ശേഷം പ്രൊപ്പാക്വിസാഫോപ് + ഇമസെഥപയർ ഹെക്ടറിന് 125 ഗ്രാം, തുടർന്ന് വിതച്ച് 40 ദിവസത്തിന് ശേഷം കൈകൊ ു കളനീക്കം നടത്തുന്നതും

T4), വിത്ത് വിതച്ച അടുത്ത ദിവസം പെൻഡിമെഥാലിൻ ഹെക്ടറിന് 1 കിലോ പ്രയോഗിച്ച്, തുടർന്ന് വിതച്ച് 15 ദിവസത്തിന് ശേഷം പ്രൊപ്പാക്വിസാഫോപ്ഹെക്ടറിന് 100 ഗ്രാം പ്രയോഗിക്കുന്നതും (T7) ഉഴുന്നിലെ ഉത്പാദനം, കളനിയന്ത്രണ കാര്യക്ഷമത, മൊത്ത വരുമാനം എന്നിവയുടെ അടിസ്ഥാനത്തിൽ ഏറ്റവും ഫലപ്രദമായ കളനിയന്ത്രണ രീതികളായി തിരിച്ചറിഞ്ഞു.

വിതച്ച് 15 ദിവസങ്ങൾക്കു ശേഷം പ്രൊപ്പാക്വിസാഫോപ് + ഇമസെഥപയർ മണ്ണിലേക്ക് പ്രയോഗിച്ചതും, തുടർന്ന് വിതച്ച് 40 ദിവസങ്ങൾക്കു ശേഷം കൈകൊ ു കളനീക്കം ചെയ്യുന്നതുമായ രീതിയെയാണ് തെങ്ങിൻ തോപ്പിൽ ഇടവിളയായി കൃഷിചെയ്യുന്ന ഉഴുന്നിൽ കൂടുതൽ ഉത്പാദനം ലഭ്യമാക്കാൻ ഏറ്റവും ലാഭകരമായ സംയോജിത കളനിയന്ത്രണ രീതി.