INTEGRATED WEED MANAGEMENT IN GREEN GRAM
[*Vigna radiata* (L.) Wilczek]

By

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(2019-11-215)

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THESIS

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DEPARTMENT OF AGRONOMY
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KERALA, INDIA

2021

DECLARATION

I, hereby declare that the thesis entitled **"Integrated weed management in green gram [*Vigna radiata* (L.) Wilczek]"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

Saveri Gopakumar

(2019-11-215)

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Date: 08-11-2021

CERTIFICATE

Certified that this thesis entitled **"Integrated weed management in green gram [*Vigna radiata* (L.) Wilczek]"** is a bonafide record of research work done independently by **Ms. Saveri Gopakumar (2019-11-215)** 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 her.

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We, the undersigned members of the advisory committee of **Ms. Saveri Gopakumar (2019-11-215)**, a candidate for the degree of **Master of Science in Agriculture** with major field in **Agronomy,** agree that this thesis entitled **"Integrated weed management in green gram [*Vigna radiata* (L.) Wilczek]"** may be submitted by **Ms. Saveri Gopakumar**, in partial fulfillment of the requirement for the degree.

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Introduction

1. INTRODUCTION

Pulses form the second major category of food crops in India, just after cereals. Being good sources of protein, carbohydrates, vitamins and minerals, they are an indispensable part of human diet. In addition, they are known to enhance soil fertility by virtue of their nitrogen fixing ability, and their deep root system and profuse vegetative growth help in soil and water conservation, making them an integral component of sustainable agriculture. Although India is the world's leading producer of pulses, accounting for 34 per cent of the total area and 20 per cent of the total production, the productivity of pulses in India (441.3 kg/ha) is much below than the world average (759.3 kg/ha) (FAOSTAT, 2019).

Green gram is a short duration, *kharif* season pulse crop, which can be cultivated in *rabi* and summer seasons as well. Green gram has an important place in nutritional security as it is a rich source of protein (25 %), riboflavin, thiamine and ascorbic acid. Being a legume, it is known to fix atmospheric nitrogen @ 16-80 kg N/ha per year (Hayat *et al*., 2008). It can also be used as cover crop or catch crop, and makes an excellent green manure crop. India ranks first in the production of green gram with an area of 4.58 M ha, production of 2.50 M t and productivity of 548 kg/ha (IndiaAgriStat, 2019-20). But, the production of green gram has remained almost static in the recent years, which is a direct result of various biotic and abiotic stresses. Weeds are the prominent among the biotic factors, leading to substantial yield loss.

Weeds compete with crop for resources like water, nutrients, light and space, and cause considerable reduction in yield and net monetary benefits. It is estimated that weeds account for 45 per cent of the total annual crop loss arising from biotic stresses, which is much higher compared to that due to insects (30 %), diseases (20 %) or other pests (5 %) (Rao, 2000). Green gram is extremely susceptible to competition from weeds during the early stages due to slow initial growth, but later, it develops dense foliage, which can create a smothering effect on weeds. Thus, uncontrolled weed growth during the critical periods of crop-weed competition can cause considerable reduction in the yield of green gram.

Hand weeding is the most common and effective method of weed control in green gram, which ultimately results in higher seed yield and haulm yield. However, the unavailability of timely labour, high labour costs and adverse weather conditions have created practical difficulties in adopting manual weeding on a large scale. This created the need for chemical weed management using herbicides, which is being widely accepted due to ease of application, quick action and reduced labour charges. However, continuous use of herbicides resulted in problems like environmental contamination and resistance development. Thus, there is a need to integrate different cultural, mechanical, chemical and biological methods of weed control to evolve weed management strategies that can successfully lower the weed population below the economic threshold levels without causing much damage to the ecosystem.

Integrated weed management is a process of scientific decision making which utilizes the information on environmental factors, and ecology and biology of weeds to coordinate the available options of weed control in the most economical manner and at the same time, taking due care of the risks that it may pose to the people and environment (Sanyal, 2008). The development of an integrated approach to weed management is becoming inevitable with the understanding that relying only on a single method of weed control is impractical and uneconomical. Adoption of appropriate methods of weed prevention is rudimentary for successful crop production. Mechanical methods like hand weeding, hand hoeing and mulching have been proved effective for weed control in green gram. There are also several cultural methods like crop rotation, planting at a closer spacing and stale seedbed technique which supplement weed management in green gram. Chemical weed management has been gaining popularity in the recent times with the introduction of high potency, low dose, non-residual herbicides which provide broad spectrum weed control in pulses. Pre-emergence herbicides like pendimethalin and oxyfluorfen, and post-emergence herbicides like quizalofop-ethyl and fenoxoprop-ethyl are commonly being used to control weeds in green gram and other pulse crops. Pre-emergence herbicides are highly efficient in controlling all kinds of weeds in green gram in the initial periods of crop growth up to about 30 days after sowing. However, no such post-emergence herbicides are available which provide season long control of broad leaved weeds in pulses (Kumar *et al*., 2016). Thus, integration of pre-emergence herbicides with hand weeding at 30 DAS has been attempted and has proved successful in achieving a broad-spectrum weed control in green gram.

Being a short duration crop with low water requirements, green gram can be successfully cultivated in the residual moisture in rice fallows after the harvest of rice. However, the low productivity of green gram is a major impediment to adoption of green gram cultivation on a large scale by farmers of Kerala. Hence, the present study on "Integrated weed management in green gram [*Vigna radiata* (L.) Wilczek]" was undertaken with the following objectives:

- To study the effects of different cultural, mechanical and chemical weed control methods on productivity and profitability in green gram
- To develop an integrated weed management strategy for green gram

Review of literature

2. REVIEW OF LITERATURE

Weeds are the major biotic constraints that hinder pulse crops like green gram from achieving their complete production potential. They not only affect the crop directly by competing with resources and reducing the yield, but also make intercultural operations laborious and harbor many disease causing organisms and pests. Knowledge about the type and intensity of weed flora and critical period of crop-weed competition is a pre-requisite in developing economically viable and environmentally safe weed control strategies for successful green gram production.

2.1 Weed spectra in green gram

Weed flora in green gram is diverse. A large number of species belonging to the classes broad leaved weeds, grasses and sedges are reported to adversely affect the growth and yield of green gram. Sangakkara *et al.* (1995) observed that broad leaved weeds cause maximum yield reduction in green gram (60 %), followed by grasses (42 %) and sedges (6 %). The distribution of weed flora is mainly determined by the location, season and other agro-climatic factors.

Punia *et al.* (2013) reported 22 weed species (14 broad leaved, 5 grasses and 3 sedges) to be dominant in the green gram ecosystem. They were *Digera arvensis, Trianthema portulacastrum, Mollugo distachya, Giesekia phernecoides, Cleome viscosa, Cucumis callosus, Tribulus terrestris, Corchrus aestuans, Corchrus tridens, Crotolaria medicaginea, Corchrus olitorius, Amaranthus spinosus, Convolvulus arvensis, Commelina kurzi, Dactyloctenium aegyptium, Digitaria sanguinalis, Echinochloa colona, Brachiaria repens, Cenchrus echinatus, Cyperus rotundus, Bulbostyllis barbata* and *Cyperus compressus*. Verma and Kushwaha (2018) observed that *Digera muricata* was the most dominant broad leaved weed with a relative density of 49.53 per cent, whereas *Dactyloctenium aegyptium* (11.84 %) and *Echinochloa colonum* (9.65 %) were the major grasses.

According to Kumar *et al.* (2017), *Digera arvensis* alone contributed to 39 per cent of the total weed dry weight in *kharif* season green gram, which was closely followed by *Cyperus* sp. (30 per cent). The other dominant weeds included *Arachne racemosa, Celosia argentea, Eragrostis pilosa, Leptochloa panicea, Setaria glauca, Chenopodium album, Conyza* spp, *Datura stramonium, Poa* spp, *Matricaria* spp, *Dinebra retroflexa, Rottboellia exaltata, Panicum repens* and *Trichodesma indicus* (Bahar *et al.*, 2017; Poornima *et al.*, 2018; Sassode *et al*., 2020). Senthivelu *et al.* (2020) concluded that 75 per cent of the total weeds observed in *Kharif season* green gram were broad leaved, 13 per cent were grasses and 8 per cent were sedges. The major broad leaved weeds were *Amaranthus viridis, Boerhaavia diffusa, Boerhaavia erecta, Cleome viscosa, Commelina benghalensis, Corchorus fascicularis, Corchorus olitorius, Digera arvensis, Euphorbia hirta, Euphorbia microphylla, Parthenium hysterophorus, Phyllanthus niruri, Phyllanthus maderaspatensis* and *Trianthema portulacastrum*, whereas *Chloris barbata, Cynadon dactylon, Echinochloa colonum* and *Echinochloa crus-galli* were the important grasses. *Cyperus difformis* and *Cyperus rotundus* were the only sedges observed.

The dominant weeds associated with *rabi* season green gram included *Amaranthus viridis, Alternanthera sessilis, Cassia tora, Convolvulus arvensis, Digera arvensis, Eclipta alba, Euphorbia hirta, Euphorbia maderaspatensis, Physalis minima, Vernonia cinerea, Brachiaria* sp., *Digitaria sanguinalis, Echinochloa crus-galli, Eragrostis major, Sorghum halapense* (Patel, 2015), *Boerhaavia diffusa, Cleome viscosa, Digera muricata, Phyllanthus niruri, Trianthema portulacastrum, Tridax procumbens, Chloris barbata, Cynodon dactylon, Dactyloctenium aegyptium* and *Cyperus rotundus* (Muthuram *et al.*, 2018).

A broad spectrum weed flora was associated with summer season green gram also. This included *Acanthospermum hispidum, Alysicarpous rugosus, Amaranthus viridis, Boerhaavia diffusa, Digera arvensis, Euphorbia hirta, Indigofera glandulosa, Leucas aspera, Portulaca oleraceae, Phyllanthus niruri, Tridax procumbens, Brachiaria* spp, *Cynodon dactylon, Eluropus villosus, Panicum colonum* and *Cyperus rotundus* (Chhodavadia *et al.*, 2014). Kumar *et al*. (2016) reported that *Cyperus rotundus* constituted 54 per cent of the total weeds in summer green gram, followed by grasses (34 per cent) and broad leaved weeds (6 per cent).

Shivran *et al.* (2017) opined that *Euphorbia hirta, Oldenlandia corymbosa, Echinochloa colonum, Eragrostis pilosa* and *Cyperus rotundus* were the major weeds of green gram grown under agri-horti systems.

2.2 Losses due to weeds in green gram

Weeds are found associated with crops throughout their growth period and cause considerable reduction in their yield. Due to the slow initial growth of green gram and high competitive ability of weeds, they are found to adversely affect the crop growth and productivity. Karmakar *et al.* (2015) recorded that the reduction in seed yield of green gram due to weeds could be as high as 25.7 per cent whereas it was only 19.1 per cent for insects and 16.3 per cent for diseases. Gharde *et al.* (2018) reported that the yield loss due to weeds in green gram resulted in an economic loss of $161 million in India. The reduction in yield depended mainly on the crop cultivar, type of weeds, and their density and biomass at various stages of crop growth.

According to Enyi (1973), delaying of weeding up to 42 days after sowing (DAS) in green gram resulted in greater weed biomass with a simultaneous decrease in seed yield. Singh *et al.* (1991) concluded that the critical period of crop-weed competition for *Kharif* season green gram was the first 30 DAS, whereas for summer sown green gram, it was 15-30 DAS. It was observed by Sangakkara *et al.* (1995) that uncontrolled weed growth during the vegetative phase adversely affected the yields of green gram. Sheoran *et al.* (2008) reported that weed infestation during the period from 20 DAS to 40 DAS caused the maximum yield reduction in *Kharif* season green gram. Similarly, Mandal *et al.* (2006) stated that weed-free environment from 7-14 DAS to 28 DAS resulted in higher seed yields in summer season green gram.

Weeds are known to cause severe yield reduction in green gram which could be up to the tune of 72.5 per cent in *Kharif* season green gram and 70 per cent in summer season green gram (Singh *et al.*, 1991). Punia *et al*. (2004) observed a reduction of

45.8 per cent, 29.5 per cent and 23.5 per cent in the seed yields of green gram under heavy infestation by weeds *Trianthema prortulacastrum, Cyperus rotundus* and *Echinochloa colona* respectively. The yield reduction due to severe competition from weeds was estimated to be 40-50 per cent in various green gram cultivars (IIPR, 2009). Mirjha *et al.* (2013) observed a 78 per cent increase in weed density in unweeded control at 50 DAS as compared with 25 DAS, which resulted in a 51 per cent decrease in seed yield of green gram. Godara *et al.* (2014) reported that heavy infestation by weeds resulted in 74 per cent reduction in gross income of green gram.

2.3 Weed management in green gram

2.3.1 Hand weeding

Hand weeding has been proved very effective in controlling all kinds of weeds in green gram. Several studies in green gram confirmed that hand weeding during the critical periods of crop-weed competition resulted in significantly higher yields and net returns.

Malik *et al*. (2005) reported that hand weeding twice at 25 DAS and 45 DAS showed significant reduction in both density and dry weight of weeds as compared with either herbicidal treatment or two mechanical hoeings. Chaudhari *et al.* (2016) also opined that two hand weedings at 20 DAS and 30 DAS showed a prominent decrease in the population of broad leaved weeds, grasses as well as sedges.

Hand weeding at 20 DAS resulted in a weed control efficiency of 69.96 per cent whereas it was increased to 99.49 per cent when two hand weedings were carried out at 15 DAS and 30 DAS (Shivran *et al.*, 2017). Gupta *et al*. (2019) found that the weed dry weight (7.67 g/m^2) and weed persistence index (0.13) were much lower compared to unweeded control when hand weeding was carried out twice at 20 DAS and 40 DAS.

2.3.2 Stale seed bed

Stale seed bed technique is reported to lower the weed seed bank by delaying sowing after tillage, resulting in emergence of weed seedlings that are then destroyed before planting, without causing much disturbance to the seedbed (Mohler, 2001).

Johnson and Mullinix (1995) recorded lower populations of *Desmodium tortosum*, *Panicum texanum* and *Cyperus esculentus* in peanut under stale seed beds that were tilled shallow. Shaw (1996) reported that stale seed bed could prevent germination of weed seeds throughout the cropping period. Stale seed bed recorded a significant reduction in the weed dry matter in cowpea with a weed control efficiency of 52.5 per cent and weed index of 40.5 per cent (Hanumanthappa *et al.*, 2012).

Saikia *et al.* (2013) stated that adoption of stale seed bed in black gram could effectively reduce the weed count at 45 DAS. Chandrakar *et al.* (2015) observed that there was a reduction of 48 per cent in weed dry matter when stale seed bed was practiced in lentil.

2.3.3 Herbicides

Herbicides are being widely used for weed management owing to their high efficiency and reduced labour costs. In India, there had been a threefold increase in the use of herbicides within 10 years from 2005-2015 without much increase in the area under cultivation (Gupta *et al.*, 2017). Several herbicides have been identified which provide season-long weed control in green gram. However, Ghosh *et al.* (2017) observed a 10.3 per cent increase in the productivity of green gram under pre-emergence herbicidal treatments compared to that of post-emergence herbicides. The success of herbicides for weed control is determined by several factors such as the composition and intensity of weed flora, mode of action of herbicide, its concentration etc.

a) Oxyfluorfen

Singh *et al.* (2015) observed that pre-emergence application of oxyfluorfen @ 200 g/ha caused significant reduction in total weed population from 20 DAS till harvest, compared to unweeded control. Patel (2015) recorded that there was up to 66.4 per cent reduction in weed dry matter when pre-emergence oxyfluorfen was applied @ 300 g/ha in green gram, which also resulted in higher yield (955.9 kg/ha) and lower weed index (24.54 per cent).

Ghosh *et al.* (2017) reported that pre-emergence application of oxyfluorfen @ 100 g/ha resulted in excellent weed control in green gram with a weed control efficiency of 54.3 per cent. Anand *et al.* (2020) observed a significant reduction of 48.5 per cent in the weed dry weight with a weed control efficiency of 49.77 per cent in rice bean under application of pre-emergence oxyfluorfen @ 50 g/ha.

b) Imazethapyr

Mishra *et al*. (2017) observed a lower biomass of broad leaved weeds and grasses under pre-emergence application of imazethapyr @ 80 g/ha, with a weed index of 3 per cent and weed control efficiency of 71 per cent. It was further confirmed by Nagender *et al*. (2017) that the population of broad leaved weeds, sedges as well as grasses were lower than the unweeded control under the pre-emergence application of imazethapyr @ 75 g/ha.

Yadav *et al.* (2019) recorded that both the density and biomass of *Echinochloa colona* and *Cyperus rotundus* were significantly reduced under the pre-emergence application of imazethapyr @ 100 g/ha. Rana *et al.* (2019) observed a reduction of 71 per cent in weed biomass under application of pre-emergence imazethapyr @ 70 g/ha in garden pea.

c) Imazethapyr+imazamox (Pre-mix)

Singh *et al.* (2016) opined that the pre-mix herbicidal combinations were more effective in lowering the weed load compared to their individual formulations which might be due to their synergistic effect. Mishra *et al.* (2017) observed that the pre-emergence application of imazethapyr+imazamox @ 80 g/ha reduced the weed density of both broad leaved weeds and grasses in green gram and had lower values of weed index (6 per cent), whereas weed control efficiency was reported to be 70 per cent.

Gupta *et al.* (2017) reported that pre-emergence application of imazethapyr+imazamox @ 80 g/ha resulted in significant reduction in the weed biomass as well as the number of broad leaved weeds, grasses and sedges in black gram. Similarly, Rana *et al.* (2019) found that pre-emergence application of imazethapyr+imazamox @ 80 g/ha provided excellent weed control in black gram with a weed control efficiency of 92 per cent.

d) Diclosulam

Bailey *et al*. (1999) reported that pre-emergence application of diclosulam provided effective control of weeds like *Chenopodium album, Eclipta prostrata, Ipomoea* spp and *Sida spinosa.* Singh *et al.* (2009) observed that pre-emergence application of diclosulam @ 26 g/ha showed a significant reduction in the population and dry mass of broad leaved weeds, grasses and sedges and recorded a weed control efficiency of 83.1 per cent in soybean.

Deepa (2015) concluded that the pre-emergence application of diclosulam @ 27 g/ha provided good control of all types of weeds, and recorded 79.1 per cent weed control efficiency and 13.4 per cent weed index in green gram. Kumar (2018) observed that the weed dry weight was decreased by 22.4 per cent by the pre-emergence application of diclosulam @ 22 g/ha in black gram.

2.3.4 Integrated weed management

Integrated weed management is the integration of different weed control methods in a holistic manner to bring down the weed density to such levels that are manageable by farmers, taking due care of the environmental effects of different weed control methods, which also provides a potential to increase the sustainability of cropping system and decrease development of herbicide resistance (Harker and O'Donovan, 2013).

Sahu *et al.* (2019) opined that the superiority of integration of chemical and physical weed control methods might be attributed to their synergistic action in lowering the weed density and biomass. Senthivelu *et al.* (2020) stated that integration of chemical and mechanical/physical weed control methods during the critical periods of crop-weed competition in green gram resulted in a significant reduction in weed population.

Application of pre-emergence herbicides like imazethapyr, oxyfluorfen or pendimethalin *fb* hand weeding at 30 DAS provided season-long weed control in green gram, owing to the efficacy of pre-emergence herbicides in restricting weed growth in the germinating stage which provided satisfactory weed control in the initial stages, and destruction of later emerging weeds by hand weeding (Thirumalaivasan *et al*., 2016).

Nainwal *et al*. (2010) observed the superiority of pre-emergence diclosulam @ 18 g/ha *fb* hand weeding at 20 DAS in controlling both the broad leaved and grassy weeds of soybean, and reported that it recorded a significantly lower weed biomass than the sole application of chemical. Meena (2011) concluded that application of pre-emergence oxyfluorfen when followed by hand weeding and interculture at 40 DAS could effectively lower the population of broad leaved weeds, grasses and sedges in green gram.

Tiwari *et al.* (2018) observed that weeds of black gram could be effectively controlled by imazethapyr+imazamox @ 75 g/ha *fb* hand weeding at 35 DAS with a significant reduction in both weed density and weed biomass. Sasode *et al.* (2020) reported that the application of pre-emergence imazethapyr @ 80 g/ha in green gram resulted in a weed control efficiency of 79.1 per cent, whereas its integration with hand weeding at 40 DAS recorded an increased weed control efficiency of 87.5 per cent.

Tehria *et al*. (2015) found that stale seed bed alone was less effective in controlling weeds in pea. Kumar *et al.* (2015) reported that stale seed bed followed by chemicals like glyphosate, imazethapyr or pyrozosulfuron could effectively reduce the population of broad leaved weeds like *Ageratum conyzoides, Eclipta alba, Phyllanthus niruri, Portulaca oleracea, Trianthema portulacastrum* and *Euphorbia hirta,* grasses like *Digitaria sanguinalis, Eleusine indica, Cynodon dactylon, Setaria glauca* and *Brachiaria* spp, and sedges.

According to Kumar *et al.* (2018), integration of stale seed bed with glyphosate and pretilachlor resulted in a significant reduction in the population and dry weight of weeds like *Cyperus rotundus, Echinochloa colona, Eleusine indica, Trianthema portulacastrum* and *Physalis minima.* Siddhiqui (2018) recorded a weed control efficiency of 53.74 per cent in pigeon pea+soybean intercropping system when the later emerging weeds in a stale seed bed was removed by application of imazethapyr+imazamox @ 10 g/ha. Kumre (2019) concluded that stale seed bed followed by hand weeding at 40 DAS successfully controlled all kinds of weeds in chickpea with a weed control efficiency of 88.82 per cent.

2.4 Effect of weed management practices on nutrient removal by weeds

Nutrient removal by weeds is directly proportional to its dry matter. Higher competition from weeds deprives the crop of the essential nutrients necessary for its growth and development. Bhutada and Bhale (2015) observed that during the initial crop growth stages of cowpea, weeds removed considerably higher quantities of nitrogen (5-6 times), phosphorus (5-12 times) and potassium (2-5 times) when compared with the crop.

Under weed-free conditions, nutrient uptake was higher (97.16, 12.56 and 94.56 kg/ha of N, P and K, respectively) for green gram. In unweeded control, however, the uptake of nutrients by green gram was significantly lower (44.97, 6.02 and 46.31 kg/ha of N, P and K, respectively) as substantial quantities of N (61.95 kg/ha), P (12.07 kg/ha) and K (51.39 kg/ha) were removed by weeds. It was found that any of the weed management practices could effectively lower the uptake of nutrients by weeds (Kataria *et al.*, 2016).

Jat (2008) stated that the nutrient removal by weeds was significantly lower when two hand weedings were carried out at 20 DAS and 40 DAS in green gram. Kavad *et al.* (2016) reported that the nutrient removal by weeds was substantially decreased by the integration of pre-emergence oxyfluorfen @ 180 g/ha with hand weeding at 30 DAS, as a result of which N, P and K uptake by black gram was increased by 130 per cent, 33.33 per cent and 32 per cent respectively over unweeded control.

Sinchana *et al.* (2020) observed that stale seed bed in cowpea resulted in a lower uptake of nutrients by weeds (9.62, 0.74, 6.18 kg/ha of N, P and K, respectively) as compared with a normal seed bed (18.83, 1.38, 13.81 kg/ha of N, P and K, respectively). The nutrient removal by weeds in black gram was significantly reduced under the pre-emergence application of imazethapyr @ 80 g/ha or imazethapyr+imazamox @ 80 g/ha. This resulted in a significant increase in the soil available nutrient fraction (323.9, 37.1 and 274.7 kg/ha of N, P and K, respectively) compared to the unweeded check (281.6, 32.1 and 214.2 kg/ha of N, P and K, respectively) (Malhi *et al*., 2020).

Deepa (2015) observed a significant reduction in the nutrient removal by weeds from 26.47 kg/ha of N, 17.80 kg/ha of P and 21.00 kg/ha of K in unweeded control to 5.93 kg/ha of N, 3.50 kg/ha of P and 5.57 kg/ha of K under the pre-emergence application of diclosulam @ 27 g/ha in green gram.

2.5 Effect of weed management practices on soil microbes

Kaszubiak (1970) stated that the impact of herbicides on soil microbes varied with the nature of herbicide, its concentration and time of sampling. Herbicides, being bio-active compounds, altered the population and activities of micro-organisms and affected the ecological balance and productivity of agricultural soils (Latha and Gopal, 2010).

Khairnar *et al.* (2014) opined that the soil microbial counts were reduced under herbicidal treatment, which was more evident in pre-mix herbicides than the application of a single herbicide, but it was not significant at recommended doses. Singh *et al*. (2020) observed that total microbial population in pigeon pea recorded significantly higher values in plots that were maintained weed-free compared to those which received various chemical control treatments, but it was statistically on par to those in which only hand weeding was carried out.

Adhikary *et al.* (2014) observed that oxyfluorfen had an inhibitory effect on soil microbial population initially upto 15 DAS. Shruti *et al.* (2015) also concluded that oxyfluorfen had suppressing effect on soil microbes immediately after application, but at later stages, microbial population recovered as a result of degradation of herbicides by enzymes.

Mukhopadhyay and Biswas (2019) reported that the treatment of soil with imazethapyr increased the total count of bacteria, fungi and actinomycetes, owing to the capability of microorganisms in utilising the herbicides as a source of nitrogen or carbon. According to Kumawat *et al.* (2020), imazethapyr was toxic to microorganisms, particularly bacteria, when used above their recommended doses. Singh and Singh (2020) observed that application of imazethapyr showed a significant reduction in soil bacterial population in green gram at 35 DAS but not at harvest, whereas its effect on fungi and actinomycetes were non-significant at both 35 DAS and harvest.

Prachand *et al.* (2014) reported that the population of soil microorganisms was significantly reduced with the application of imazethapyr+imazamox within 15 days, but it was not significant at the time of harvest, indicating that the effect of herbicide was temporary. Mahajan *et al.* (2020) reported that post-emergence application of imazethapyr+imazamox recorded slightly lower values in the population of bacteria and actinomycetes than the pre-emergence application of the same.

Higher doses of pre-emergence diclosulam recorded significantly lower counts of bacteria, fungi and actinomycetes when compared to untreated plots (Jakhar, 2011). Deepa (2015) reported a significant reduction in the count of bacteria (39.04×10^7 cfu/g), fungi (20.87×10^4 cfu/g) and actinomycetes (36.87×10^3 cfu/g) under application of diclosulam @ 17.5 g/ha as compared with two hand weedings (66.08×10^7, 43.91×10^4 and 65.44×10^3 cfu/g of soil of bacteria, fungi and actinomycetes, respectively) as observed at 35 DAS in green gram.

2.6 Effect on weed management practices on plant growth and yield

Ali *et al*. (2013) observed that uncontrolled weed growth in green gram decreased the plant height by 30 per cent, number of pods/plant by 55.6 per cent, length of pod by 24.6 per cent, test weight by 30.3 per cent and seed yield by 72.8 per cent. Efficient weed control strategies in green gram reduced the crop-weed competition for resources like water, nutrients and light, thereby accelerating the photosynthetic rate, carbohydrate assimilation and dry matter production, which consequently resulted in enhanced values for yield attributes and finally, yield (Patel *et al.*, 2020).

According to Khaliq *et al.* (2002), two hand hoeings at 15 DAS and 30 DAS recorded significantly higher plant height, number of grains/pod, 1000 seed weight and seed yield. Kundu *et al.* (2011) observed a 111.50 per cent increase in seed yield of green gram over unweeded control when hand weeding was carried out twice at 15 DAS and 30 DAS.

Senthivelu *et al.* (2015) reported a 67 per cent reduction in the yield of green gram in unweeded control when compared with the plots where hand weeding was carried out twice at 20 DAS and 40 DAS. According to Singh *et al.* (2015), the highest seed yield in green gram was recorded when hand weeding was done at 20 DAS and 40 DAS with a harvest index of 0.28. Kaur *et al.* (2016) also found that the yield attributes of green gram like plant height, branches/plant, pods/plant and seed yield recorded significantly higher values when hand weeding was carried out twice at 20 DAS and 40 DAS.

Jain and Tiwari (1995) observed that integration of stale seed bed with application of oxadiazon @ 100 g/ha resulted in higher seed yield in soybean. Gopinath *et al*. (2009) reported that the seed yield of garden pea was increased up to 12 times compared to unweeded control under integration of stale seed bed with hand weeding at 60 DAS. According to Senthilkumar *et al.* (2019), stale seed bed recorded higher number of branches/plant, mature pods/plant, 100 kernel weight, pod yield and haulm yield in groundnut.

Singh *et al.* (2009) observed that application of diclosulam @ 22 g/ha or 26 g/ha in soybean recorded significantly higher pods/plant, seeds/pod, 1000 seed weight and seed yield owing to its high weed control efficiency. According to Singh *et al*. (2015), a 62 per cent increase in seed yield and 52 per cent increase in haulm yield of green gram was observed in plots treated with pre-emergence oxyfluorfen as compared with unweeded control. Mishra *et al.* (2017) concluded that the pre-emergence application of imazethapyr @ 80 g/ha and pre-emergence application of imazethapyr+imazamox @ 80 g/ha in green gram recorded seed yields of 1.40 t/ha and 1.36 t/ha respectively, both of which were significantly higher to that of unweeded control (0.81 t/ha).

Chhodavadia *et al.* (2013) reported that the application of oxyfluorfen @ 180 g/ha *fb* hand weeding at 30 DAS gave significantly higher values for yield attributes of green gram like plant height, number of branches/plant, number of pods/plant, length of pod, number of grains/pod, grain weight/plant, test weight and grain yield. Patel *et al.* (2016) opined that application of imazethapyr @ 75 g/ha *fb* interculture and hand weeding @ 30 DAS resulted in higher seed yield and haulm yield compared to untreated plots, and was at par with interculture and hand weeding carried out at 20 DAS and 40 DAS. The integration of pre-emergence herbicides with hand weeding at 30 DAS resulted in a considerable increase in grain yield of green gram which was as high as 79 per cent for oxyfluorfen and 80 per cent for imazethapyr (Thirumalaivasan *et al.*, 2016).

According to Nainwal *et al.* (2010), there was a yield reduction of 78 per cent in untreated plots of soybean when compared to the plots where application of diclosulam @ 18 g/ha was followed by a hand weeding at 20 DAS. Tiwari *et al.* (2018) reported that the yield parameters of black gram like pods/plant, seeds/pod, seeds/plant, 100 seed weight and seed yield was considerably increased under the application of pre-emergence application of imazethapyr+imazamox @ 75 g/ha *fb* hand weeding at 35 DAS. Sinchana *et al*. (2020) observed that the number of pods/plant and pod weight in cowpea was significantly increased under the pre-emergence application of diclosulam @ 12.5 g/ha *fb* hand weeding at 25 DAS, which resulted in an increase in seed yield by 80.8 per cent over unweeded control.

2.6 Effect of weed management practices on economics of cultivation

Timely weed management practices are extremely necessary to get optimum yield in any crop, which in turn results in maximizing the economic returns. Patel *et al.* (2017) studied the effects of different combinations of nutrient, pest and weed management on the production economics of green gram and observed that maximum B:C ratio was obtained under efficient weed management practices (1.36), which was followed by a combination of weed and nutrient management (1.23) and then by the combined application of weed, nutrient and pest management practices (1.20).

Heatherly *et al.* (1986) recorded that stale seed bed in irrigated soybean resulted in an increase of about $23 to $31 per acre in terms of economic returns as compared to conventional seedbed. Gopinath *et al.* (2009) reported that integration of stale seed bed with hand weeding at 60 DAS resulted in maximum gross revenue in groundnut.

According to Khaliq *et al.* (2002), hand hoeing twice at 15 DAS and 30 DAS fetched the maximum economic return with the highest gross income as well as net income in green gram. Singh *et al*. (2019) stated that though hand weeding twice at 20 DAS and 40 DAS resulted in satisfactory gross returns and net returns, there was a reduction in B:C ratio due to the high labour costs involved.

Rao *et al*. (2017) opined that the cost of cultivation was higher in the plots where manual weedings were done at 20 DAS and 40 DAS as compared with those which received either sole application of chemical herbicide, or integration of chemical with manual weeding, because of which a reduction in net returns and B:C ratio was observed. Senthivelu *et al.* (2020) also found that despite the highest gross returns obtained when two hand weedings were carried out at 20 DAS and 40 DAS, a single hand weeding at 30 DAS resulted in the maximum net returns and B:C ratio.

According to Deepa (2015), application of pre-emergence diclosulam @ 17.5 g/ha in green gram fetched net benefits of Rs. 38,271, with a B:C ratio of 3.41. Mishra *et al*. (2017) found that hand hoeing twice at 20 DAS and 40 DAS recorded the highest B:C ratio of 2.91, whereas pre-emergence imazethapyr @ 80 g/ha and imazethapyr+imazamox @ 70 g/ha also recorded a satisfactory B:C ratio of 2.90 and 2.79 respectively, compared to unweeded control which resulted in a lower B:C ratio of only 1.84.

Chhodavadia *et al.* (2013) reported that the highest net returns and B:C ratio was recorded under hand weeding and interculture at 20 DAS and 40 DAS, which was statistically similar to the pre-emergence application of oxyfluorfen @ 180 g/ha *fb* hand weeding at 30 DAS. Patel *et al.* (2016) observed that both interculture and hand weeding at 20 DAS and 40 DAS, and application of pre-emergence imazethapyr @ 75 g/ha *fb* interculture at 30 DAS provided adequate economic benefits with a B:C ratio of 1.45 and 1.33 respectively, whereas it was just 0.40 for unweeded control.

Gupta *et al*. (2019) found that the pre-mix of imazethapyr+imazamox @ 80 g/ha was superior to hand weeding and other chemicals used in terms of monetary benefits with a B:C ratio of 3.03. Sasode *et al.* (2020) stated that though the highest seed yield in green gram was recorded under hand weeding twice at 20 DAS and 40 DAS, highest net return (Rs. 31,100/ha) and B:C ratio (2.52) was recorded under the pre-emergence application of imazethapyr @ 80 g/ha.

Ramesh and Radhika (2020) reported that satisfactory weed control was achieved under pre-emergence application of oxyfluorfen @ 200 g/ha *fb* hand weeding at 30 DAS which resulted in higher yields and a B:C ratio of 1.52. According to Maji *et al.* (2020), pre-mix herbicidal combinations recorded higher monetary benefits in comparison with application of a single herbicide and reported that the combination of imazethapyr+imazethapyr @ 60 g/ha resulted in a B:C ratio of 1.92 whereas it was 1.84 under the application of imazethapyr @ 40 g/ha.

Though a lot of literature was available relating to weed management in green gram, such studies were not made where the effect of stale seed bed was evaluated against the integration of various pre-emergence herbicides with hand weeding. Hence, the present study entitled "Integrated weed management in green gram (*Vigna radiata* (L.) Wilczek)" was undertaken to develop a viable weed management strategy in green gram.

Materials and methods

3. MATERIALS AND METHODS

The research programme entitled “Integrated weed management in green gram [*Vigna radiata* (L.) Wilczek]” was undertaken from December 2020 to March 2021 at the Department of Agronomy, College of Agriculture, Vellanikkara. An account of the materials used and methods adopted is given in this chapter.

3.1 GENERAL DETAILS

Location

The field experiment was taken up at *Kotteppadam* rice field under the Department of Agronomy, College of Agriculture, Vellanikkara. The field is located at a latitude of 10° 31′ N and longitude of 76° 13′ E, and is situated 40.3 m above Mean Sea Level (MSL). The experimental site was left fallow during the previous year.

Soil

The soil of *Kotteppadam* rice field is sandy loam in texture and acidic in reaction. It belongs to the taxonomical order *Entisol*. The soil is medium in organic carbon and available phosphorus, and low in available nitrogen and potassium. The chemical properties of the soil prior to experiment are presented in Table 1.

Season and climate

The experiment was undertaken from December 2020 to March 2021. The region experiences a warm humid climate. The data on important meteorological parameters are presented in Appendix.

Planting material

Seeds of green gram variety CO 8, purchased from KAU Sales and Information counter, Vellanikkara, was used as the planting material. It is a short duration variety (55-60 days) of green gram developed by the Tamil Nadu Agricultural University in 2013 and showed good resistance to yellow mosaic disease and stem necrosis, and moderate resistance to root rot.

Table 1. Chemical properties of soil before the experiment

Sl. No.	Particulars	Value	Method adopted	Reference
1.	pH	4.27	1:2.5 (soil: water) suspension – pH meter	Jackson (1958)
2.	EC (dS/m)	0.73	1:2.5 (soil: water) suspension – EC meter	Jackson (1958)
3.	Organic carbon (%)	0.53	Walkley and Black method	Jackson (1958)
4.	Available N (kg/ha)	75.6	Alkaline permanganate method	Subbiah and Asija (1956)
5.	Available P (kg/ha)	37.5	Bray-1 extractant-ascorbic acid reductant method	Watanabe and Olsen (1965)
6.	Available K (kg/ha)	93.5	Neutral normal ammonium acetate method – Flame photometry	Jackson (1958)

3.2 DETAILS OF THE EXPERIMENT

3.2.1 Treatments

The experiment included eight treatments, replicated thrice in a randomized block design (RBD), and included both chemical and non-chemical methods of weed control. All the chemicals were applied pre-emergence and sowing was carried out one day later. The details of the herbicides used are presented in Table 2.

3.2.2 Land preparation and sowing

The field was ploughed with a tractor, cleared of weeds and levelled. Field layout was done with individual plot size of 20 m^2 (5m × 4m). Separate randomization was carried out for each replication and seed bed preparation was done only in those plots which receive stale seed bed treatment. Irrigation was given to the stale seed beds to stimulate weed seed germination in those plots. The entire experimental field was left undisturbed for fourteen days and the new flushes of weeds emerged in the stale seed beds were destroyed after fifteen days of field preparation by gentle raking without disturbing the seed bed further. Then, seed bed preparation was carried out in the remaining plots also and pre-emergence herbicidal treatments were applied on the same day. Line sowing of seeds was done the next day at a spacing of 25 cm ×15 cm. Layout plan of the experiment is presented in Fig. 1.

3.2.3 Fertilizer application

Application of fertilizers was done as per the Package of Practices Recommendations so as to supply 20:30:30 kg N, P and K per hectare (KAU, 2016). Urea (44 kg/ha), factamphos (167 kg/ha) and muriate of potash (50 kg/ha) were used as sources of nitrogen, phosphorus and potassium respectively. Half dose of nitrogen and full doses of phosphorus and potassium were applied as basal dose and the remaining nitrogen was given in two equal splits at 15 DAS and 30 DAS.

3.2.4 Plant protection measures

Infestation by thrips was noticed in the field which was controlled by the application of Pegasus® @ 1g/L and Confidor® @ 3 mL/10L. The crop also showed symptoms of dry rot, which was controlled by the application of Tilt® @ 1mL/L.

3.2.5 Harvesting

Harvesting of mature pods of green gram was done in three rounds as and when the colour of pods changed from green to black. The first picking was carried out on 20th February 2021, after 65 DAS, while the subsequent ones were done on 26th February 2021 and 3rd March 2021. The pods were sun-dried and seeds separated by manual threshing.

Table 2. Details of herbicides used in the experiment

Sl. No.	Herbicide	Dose (g/ha)	Trade name and formulation	Name of firm
1.	Oxyfluorfen	150	Goal 23.5% EC	Dow Agro Sciences
2.	Imazethapyr	50	Pursuit 10% SL	BASF
3.	Imazethapyr + imazamox	80	Odyssey 70 WG	BASF
4.	Diclosulam	15	Strongarm 84% WDG	Dow Agro Sciences

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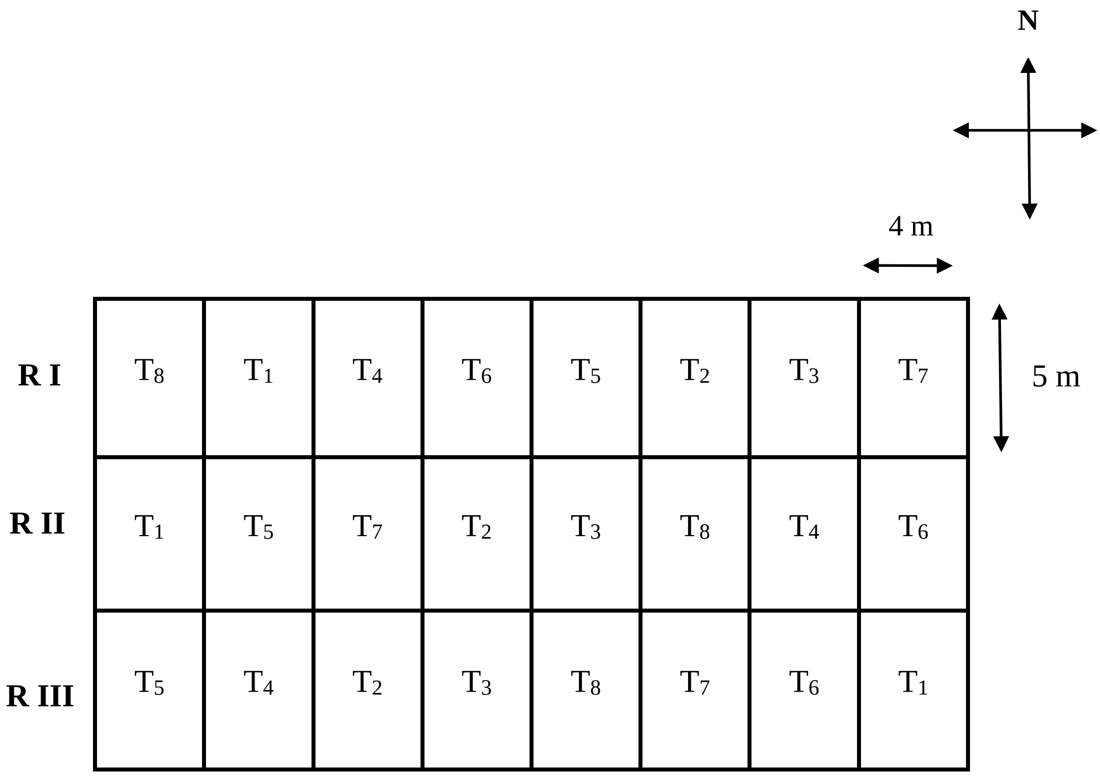

Fig 1. Layout plan of field experiment

Design : RBD

Replications : 3

Plot size : 20 m^2

T_1	Stale seed bed for 14 days followed by (*fb*) shallow digging
T_2	Stale seed bed for 14 days *fb* shallow digging, *fb* oxyfluorfen @ 150 g/ha at 0-3 DAS
T_3	Oxyfluorfen @ 150 g/ha at 0-3 DAS, *fb* hand weeding at 25 DAS
T_4	Imazethapyr @ 50 g/ha at 0-3 DAS, *fb* hand weeding at 25 DAS
T_5	Imazethapyr + imazamox (RM) @ 80 g/ha at 0-3 DAS, *fb* hand weeding at 25 DAS
T_6	Diclosulam @ 15 g/ha at 0-3 DAS, *fb* hand weeding at 25 DAS
T_7	Hand weeding (HW) at 20 DAS and 40 DAS
T_8	Unweeded control

3.3 OBSERVATIONS

3.3.1 Observations on weeds

a) Weed count

A quadrat of size 0.5 m × 0.5 m was placed randomly at two spots in each plot and the weeds present in it were identified. Species-wise weed density was recorded at 30 DAS, 45 DAS and 60 DAS, and expressed in numbers/m^2. Also, the densities of broad leaved weeds and grasses were tabulated separately, and the total weed density was calculated for each treatment.

b) Weed dry matter production

The weeds in the quadrat area were uprooted, soil particles removed and air dried. Dry weight of the weeds from each treatment was recorded after oven-drying at 70 ± 5°C to constant weight. The observations were recorded at 30 DAS, 45 DAS and 60 DAS and expressed in g/m^2.

c) Nutrient removal by weeds

The oven-dried weed samples were ground using a mixer grinder and the fine powder obtained was used for subsequent digestion and analysis of nutrient content. This was done at 30 DAS, 45 DAS and 60 DAS, and nutrient removal by weeds was expressed as kg/ha after multiplying the nutrient percentage with the weed dry matter production. The methods used for plant chemical analysis are detailed in Table 3.

Table 3. Methods of plant chemical analysis

Sl. No.	Particulars	Method adopted	Reference
1.	N	Micro Kjeldahl method	Jackson (1958)
2.	P	Vanado-molybdo phosphoric yellow colour method using spectrophotometer	Jackson (1958)
3.	K	Flame photometry method	Jackson (1958)

d) Weed Control Efficiency (WCE)

Weed control efficiency (%) at 30 DAS, 45 DAS and 60 DAS was calculated using the following formula recommended by Mani *et al.* (1973).

$$\text{WCE (\%)} = \frac{X-Y}{X} \times 100$$

Where, X is the weed dry matter production in unweeded plot and Y is the weed dry matter production in treated plot.

e) Weed Index (WI)

Weed index (%) was worked out by the following formula suggested by Gill and Vijayakumar (1969).

$$\text{WI (\%)} = \frac{A-B}{A} \times 100$$

Where, A is the seed yield of hand weeded plot and B is the seed yield of treated plot.

3.3.2 Observations on green gram

a) Plant height

Height of five randomly selected plants from each plot was measured from the ground level to the tip of the plant and the mean value was worked out. The observations were recorded at 30 DAS and 45 DAS, and expressed in cm.

b) Number of branches per plant

Number of branches per plant was counted at 30 DAS and 45 DAS from five randomly selected plants in each plot and mean was calculated.

c) Number of pods per plant

Number of pods from five randomly selected plants in each plot was counted and mean was worked out.

d) Number of seeds per pod

Number of seeds from mature pods of five randomly selected plants in each plot was counted at the time of first harvest and the mean was calculated to get the number of seeds per pod.

e) 100 seed weight

Weight of 100 bold seeds from each plot was measured and expressed in grams.

f) Grain yield

Total seed yield from each plot was recorded after threshing and winnowing, and expressed in kg/ha.

g) Haulm yield

After harvest of the pods, haulm weight was measured from each plot separately and expressed in kg/ha.

3.3.3 Soil analysis

Representative soil samples were collected from the plots before and after the experiment, air-dried and sieved through sieves of appropriate mesh sizes for estimation of pH, electrical conductivity, organic carbon and available nutrient (N, P and K) content using the methods detailed in Table 1. Fresh soil samples collected on the same day were used without air drying for soil microbial analysis.

Soil microbial analysis

The total count of bacteria, fungi and actinomycetes in the soil before sowing, at flowering and immediately after harvest was enumerated by using serial dilution technique (Johnson and Curl, 1972) and expressed in cfu/g. The media used for analysis are specified in Table 4.

Table 4. Culture media used in soil microbial analysis

Sl. No.	Microbes	Medium	Reference
1.	Bacteria	Nutrient agar medium	Lapage *et al*. (1970)
2.	Actinomycetes	Kenknight's agar medium	Rao (1977)
3.	Fungi	Rose Bengal Agar medium	Martin (1950)

3.3.4 Incidence of pests and diseases

Timely monitoring of the field for pests and diseases was carried out and observations recorded.

3.3.5 Economics of cultivation

Cost of cultivation, gross income and net income was calculated taking into consideration the prevailing labour charges, input costs and market price of green gram, and expressed in rupees/ha. The Benefit-Cost Ratio (BCR) was worked out for each treatment by dividing the gross returns by the total cost of cultivation.

3.3.6 Statistical analysis

Statistical analysis of the data obtained from field experiment was carried out using the online statistical package WASP 2.0 (Web based Agricultural Statistics software Package). Square root transformation $\sqrt{(x + 0.5)}$ and was applied wherever data showed wide variations so as to make ANOVA valid (Gomez and Gomez, 1984).

Plate 1. Layout of field experiment

Plate 2. Spraying of pre-emergence herbicide

Plate 3. Line sowing

Plate 4. Field view at 10 DAS

Plate 5. Hand weeding

Plate 6. Field view at 45 DAS

Plate 7. Stale seed bed (T_1) at pod formation stage

Plate 8. Stale seed bed *fb* oxyfluorfen (T_2) at pod formation stage

Plate 9. Oxyfluorfen *fb* hand weeding (T_3) at pod formation stage

Plate 10. Imazethapyr *fb* hand weeding (T_4) at pod formation stage

Plate 11. Imazethapyr + imazamox *fb* hand weeding (T_5) at pod formation stage

Plate 12. Diclosulam *fb* hand weeding (T_6) at pod formation stage

Plate 13. Hand weeding at 20 DAS and 40 DAS (T_7) at pod formation stage

Plate 14. Unweeded control (T_8) at pod formation stage

Plate 15. Experimental field at 55 DAS

Plate 16. Harvesting

Results

4. RESULTS

The field experiment of the investigation on "Integrated weed management in green gram [*Vigna radiata* (L.) Wilczek]" was conducted from December 2020 to March 2021 at the Department of Agronomy, College of Agriculture, Vellanikkara. The observations recorded were statistically analysed and the results obtained are presented in this chapter.

4.1 OBSERVATIONS ON WEEDS

4.1.1 Weed spectrum

The experimental field was infested by both broad leaved weeds and grasses. The major broad leaved weeds observed were *Melochia corchorifolia* (chocolate weed), *Aeschynomene indica* (Indian jointvetch), *Grangea maderaspatana* (Madras carpet), *Phyllanthus amara* (liver plant), *Heliotropium indicum* (Indian heliotrope), *Mimosa invisa* (giant sensitive plant) and *Mimosa pudica* (Touch-me-not). Among grasses, *Brachiaria mutica* (para grass), *Digitaria ciliaris* (tropical crab grass), *Echinochloa colona* (awnless barnyard grass), *Cynodon dactylon* (Bermuda grass) and *Oryza sativa* (rice) were found dominant. It was observed that various integrated weed management practices could successfully lower the density of all types of weeds in green gram.

4.1.2 Weed density

Species-wise weed density at 30 DAS (Tables 5 and 6), 45 DAS (Tables 7 and 8) and 60 DAS (Tables 9 and 10), as well as the total weed density at 30 DAS (Table 11), 45 DAS (Table 12) and 60 DAS (Table 13) were recorded. It was found that the populations of both broad leaved weeds and grasses were lowered to varying levels in plots which received treatments in comparison to the unweeded control.

At 30 DAS, a significant reduction was observed in weed density in all the treatment plots when compared with the unweeded control. Broad leaved weeds dominated the field, *Melochia corchorifolia* being the most prominent species. Other weed species identified were *Phyllanthus amara* and *Grangea maderaspatana* among broad leaved weeds, and *Brachiaria mutica, Digitaria ciliaris, Echinochloa colona* and *Oryza sativa* among grasses. The effect of various weed management practices followed a similar trend for both broad leaved weeds and grasses, with the highest weed count in unweeded control (T_8) followed by stale seed bed alone (T_1) or in combination with oxyfluorfen (T_2). The weed count of both broad leaved weeds and grasses were significantly lower under hand weeding and the pre-emergence application of herbicides followed by hand weeding, i.e., treatments T_3 to T_7. The total weed count was found highest (77.33 no./m^2) under unweeded control, whereas the lowest weed count (3.33 no./m^2) was observed under two hand weedings (T_7) and the plot treated with imazethapyr + imazamox *fb* hand weeding (T_5), both of which were statistically on par with diclosulam *fb* hand weeding (T_6), oxyfluorfen *fb* hand weeding (T_3) and imazethapyr *fb* hand weeding (T_4).

At 45 DAS, *Melochia corchorifolia* was again the most dominant weed species, but a wider diversity and density of weeds were observed in the experimental field. In addition to the weeds observed at 30 DAS, broad leaved weeds such as *Grangea maderaspatana, Aeschynomene indica, Heliotropium indicum, Mimosa invisa* and *Mimosa pudica*. and the grass *Cynodon dactylon* were noticed. The effect of weed management practices was more or less similar in the case of broad leaved weeds and grasses. Though a significant reduction in weed density was observed in all the treatment plots, stale seed bed (T_1) was less efficient in controlling the weeds when compared with the herbicide treated plots. The lowest total weed population (8 no./m^2) was observed under two hand weedings (T_8). All the herbicide treated plots also produced satisfactorily results in lowering the weed count and were statistically on par with each other.

All the weeds present at 30 DAS and 45 DAS were observed at 60 DAS also. The total count of broad leaved weeds was found lowest in hand weeding (T_7), which was followed by the treatments where integration of herbicide application with hand weeding was done (T_3 to T_6), which were all statistically similar. The lowest count of grass was also observed under hand weeding (T_7), and it was statistically on par with all the treatments which carried herbicide application (T_2 to T_7). The highest total weed count (262 no./m^2) was recorded in unweeded control (T_8) which was followed by stale seed bed (T_1) (91.33 no./m^2). Also, it was found that stale seed bed followed by oxyfluorfen (T_2) recorded a weed count of 32 no./m^2, which was inferior to the other treatments where application of pre-emergence herbicides was followed by hand weeding. Hand weeding (T_7) was the best treatment with the lowest weed density (15.33 no./m^2) and was statistically at par with the application of imazethapyr + imazamox *fb* hand weeding (T_5), diclosulam *fb* hand weeding (T_6) and oxyfluorfen *fb* hand weeding (T_3).

Table 5. Effect of integrated weed management practices on species-wise weed density of broad leaved weeds at 30 DAS

Treatment		Weed density (no./m²)		
		Melochia corchorifolia	***Phyllanthus amara***	***Grangea maderaspatana***
T_1	SSB for 14 days	*4.30^{b} (18.67)	1.29^{b} (1.33)	1.29^{b} (1.33)
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	1.95^{c} (4.00)	1.00^{b} (0.67)	1.00^{bc} (0.67)
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	2.00^{c} (4.00)	0.71^{b} (0.00)	0.71^{c} (0.00)
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	2.10^{c} (4.67)	0.71^{b} (0.00)	0.71^{c} (0.00)
T_5	Imazethapyr + imazamox at 0-3 DAS, *fb* HW at 25 DAS	1.80^{c} (3.33)	0.71^{b} (0.00)	0.71^{c} (0.00)
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	1.76^{c} (3.33)	0.71^{b} (0.00)	0.71^{c} (0.00)
T_7	HW at 20 DAS and 40 DAS	1.60^{c} (2.67)	0.71^{b} (0.00)	0.71^{c} (0.00)
T_8	Unweeded control	7.69^{a} (59.33)	1.90^{a} (3.33)	1.77^{a} (2.67)
CD (0.05)		0.79	0.59	0.44

* $\sqrt{(x + 0.5)}$ transformed values with original values in parantheses. In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

Table 6. Effect of integrated weed management practices on species-wise weed density of grasses at 30 DAS

Treatments		**Weed density (no./m²)**			
		Brachiaria mutica	***Digitaria ciliaris***	***Echinochloa colona***	***Oryza sativa***
T_1	SSB for 14 days	*1.29^{b} (1.33)	1.29^{ab} (1.33)	1.00^{b} (0.67)	1.29^{b} (1.33)
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	1.00^{b} (0.67)	1.00^{b} (0.67)	0.71^{b} (0.00)	1.00^{bc} (0.67)
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	1.00^{b} (0.67)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{c} (0.00)
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	0.71^{b} (0.00)	1.00^{b} (0.67)	0.71^{b} (0.00)	0.71^{c} (0.00)
T_5	Imazethapyr + imazamox at 0-3 DAS, *fb* HW at 25 DAS	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{c} (0.00)
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	1.00^{b} (0.67)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{c} (0.00)
T_7	HW at 20 DAS and 40 DAS	1.00^{b} (0.67)	0.71^{b} (0.00)	0.71^{b} (0.00)	0.71^{c} (0.00)
T_8	Unweeded control	2.27^{a} (4.67)	1.76^{a} (2.67)	1.58^{a} (2.00)	1.76^{a} (2.67)
CD (0.05)		0.76	0.56	0.31	0.51

* $\sqrt{(x + 0.5)}$ transformed values with original values in parantheses. In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

Table 7. Effect of integrated weed management practices on species-wise weed density of broad leaved weeds at 45 DAS

Treatments		Weed density (no./m^2)					
		Melochia corchorifolia	***Phyllanthus amara***	***Grangea maderaspatana***	***Aeschynomene indica***	***Heliotropium indicum***	***Mimosa* spp**
T_1	SSB for 14 days	*7.04^b (50.00)	2.20^a (4.67)	2.20^{ab} (4.67)	1.58^a (2.00)	1.18^b (1.33)	1.29^b (1.33)
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	4.30^c (18.67)	1.00^b (0.67)	0.71^c (0.00)	1.29^{ab} (1.33)	0.71^b (0.00)	1.18^b (1.33)
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	4.31^c (18.67)	0.71^b (0.00)	1.47^{bc} (2.00)	0.71^b (0.00)	0.71^b (0.00)	1.47^{ab} (2.00)
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	4.47^c (20.00)	1.29^b (1.33)	1.47^{bc} (2.00)	1.29^{ab} (1.33)	0.71^b (0.00)	0.71^b (0.00)
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	3.66^c (14.00)	1.00^b (0.67)	1.58^b (2.00)	1.29^{ab} (1.33)	0.71^b (0.00)	0.71^b (0.00)
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	4.10^c (17.33)	0.71^b (0.00)	0.71^c (0.00)	1.29^{ab} (1.33)	0.71^b (0.00)	1.00^b (0.67)
T_7	HW at 20 DAS and 40 DAS	2.34^d (6.00)	1.00^b (0.67)	0.71^c (0.00)	0.71^b (0.00)	0.71^b (0.00)	1.29^b (1.33)
T_8	Unweeded control	12.17^a (148.67)	2.47^a (6.00)	2.67^a (6.67)	1.94^a (3.33)	2.26^a (4.67)	2.26^a (4.67)
CD (0.05)		1.24	0.67	0.79	0.69	0.54	0.87

* $\sqrt{(x + 0.5)}$ transformed values with original values in parantheses. In a column, mean followed by common letters do not differ significantly at 5% level in DMRT.

Table 8. Effect of integrated weed management practices on species-wise weed density of grasses at 45 DAS

Treatments		Weed density (no./m^2)				
		Brachiaria mutica	***Digitaria ciliaris***	***Echinochloa colona***	***Oryza sativa***	***Cynodon dactylon***
T_1	SSB for 14 days	*1.29^b (1.33)	1.76^{ab} (2.67)	1.29^b (1.33)	1.58^{ab} (2.00)	1.00^b (0.67)
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	0.71^b (0.00)	1.47^{abc} (2.00)	1.29^b (1.33)	0.71^c (0.00)	1.00^b (0.67)
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	1.00^b (0.67)	0.71^c (0.00)	0.71^c (0.00)	0.71^c (0.00)	0.71^b (0.00)
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	1.00^b (0.00)	0.71^c (0.00)	1.00^{bc} (0.67)	1.00^{bc} (0.67)	0.71^b (0.00)
T_5	Imazethapyr + imazamox at 0-3 DAS, *fb* HW at 25 DAS	0.71^b (0.00)	1.00^{bc} (0.67)	0.71^c (0.00)	1.00^{bc} (0.67)	0.71^b (0.00)
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	0.71^b (0.00)	1.47^{abc} (2.00)	0.71^c (0.00)	1.18^{abc} (1.33)	0.71^b (0.00)
T_7	HW at 20 DAS and 40 DAS	0.71^b (0.00)	0.71^c (0.00)	0.71^c (0.00)	0.71^c (0.00)	0.71^b (0.00)
T_8	Unweeded control	1.94^a (3.33)	2.08^a (4.00)	2.12^a (4.00)	1.76^a (2.67)	1.76^a (2.67)
CD (0.05)		0.61	0.81	0.56	0.63	0.49

* $\sqrt{(x + 0.5)}$ transformed values with original values in parantheses. In a column, mean followed by common letters do not differ significantly at 5% level in DMRT.

Table 9. Effect of integrated weed management practices on species-wise weed density of BLW at 60 DAS

Treatments		Weed density (no./m^2)					
		Melochia corchorifolia	***Phyllanthus amara***	***Grangea maderaspatana***	***Aeschynomene indica***	***Heliotropium indicum***	***Mimosa* spp**
T_1	SSB for 14 days	*7.14^{b} (51.33)	2.79^{a} (7.33)	2.08^{ab} (4.00)	1.76^{a} (2.67)	1.29^{b} (1.33)	1.29^{b} (1.33)
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	4.47^{c} (20.00)	1.76^{bc} (2.67)	1.47^{bc} (2.00)	1.76^{a} (2.67)	0.71^{c} (0.00)	0.71^{c} (0.00)
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	3.93^{c} (16.00)	0.71^{e} (0.00)	0.71^{d} (0.00)	1.00^{b} (0.67)	0.71^{c} (0.00)	0.71^{c} (0.00)
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	4.35^{c} (20.00)	1.00^{de} (0.67)	1.00^{cd} (0.67)	1.00^{b} (0.67)	1.00^{bc} (0.67)	0.71^{c} (0.00)
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	3.96^{c} (16.00)	0.71^{e} (0.00)	0.71^{d} (0.00)	1.00^{b} (0.67)	0.71^{c} (0.00)	0.71^{c} (0.00)
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	4.05^{c} (16.67)	0.71^{e} (0.00)	0.71^{d} (0.00)	0.71^{b} (0.00)	0.71^{c} (0.00)	0.71^{c} (0.00)
T_7	HW at 20 DAS and 40 DAS	3.33^{c} (11.33)	1.29^{cd} (1.33)	0.71^{d} (0.00)	1.00^{b} (0.67)	0.71^{c} (0.00)	0.71^{c} (0.00)
T_8	Unweeded control	14.06^{a} (198.00)	2.26^{ab} (4.67)	2.65^{a} (6.67)	2.41^{a} (5.33)	2.39^{a} (5.33)	2.21^{a} (4.67)
CD (0.05)		1.40	0.55	0.68	0.71	0.55	0.52

* $\sqrt{(x + 0.5)}$ transformed values with original values in parantheses. In a column, mean followed by common letters do not differ significantly at 5% level in DMRT.

Table 10. Effect of integrated weed management practices on species-wise weed density of grasses at 60 DAS

Treatments		Weed density (no./m^2)				
		Brachiaria mutica	***Digitaria ciliaris***	***Echinochloa colona***	***Oryza sativa***	***Cynodon dactylon***
T_1	SSB for 14 days	*1.47^b (2.00)	4.10^a (16.67)	1.29^{ab} (1.33)	1.29^b (1.33)	1.47^b (2.00)
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	1.29^b (1.33)	1.47^b (2.00)	1.00^{bc} (0.67)	1.00^b (0.67)	1.00^{bc} (0.67)
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	1.00^b (0.67)	1.29^b (1.33)	0.71^c (0.00)	1.00^b (0.67)	0.71^c (0.00)
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	1.00^b (0.67)	1.58^b (2.00)	0.71^c (0.00)	0.71^b (0.00)	1.29^{bc} (1.33)
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	0.71^b (0.00)	1.29^b (1.33)	0.71^c (0.00)	1.00^b (0.67)	0.71^c (0.00)
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	1.00^b (0.67)	1.29^b (1.33)	0.71^c (0.00)	0.71^b (0.00)	0.71^c (0.00)
T_7	HW at 20 DAS and 40 DAS	0.71^b (0.00)	1.29^b (1.33)	1.00^{bc} (0.67)	0.71^b (0.00)	0.71^c (0.00)
T_8	Unweeded control	2.65^a (6.67)	4.31^a (18.67)	1.58^a (2.00)	2.08^a (4.00)	2.65^a (6.67)
CD (0.05)		0.77	0.99	0.52	0.69	0.71

* $\sqrt{(x + 0.5)}$ transformed values with original values in parantheses. In a column, mean followed by common letters do not differ significantly at 5% level in DMRT.

Table 11. Effect of integrated weed management practices on weed density at 30 DAS

Treatments		Weed density (no./m^2)		
		BLW	Grasses	Total
T_1	SSB for 14 days	*4.60^{b} (21.33)	2.26^{b} (4.67)	5.90^{b} (26.00)
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	2.30^{c} (5.33)	1.47^{bc} (2.00)	2.70^{c} (7.33)
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	2.00^{c} (4.00)	1.00^{c} (0.67)	2.15^{cd} (4.67)
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	2.10^{c} (4.67)	1.00^{c} (0.67)	2.30^{cd} (5.33)
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	1.80^{c} (3.33)	0.71^{c} (0.00)	1.80^{d} (3.33)
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	1.76^{c} (3.33)	1.00^{c} (0.67)	1.87^{d} (4.00)
T_7	HW at 20 DAS and 40 DAS	1.60^{c} (2.67)	1.00^{c} (0.67)	1.80^{d} (3.33)
T_8	Unweeded control	8.06^{a} (65.33)	3.53^{a} (12.00)	8.78^{a} (77.33)
SE m (±)		0.26	0.27	0.23
CD (0.05)		0.81	0.84	0.71

* $\sqrt{(x + 0.5)}$ transformed values with original values in parantheses. In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

Table 12. Effect of integrated weed management practices on weed density at 45 DAS

Treatments		Weed density (no./m^2)		
		BLW	Grasses	Total
T_1	SSB for 14 days	*7.98[b] (64.00)	2.90[b] (8.00)	8.46[b] (72.00)
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	4.67[c] (22.00)	2.08[c] (4.00)	5.09[c] (26.00)
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	4.76[c] (22.67)	1.00[e] (0.67)	4.83[c] (23.33)
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	4.96[c] (24.67)	1.47[cde] (2.00)	5.16[c] (26.67)
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	4.19[c] (18.00)	1.29[de] (1.33)	4.36[c] (19.33)
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	4.31[c] (19.33)	1.94[cd] (3.33)	4.71[c] (22.67)
T_7	HW at 20 DAS and 40 DAS	2.73[d] (8.00)	0.71[e] (0.00)	2.73[d] (8.00)
T_8	Unweeded control	13.17[a] (174.00)	4.12[a] (16.77)	13.79[a] (190.67)
SE m (±)		0.38	0.26	0.37
CD (0.05)		1.18	0.80	1.15

* $\sqrt{(x + 0.5)}$ transformed values with original values in parantheses. In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

Table 13. Effect of integrated weed management practices on weed density at 60 DAS

Treatments		Weed density (no./m^2)		
		BLW	Grasses	Total
T_1	SSB for 14 days	*8.24^b (68.00)	4.83^b (23.33)	9.55^b (91.33)
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	5.21^c (27.33)	2.21^c (4.67)	5.64^c (32.00)
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	4.03^{cd} (16.67)	1.61^c (2.67)	4.37^d (19.33)
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	4.64^{cd} (22.67)	2.08^c (4.00)	5.09^{cd} (26.67)
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	4.03^{cd} (16.67)	1.47^c (2.00)	4.25^d (18.67)
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	4.05^{cd} (16.67)	1.58^c (2.00)	4.29^d (18.67)
T_7	HW at 20 DAS and 40 DAS	3.59^d (13.33)	1.47^c (2.00)	3.89^d (15.33)
T_8	Unweeded control	14.95^a (224.00)	6.19^a (38.00)	16.18^a (262.00)
SE m (±)		0.16	0.34	0.18
CD (0.05)		0.49	1.06	0.57

* $\sqrt{(x + 0.5)}$ transformed values with original values in parantheses. In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

4.1.3 Weed dry matter production

At 30 DAS, the highest weed dry matter production (79.99 g/m^2) was recorded in unweeded control (T_8). All the weed management practices were effective in lowering the weed dry weight, but stale seed bed (T_1) recorded a dry weight of 11.75 g/m^2, which was higher compared to the herbicidal treatments. The treatments T_2 to T_7 produced satisfactory results with weed dry matter production ranging from 0.16 g/m^2 to 0.55 g/m^2 and were statistically on par with each other.

At 45 DAS, the highest weed dry matter production (295.17 g/m^2) was observed in unweeded control (T_8) and the lowest (3.12 g/m^2), in hand weeding (T_7). The pre-emergence application of diclosulam *fb* hand weeding (T_6) (7.74 g/m^2), imazethapyr + imazamox *fb* hand weeding (T_5) (8.10 g/m^2), oxyfluorfen *fb* hand weeding (T_3) (10.94 g/m^2) and imazethapyr *fb* hand weeding (T_4) (13.13 g/m^2) resulted in lower values of weed dry weight and were statistically on par with each other. However, stale seed bed (T_1) and stale seed bed *fb* pre-emergence oxyfluorfen (T_2) produced higher values of weed dry matter production compared to hand weeding or the integration of pre-emergence herbicides with hand weeding.

At 60 DAS, unweeded control (T_8) recorded the highest dry weight of 352.81 g/m^2. Hand weeding (T_7) was found superior to all the other treatments with the lowest dry matter production of 6.48 g/m^2. Imazethapyr + imazamox *fb* hand weeding (T_5) (11.04 g/m^2), diclosulam *fb* hand weeding (T_6) (7.74 g/m^2) and oxyfluorfen *fb* hand weeding (T_3) (13.87) also resulted in significantly lower weed dry matter production and were statistically on par with each other. Among the herbicidal treatments, significantly higher weed dry weight (19.04 g/m^2) was observed under imazethapyr *fb* hand weeding (T_4). It was also observed that stale seed bed did not produce good results with regard to weed dry matter production. Thus, weed dry matter production (Table 14) varied between the various treatments and was in the order unweeded control > stale seed bed > stale seed bed *fb* oxyfluorfen > imazethapyr *fb* hand weeding > oxyfluorfen *fb* hand weeding > diclosulam *fb* hand weeding > imazethapyr + imazamox *fb* hand weeding > hand weeding.

Table 14. Effect of integrated weed management practices on weed dry matter production

Treatments		Weed dry matter production (g/m^2)		
		30 DAS	45 DAS	60 DAS
T_1	SSB for 14 days	*3.41^b (11.75)	16.14^a (260.67)	17.64^b (311.17)
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	0.74^c (0.55)	7.07^b (50.47)	8.97^c (80.70)
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	0.47^c (0.25)	3.30^c (10.94)	3.72^e (13.87)
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	0.53^c (0.31)	3.60^c (13.13)	4.36^d (19.04)
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	0.45^c (0.21)	2.82^c (8.10)	3.31^e (11.04)
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	0.48^c (0.24)	2.77^c (7.74)	3.35^e (11.20)
T_7	HW at 20 DAS and 40 DAS	0.39^c (0.16)	1.67^d (3.12)	2.52^f (6.48)
T_8	Unweeded control	8.93^a (79.99)	17.17^a (295.17)	18.78^a (352.81)
SE m (±)		0.47	0.39	0.41
CD (0.05)		1.43	1.21	1.25

* $\sqrt{(x + 0.5)}$ transformed values with original values in parantheses. In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

4.1.4 Nutrient removal by weeds

Nutrient removal by weeds was significantly affected by integrated weed management practices in green gram. It was observed that nitrogen removal (Table 15), phosphorus removal (Table 16) and potassium removal (Table 17) by weeds were highest in unweeded control (T_8), whereas the lowest values were recorded in hand weeding (T_7), as observed at 30 DAS, 45 DAS and 60 DAS. This was in tune with the trend in weed dry matter production.

Nitrogen removal by weeds

At 30 DAS, unweeded control (T_8) recorded the highest removal of nitrogen by weeds (16.02 kg/ha). Hand weeding (T_7) registered the lowest nitrogen removal (0.01 kg/ha) which was statistically on par with all the remaining treatments (T_1 to T_6).

At 45 DAS, nitrogen removal recorded the highest (60.89 kg/ha) and the lowest (0.35 kg/ha) values in unweeded control (T_8) and hand weeding (T_7) respectively. It was also observed that the integrated weed management practices with pre-emergence herbicide followed by hand weeding at 25 DAS (T_3, T_4, T_5, T_6) registered significantly lower values of nitrogen removal as compared with unweeded control (T_7), stale seed bed (T_1) and stale seed bed followed by oxyfluorfen (T_2).

At 60 DAS, highest nitrogen removal (57.60 kg/ha) was calculated in unweeded control (T_7) which was followed by stale seed bed (T_1) (33.41 kg/ha) and stale seed bed followed by oxyfluorfen (T_2) (8.06 kg/ha). Hand weeding (T_7) recorded the lowest nitrogen removal of 0.64 kg/ha, which was statistically on par with all the treatments were herbicide application was integrated with hand weeding (T_3 to T_7).

Phosphorus removal by weeds

At 30 DAS, highest phosphorus removal (2.78 kg/ha) was noted in unweeded control (T_8), followed by stale seed bed (T_1) (0.292 kg/ha). Though the lowest uptake of phosphorus by weeds (0.004 kg/ha) was observed in hand weeding (T_7), it was statistically comparable with the remaining treatments (T_2 to T_6) which all included pre-emergence herbicides in combination with either stale seed bed or hand weeding.

At 45 DAS, phosphorus uptake by weeds was found to be highest (8.33 kg/ha) in unweeded control (T_8) which was statistically on par with stale seed bed (T_1) (7.57 kg/ha). Again hand weeding (T_7) recorded the lowest uptake of phosphorus by weeds (0.08 kg/ha) and was statistically on par with all the integrated weed management practices (T_2 to T_6).

At 60 DAS, the highest phosphorus removal by weeds (6.36 kg/ha) was observed in unweeded control (T_8), followed by stale seed bed (T_1) (5.13 kg/ha) and stale seed bed *fb* oxyfluorfen (T_2) (1.28 kg/ha). Phosphorus uptake by weeds was found lowest (0.10 kg/ha) in hand weeding (T_7) and was statistically comparable to all the treatments where herbicide application was integrated with hand weeding (T_3 to T_6).

Potassium removal by weeds

At 30 DAS, unweeded control (T_8) recorded the highest uptake of potassium by weeds (46.94 kg/ha), followed by stale seed bed (T_1) (7.43 kg/ha). All the other treatments (T_2 to T_7) were statistically at par with each other, with potassium uptake ranging from 0.08 kg/ha in hand weeding (T_7) to 0.29 kg/ha in stale seed bed *fb* hand weeding (T_2).

At 45 DAS, unweeded control (T_8) and stale seed bed (T_1) registered the highest potassium removal (91.15 kg/ha and 74.33 kg/ha, respectively). All the other treatments (T_2 to T_7) were statistically at par with each other and the lowest potassium removal (0.56 kg/ha) was noted in hand weeding (T_7). Even then, comparatively higher value of potassium uptake (9.61 kg/ha) was observed in stale seed bed *fb* hand weeding (T_2) whereas the integration of pre-emergence herbicides with hand weeding (T_3 to T_7) recorded values ranging from 1.18 kg/ha to 3.40 kg/ha.

At 60 DAS, uptake of potassium by weeds was the highest (141.60 kg/ha) in unweeded control (T_8), and then in stale seed bed (T_1) (60.98 kg/ha) and stale seed bed *fb* oxyfluorfen (T_2) (22.74 kg/ha). The lowest potassium uptake (1.12 kg/ha) was noted in hand weeding (T_7) once again, which was statistically at par with all the treatments where herbicide application was integrated with hand weeding (T_3 to T_6).

Table 15. Effect of integrated weed management practices on nitrogen removal by weeds

Treatments		N removal by weeds (kg/ha)		
		30 DAS	45 DAS	60 DAS
T_1	SSB for 14 days	1.69^b	36.49^b	33.41^b
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	0.07^b	6.76^c	8.06^c
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	0.03^b	1.31^d	1.53^d
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	0.03^b	1.93^d	2.00^d
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	0.02^b	1.00^d	1.06^d
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	0.02^b	0.87^d	1.03^d
T_7	HW at 20 DAS and 40 DAS	0.01^b	0.35^d	0.64^d
T_8	Unweeded control	16.02^a	60.89^a	57.60^a
SE m (±)		0.95	1.46	1.77
CD (0.05)		2.87	4.44	5.36

In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

Table 16. Effect of integrated weed management practices on phosphorus removal by weeds

Treatments		P removal by weeds (kg/ha)		
		30 DAS	**45 DAS**	**60 DAS**
T_1	SSB for 14 days	0.29^b	7.57^a	5.13^b
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	0.013^c	1.25^b	1.28^c
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	0.006^c	0.29^b	0.21^d
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	0.010^c	0.37^b	0.40^d
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	0.007^c	0.22^b	0.16^d
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	0.006^c	0.25^b	0.17^d
T_7	HW at 20 DAS and 40 DAS	0.004^c	0.08^b	0.10^d
T_8	Unweeded control	2.78^a	8.33^a	6.36^a
SE m (±)		0.06	0.84	0.22
CD (0.05)		0.19	2.56	0.66

In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

Table 17. Effect of integrated weed management practices on potassium removal by weeds

Treatments		K removal by weeds (kg/ha)		
		30 DAS	**45 DAS**	**60 DAS**
T_1	SSB for 14 days	7.43^{b}	74.33^{a}	60.98^{b}
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	0.29^{c}	9.61^{b}	22.74^{bc}
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	0.11^{c}	3.40^{b}	2.01^{c}
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	0.17^{c}	3.02^{b}	2.99^{c}
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	0.09^{c}	2.11^{b}	1.43^{c}
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	0.10^{c}	1.18^{b}	2.19^{c}
T_7	HW at 20 DAS and 40 DAS	0.08^{c}	0.56^{b}	1.12^{c}
T_8	Unweeded control	46.94^{a}	91.15^{a}	141.60^{a}
SE m (±)		1.38	18.57	16.13
CD (0.05)		4.19	56.34	48.92

In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

4.1.5 Weed Control Efficiency (WCE)

Weed control efficiency of various weed management practices were calculated and data are presented in Table 18. At 30 DAS, all the integrated weed management practices recorded very high weed control efficiencies. The lowest weed control efficiency (85.30 %) was observed for stale seed bed (T_1) whereas all the other treatments (T_1 to T_7) had weed control efficiencies ranging from 99.30 per cent to 99.80 per cent.

At 45 DAS, a sharp decline was observed in the weed control efficiency of stale seed bed (T_1) (11.69 %). Stale seed bed *fb* oxyfluorfen (T_2) also recorded a decreased weed control efficiency of 82.90 %. The highest weed control efficiency (98.94 %) was observed with two hand weedings (T_7). The integrated weed management practice with any of the pre-emergence herbicides (oxyfluorfen, imazethapyr, imazethapyr + imazamox, and diclosulam) and a hand weeding at 25 DAS (T_3 to T_6) also recorded high weed control efficiencies with values ranging from 95.55 per cent to 97.38 per cent. Among the herbicidal treatments, the highest weed control efficiency (97.38 %) was observed for diclosulam *fb* hand weeding (T_6) which was closely followed by imazethapyr + imazamox *fb* hand weeding (T_5) (97.25 %).

At 60 DAS, though a slight decrease was observed in the weed control efficiencies of all the treatments, the trends in their values for different treatments were more or less the similar to that observed at 45 DAS. The highest weed control efficiency (98.16 per cent) was observed with two hand weedings (T_7), followed by imazethapyr + imazamox *fb* hand weeding (T_5) (96.87 per cent) and diclosulam *fb* hand weeding (T_6) (96.82 per cent). Stale seed bed (T_1) resulted in the lowest weed control efficiency, with a value of 11.80 per cent and the integration of stale seed bed with pre-emergence oxyfluorfen (T_2) recorded a weed control efficiency of 77.13 per cent. Thus, the weed control efficiencies of various treatments could be summarized as hand weeding > imazethapyr + imazamox *fb* hand weeding > diclosulam *fb* hand weeding > oxyfluorfen *fb* hand weeding > imazethapyr *fb* hand weeding > stale seed bed *fb* oxyfluorfen > stale seed bed.

4.1.6 Weed index

Weed index was calculated for each treatment and the results are presented in Table 18. The lowest weed index (5.82 %) was observed in imazethapyr + imazamox *fb* hand weeding (T_5) which was followed by diclosulam *fb* hand weeding (T_5) (8.22 %). Unweeded control (T_8) recorded a weed index of 70.03 per cent. It could be inferred that the weed index showed an increasing trend in the order imazethapyr + imazamox *fb* hand weeding < diclosulam *fb* hand weeding < oxyfluorfen *fb* hand weeding < imazethapyr *fb* hand weeding < stale seed bed *fb* oxyfluorfen < stale seed bed.

Table 18. Effect of integrated weed management practices on weed control efficiency and weed index

Treatments		WCE (%)			WI (%)
		30 DAS	45 DAS	60 DAS	
T_1	SSB for 14 days	85.30	11.69	11.80	28.10
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	99.30	82.90	77.13	17.83
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	99.69	96.29	96.07	13.20
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	99.61	95.55	94.60	13.56
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	99.74	97.25	96.87	5.82
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	99.70	97.38	96.82	8.22
T_7	HW at 20 DAS and 40 DAS	99.80	98.94	98.16	-
T_8	Unweeded control	-	-	-	70.03

4.2 OBSERVATIONS ON GREEN GRAM

4.2.1 Plant height

At 30 DAS, plants in the unweeded control (T_8) recorded the lowest plant height of 10.87 cm, whereas significantly higher values of plant height were observed in all other treatments (Table 19). The treatments T_1 to T_7 had values varying from 13.07 cm to 13.50 cm, and were statistically on par with each other.

At 45 DAS, the greatest plant height (27.67 cm) was observed with two hand weedings (T_7) which was statistically on par with stale seed bed *fb* oxyfluorfen (T_2) (27.17 cm). Stale seed bed (T_1) also recorded a comparatively higher plant height of 25.63 cm. Again, unweeded control (T_8) recorded a lower plant height (22.00 cm), compared to which the various integrated weed management practices consisting of pre-emergence herbicide and hand weeding at 25 DAS (T_3 – T_6) recorded significantly higher values of plant height (24.07 cm to 24.97 cm). It was observed that the plant height varied among the different treatments as hand weeding > stale seed bed *fb* hand weeding > stale seed bed > imazethapyr + imazamox *fb* hand weeding > oxyfluorfen *fb* hand weeding > diclosulam *fb* hand weeding > imazethapyr *fb* hand weeding > unweeded control.

4.2.2 Number of branches per plant

The weed management practices had a significant effect on the number of branches per plant at 45 DAS but not at 30 DAS (Table 20). At 30 DAS, the number of branches had values ranging from 3.93 to 4.66 for different treatments which were statistically at par. However, at 45 DAS, significantly higher number of branches (7.60) was found in hand weeding (T_7), which was statistically on par with diclosulam *fb* hand weeding (T_6) (7.33). The lowest number of branches per plant was observed in unweeded control (T_8) (6.27) which was statistically on par with oxyfluorfen *fb* hand weeding (T_3) (6.47).

Table 19. Effect of integrated weed management practices on height of green gram

Treatments		Plant height (cm)	
		30 DAS	45 DAS
T_1	SSB for 14 days	13.07[a]	25.63[bc]
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	13.13[a]	27.17[ab]
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	13.33[a]	24.57[c]
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	13.47[a]	24.07[c]
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	13.33[a]	24.97[c]
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	13.40[a]	24.53[c]
T_7	HW at 20 DAS and 40 DAS	13.50[a]	27.67[a]
T_8	Unweeded control	10.87[b]	22.00[d]
SE m (±)		0.51	0.64
CD (0.05)		1.55	1.96

In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

Table 20. Effect of integrated weed management practices on number of branches of green gram

Treatments		Number of branches/plant	
		30 DAS	**45 DAS**
T_1	SSB for 14 days	4.47	6.67^{bc}
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	4.40	6.67^{bc}
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	4.60	6.47^{c}
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	4.13	6.60^{bc}
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	4.40	6.60^{bc}
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	3.93	7.33^{ab}
T_7	HW at 20 DAS and 40 DAS	4.67	7.60^{a}
T_8	Unweeded control	4.53	6.27^{c}
SE m (±)		-	0.26
CD (0.05)		NS	0.81

In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

4.2.3 Number of pods per plant

Highest number of pods per plant (20.73) was recorded in hand weeding (T_7) which was statistically on par with imazethapyr + imazamox *fb* hand weeding (T_5) (20.67), diclosulam *fb* hand weeding (T_6) (20.60), oxyfluorfen *fb* hand weeding (T_3) (20.53), stale seed bed *fb* oxyfluorfen (T_2) (20.33) and imazethapyr *fb* hand weeding (T_4) (20.27). The lowest number (15.00) of pods per plant was registered in unweeded control (T_8) (Table 21).

4.2.4 Number of seeds per pod

Unweeded control (T_8) recorded the lowest number of seeds per pod (7.83). The number of seeds was found to be statistically similar in all the remaining treatments (T_1 to T_7) with values ranging from 9.85 to 10.93 (Table 21).

4.2.5 100 seed weight

It was observed that integrated weed management practices in green gram did not produce any significant effect on 100 seed weight with values ranging from 4.08 g to 4.28 g (Table 21).

Table 21. Effect of integrated weed management practices on yield attributes of green gram

Treatments		No. of pods/plant	No. of seeds/pod	100 seed weight (g)
T_1	SSB for 14 days	18.40[b]	10.30[a]	4.08
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	20.33[a]	9.85[a]	4.24
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	20.53[a]	10.67[a]	4.19
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	20.27[a]	10.17[a]	4.15
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	20.67[a]	9.93[a]	4.28
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	20.60[a]	10.93[a]	4.27
T_7	HW at 20 DAS and 40 DAS	20.73[a]	10.87[a]	4.21
T_8	Unweeded control	15.00[c]	7.83[b]	4.08
SE m (±)		0.31	0.58	-
CD (0.05)		0.97	1.78	NS

In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

4.2.5 Grain yield

It was observed that the grain yield of green gram was significantly influenced by the various weed management practices (Table 22).

The highest seed yield of 583 kg/ha was observed in hand weeding (T_7), which was statistically similar to imazethapyr + imazamox *fb* hand weeding (T_5) (549 kg/ha), diclosulam *fb* hand weeding (T_6) (535 kg/ha), oxyfluorfen *fb* hand weeding (T_3) (506 kg/ha) and imazethapyr *fb* hand weeding (T_4) (504 kg/ha). However, the grain yields were comparatively lower in stale seed bed *fb* oxyfluorfen (T_2) (479 kg/ha) and stale seed bed (T_1) (419 kg/ha). Unweeded control (T_8) recorded the lowest seed yield of 175 kg/ha.

4.2.6 Haulm yield

As with grain yield, haulm yield of green gram was also significantly influenced by the integrated weed management practices (Table 22).

The highest haulm yield (1420 kg/ha) was recorded in hand weeding (T_7) which was statistically on par with all the treatments where herbicide application was integrated with hand weeding (T_3 – T_6). The lowest haulm yield (474 kg/ha) was observed in unweeded control (T_8). As with grain yield, haulm yield of green gram followed the order hand weeding > imazethapyr + imazamox *fb* hand weeding > diclosulam *fb* hand weeding > oxyfluorfen *fb* hand weeding > imazethapyr *fb* hand weeding > stale seed bed *fb* oxyfluorfen > stale seed bed.

Table 22. Effect of integrated weed management practices on grain and haulm yield of green gram

Treatments		Grain yield (kg/ha)	Haulm yield (kg/ha)
T_1	SSB for 14 days	419[c]	996[c]
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	479[bc]	1142[bc]
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	506[abc]	1241[abc]
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	504[abc]	1238[abc]
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	549[ab]	1296[ab]
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	535[ab]	1271[ab]
T_7	HW at 20 DAS and 40 DAS	583[a]	1420[a]
T_8	Unweeded control	175[d]	474[d]
SE m (±)		30.24	84.54
CD (0.05)		91.74	256.46

In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

4. Soil analysis

4.3.1 pH

The post-experimental soil analysis revealed that the pH of the soil was not significantly affected by the integrated weed management practices, and had values ranging from 4.04 (T_2: Stale seed bed *fb* oxyfluorfen) to 4.84 (T_6: Diclosulam *fb* hand weeding) (Table 23).

4.3.2 Electrical conductivity (EC)

Though there was an increase in electrical conductivity of the soil after harvest as compared to that before sowing (0.73 dS/m), integrated weed management practices did not have any significant effect on electrical conductivity of the soil (Table 23), and the post experimental analysis of soil registered an average electrical conductivity of 1.30 dS/m.

4.3.3 Organic carbon (OC)

Organic carbon was found highest (0.82 %) in unweeded control (T_8), but it could be concluded that the integrated weed management practices in green gram did not produce any significant effect on organic carbon (Table 23). After harvest, organic carbon was in the range 0.65 per cent to 0.82 per cent in the treatments, whereas it was only 0.53 per cent prior to the experiment.

Table 23. Effect of integrated weed management practices on soil pH, EC and organic carbon

Treatments		pH	EC (dS/m)	OC (%)
T_1	SSB for 14 days	4.12	0.77	0.65
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	4.04	1.04	0.80
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	4.13	1.32	0.75
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	4.10	1.41	0.71
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	4.09	1.25	0.79
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	4.84	1.39	0.65
T_7	HW at 20 DAS and 40 DAS	4.11	1.65	0.71
T_8	Unweeded control	4.62	1.52	0.82
CD (0.05)		NS	NS	NS
Pre-experiment		4.27	0.73	0.53

In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

4.3.4 Available N, P and K after the experiment

From the data on post-experimental analysis of soil, it could be concluded that the integrated weed management practices in green gram produced a significant effect on available phosphorus and potassium status of the soil but not on the nitrogen status (Table 24).

Though the integrated weed management practices did not influence the available nitrogen content in the soil, it was noted that the nitrogen content in soil after harvest had an average value of 129 kg/ha, which showed a marked increase from nitrogen content in the soil before the experiment (76 kg/ha).

The highest phosphorus content (86 kg/ha) was observed in hand weeding (T_7), which was statistically similar to diclosulam *fb* hand weeding (T_6) (83 kg/ha). The lowest phosphorus content of 42 kg/ha was observed in unweeded control (T_8). The soil phosphorus content in the treatments followed the pattern hand weeding > diclosulam *fb* hand weeding > imazethapyr + imazamox *fb* hand weeding > imazethapyr *fb* hand weeding > oxyfluorfen *fb* hand weeding> stale seed bed *fb* oxyfluorfen > stale seed bed > unweeded control.

Potassium content in soil after harvest was found the highest (310 kg/ha) in diclosulam *fb* hand weeding (T_6), which was statistically on par with hand weeding (T_7) (275 kg/ha), imazethapyr + imazamox *fb* hand weeding (T_5) (258 kg/ha), oxyfluorfen *fb* hand weeding (T_3) (257 kg/ha) and imazethapyr *fb* hand weeding (T_4) (232 kg/ha). The lowest potassium content (104 kg/ha) was observed in unweeded control (T_8) which was on par with stale seed bed (T_1) (112 kg/ha). It was noted that the potassium content in soil was in the order diclosulam *fb* hand weeding > hand weeding > imazethapyr + imazamox *fb* hand weeding > oxyfluorfen *fb* hand weeding > imazethapyr *fb* hand weeding > stale seed bed *fb* oxyfluorfen > stale seed bed > unweeded control.

Table 24. Effect of integrated weed management practices on available N, P and K in soil

Treatments		N (kg/ha)	P (kg/ha)	K (kg/ha)
T_1	SSB for 14 days	113.40	46.56^{de}	112.20^{c}
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	119.70	56.61^{cde}	204.60^{b}
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	121.80	61.90^{cd}	257.40^{ab}
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	123.90	64.73^{bc}	232.10^{ab}
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	140.70	80.07^{ab}	258.13^{ab}
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	147.00	82.72^{a}	310.20^{a}
T_7	HW at 20 DAS and 40 DAS	157.50	86.24^{a}	275.00^{ab}
T_8	Unweeded control	109.20	42.33^{e}	103.76^{c}
SE m (±)		-	5.64	27.16
CD (0.05)		NS	17.11	82.41
Pre-experiment		75.6	37.57	93.5

In a column, mean followed by common letters do not differ significantly at 5 % level in DMRT.

4.3.5 Soil microbial analysis

Data on soil microbial count revealed that the mean population of total bacteria, fungi and actinomycetes were higher than the values observed before the start of the experiment at both the flowering stage and harvest (Table 25).

Pre-experimental soil bacterial count was found to be 14 x 10^6 cfu/g. At flowering, the highest count of bacteria (20.33 × 10^6 cfu/g) was noted in hand weeding (T_7), which was statistically on par with imazethapyr + imazamox *fb* hand weeding (T_5) (16.67 × 10^6 cfu/g), unweeded control (T_8) (16.00 × 10^6 cfu/g), oxyfluorfen *fb* hand weeding (T_3) (15.00× 10^6 cfu/g), imazethapyr *fb* hand weeding (T_4) (14.67 × 10^6 cfu/g) and stale seed bed (T_1) (14.00 × 10^6 cfu/g) The lowest count was recorded in diclosulam (T_6) (7.67 × 10^6 cfu/g). Though diclosulam (T_6) (13.67 × 10^6 cfu/g) still recorded the lowest bacterial population at harvest, all the other treatments were found to be statistically on par with an average bacterial count of 27.28 × 10^6 cfu/g.

Total count of fungi before sowing was recorded as 3 x 10^4 cfu/g. At flowering, the total count of fungi was found highest (22.67× 10^4 cfu/g) in unweeded control (T_8) which was on par with hand weeding (T_7) (19.67× 10^4 cfu/g), imazethapyr *fb* hand weeding (T_4) (19.67× 10^4 cfu/g) and stale seed bed (T_1) (18.67× 10^4 cfu/g), whereas diclosulam *fb* hand weeding (T_5) (10.00 × 10^4 cfu/g) registered the lowest fungal population. At harvest, all the treatments except diclosulam *fb* hand weeding (T_5) (13.00 × 10^4 cfu/g) were found to be statistically comparable, with an average fungal population of 28.76 × 10^4 cfu/g.

The actinomycetes population in soil was unaffected by integrated weed management practices both at flowering and at harvest. The average population of actinomycetes was recorded as 1.67 x 10^5 cfu/g before sowing, which was increased to 1.87 x 10^5 cfu/g at flowering and 2.70 x 10^5 cfu/g at harvest.

Table 25. Effect of integrated weed management practices on soil microbial count (cfu/g)

Treatments		Bacteria (cfu/g)		Fungi (cfu/g)		Actinomycetes (cfu/g)	
		At Flowering	**At harvest**	**At flowering**	**At harvest**	**At flowering**	**At harvest**
T_1	SSB for 14 days	$^{*}7.14^{ab}$ (14.00 x10^6)	7.41^{a} (26.33 x10^6)	5.27^{ab} (18.67 x10^4)	5.48^{a} (30.67 x10^4)	5.26 (2.00 x10^5)	5.46 (3.00 x10^5)
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	7.08^{b} (12.00 x10^6)	7.40^{a} (25.00 x10^6)	5.06^{c} (11.67 x10^4)	5.43^{a} (27.00 x10^4)	5.26 (2.00 x10^5)	5.40 (2.67 x10^5)
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	7.17^{ab} (15.00 x10^6)	7.42^{a} (26.67 x10^6)	5.09^{c} (12.33 x10^4)	5.43^{a} (27.00 x10^4)	3.59 (1.67 x10^5)	5.26 (2.00 x10^5)
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	7.16^{ab} (14.67 x10^6)	7.40^{a} (25.33 x10^6)	5.29^{ab} (19.67 x10^4)	5.46^{a} (29.33 x10^4)	3.59 (1.67 x10^5)	5.26 (2.00 x10^5)
T_5	Imazethapyr + imazamox at 0-3 DAS, *fb* HW at 25 DAS	7.21^{ab} (16.67 x10^6)	7.46^{a} (28.67 x10^6)	5.16^{bc} (14.67 x10^4)	5.40^{a} (25.67 x10^4)	3.59 (1.67 x10^5)	5.41 (2.67 x10^5)
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	6.87^{c} (7.67 x10^6)	7.13^{b} (13.67 x10^6)	4.99^{c} (10.00 x10^4)	5.10^{b} (13.00 x10^4)	3.53 (1.33 x10^5)	5.26 (2.00 x10^5)
T_7	HW at 20 DAS and 40 DAS	7.30^{a} (20.33 x10^6)	7.49^{a} (31.00 x10^6)	5.27^{ab} (19.67 x10^4)	5.49^{a} (31.33 x10^4)	5.31 (2.33 x10^5)	5.50 (3.33 x10^5)
T_8	Unweeded control	7.19^{ab} (16.00 x10^6)	7.44^{a} (28.00 x10^6)	5.35^{a} (22.67 x10^4)	5.48^{a} (30.33 x10^4)	5.31 (2.33 x10^5)	5.50 (3.33 x10^5)
CD (0.05)		0.17	0.13	0.18	0.14	NS	NS
Pre-experiment		14×10^6 cfu/g		3×10^4 cfu/g		1.67×10^5 cfu/g	

* log(10) transformed values with original values in parantheses. In a column, mean followed by common letters do not differ significantly at 5% level in DMRT.

4.5. Economics of cultivation

Data on cost of cultivation, gross returns, net returns and B:C ratio calculated are presented in Table 28.

It was observed that the cost of cultivation was highest (Rs. 37,638/ha) in hand weeding (T_7), which was followed by imazethapyr + imazamox *fb* hand weeding (T_5) (Rs. 32,028/ha) and oxyfluorfen *fb* hand weeding (T_3) (Rs. 31,945/ha). Unweeded control (T_8) recorded the lowest cost of cultivation (Rs. 25,638/ha). Similarly, the highest gross returns (Rs. 43,699) was obtained in hand weeding (T_7), followed by imazethapyr + imazamox *fb* hand weeding (T_5) (Rs. 41,154/ha). However, net returns were higher in imazethapyr + imazamox *fb* hand weeding (Rs. 9,126/ha) and diclosulam *fb* hand weeding (Rs. 8,733/ha). Also, the benefit- cost ratio was highest (1.28) in imazethapyr + imazamox *fb* hand weeding (T_5) which was closely followed by diclosulam *fb* hand weeding (T_6) (1.27). Unweeded control (T_8) recorded the lowest B:C ratio of 0.51.

Table 26. Effect of integrated weed management practices on economics of cultivation of green gram

Treatments		Cost of cultivation/ha (Rs.)	Gross returns/ha (Rs.)	Net returns/ha (Rs.)	B:C ratio
T_1	SSB for 14 days	28,038	31,421	3,383	1.12
T_2	SSB for 14 days, *fb* oxyfluorfen at 0-3 DAS	30,745	35,905	5,160	1.16
T_3	Oxyfluorfen at 0-3 DAS, *fb* HW at 25 DAS	31,945	37,930	5,985	1.18
T_4	Imazethapyr at 0-3 DAS, *fb* HW at 25 DAS	31,188	37,774	6,586	1.21
T_5	Imazethapyr + imazamox (RM) at 0-3 DAS, *fb* HW at 25 DAS	32,028	41,154	9,126	1.28
T_6	Diclosulam at 0-3 DAS, *fb* HW at 25 DAS	31,374	40,107	8,733	1.27
T_7	HW at 20 DAS and 40 DAS	37,638	43,699	6,061	1.16
T_8	Unweeded control	25,638	13,098	-12,540	0.51

Discussion

5. DISCUSSION

A field trial was carried out at *Kotteppadam* rice field, Department of Agronomy, College of Agriculture, Vellanikkara to develop an integrated weed management strategy in green gram. A brief discussion of the results obtained is presented in this chapter.

5.1 Weed spectrum

Eleven weed species were found predominant in the experimental field, out of which six belonged to broad leaved category and five were grasses. Broad leaved weeds dominated the field at all stages of observations, accounting for 84.5 per cent of the total weed population at 30 DAS, 91 per cent at 45 DAS and 85.5 per cent at 60 DAS (Fig. 2). These observations were in close conformity with the results of Maji *et al.* (2020) and Senthivelu *et al.* (2020) who concluded that the green gram ecosystem was found to be dominated by broad leaved weeds.

Melochia corchorifolia was found to be the most aggressive weed species throughout the cropping season, and alone contributed to more than 75 per cent of the total weed density. Other broad leaved weeds observed were *Aeschynomene indica*, *Grangea maderaspatana*, *Phyllanthus amara, Heliotropium indicum*, *Mimosa invisa* and *Mimosa pudica*. During the initial stages of crop growth, *Brachiaria mutica*, by virtue of its ability to undergo rapid vegetative propagation, was the only major grass species to be identified. But later, *Digitaria ciliaris* emerged as the dominant grass species in the experimental filed. *Echinochloa colona, Oryza sativa* and *Cynodon dactylon* were also observed, though in relatively lower proportions. Similar weed species were observed by Abid (2018) when green gram was cultivated earlier at *Kotteppadam.*

5.2 Response of weeds to integrated weed management practices

Observations on species-wise weed count revealed that the integration of various pre-emergence herbicides (oxyfluorfen, imazethapyr, imazethapyr + imazamox, diclosulam) with a single hand weeding at 25 DAS could successfully lower the population of both broad leaved weeds and grasses (Figs. 3, 4 and 5). This might be due to the efficiency of pre-emergence herbicides in suppressing the germination of the weed seed bank in the soil rhizosphere prior to planting and also inhibiting the further growth of germinated weeds when combined with manual weeding at critical stages of crop-weed competition. This was in accordance with the findings of Natarajan *et al.* (2003) and Thirumalaivasan *et al*. (2016), who opined that the integration of pre-emergence herbicides with hand weeding could result in a significant reduction in weed density and dry matter production.

The lowest weed count was recorded in the treatment consisting of hand weeding at 20 DAS and 40 DAS (T_7) at all stages of observations, which could be attributed to the fact that the two hand weedings done during the critical stages of crop-weed competition ensured maximum control of both broad leaved weeds and grasses, thereby providing a nearly weed-free condition throughout the cropping season. Among the herbicidal treatments, the lowest total weed count was observed in imazethapyr + imazamox *fb* hand weeding (T_5), which might be due to the synergestic effect of the two herbicides in managing the diverse weed flora. Similar observations were reported by Tiwari *et al.* (2018) in black gram. However, stale seed bed (T_1) was less efficient in lowering the total weed count, probably due to the inefficiency of the stale seed bed technique in controlling the later flushes of weeds germinated. Elmore and Heatherly (1988) observed that stale seed bed alone resulted in a higher weed cover in soybean, whereas stale seed bed when integrated with pre-emergence herbicide application could assure a much better weed control. In the present study also, stale seed bed *fb* oxyfluorfen (T_2) recorded a lower density of both broad leaved weeds and grasses as compared to stale seed bed (T_1) alone. However, the weed population was higher in both treatments including stale seed bed ($T_1$and T_2) when compared to the integrated weed management practices involving herbicides and manual weeding (T_3 to T_6), which was most likely due to the presence of more weeds during critical period of crop-weed competition. Weed count was invariably the highest in unweeded control (T_8).

The lowest weed dry matter production was recorded in hand weeding (T_7) at all stages of observation, which might be due to the better control of weeds during the critical stages of crop-weed competition, providing conditions more favourable for crop growth, which again could result in enhanced weed suppression at later stages of crop growth by virtue of the smothering effect generated. The weed dry matter production in the hand weeded plot was 98 per cent lower than that in the unweeded control at 60 DAS. Singh *et al.* (2017) and Verma *et al.* (2017) also concluded that hand weeding twice recorded lower weed dry matter production than herbicidal treatments in green gram. Pre-emergence application of all the four herbicides on integration with hand weeding resulted in a considerable reduction in weed dry matter production, the minimum being observed in imazethapyr + imazamox *fb* hand weeding (T_5) (96.8 % lower than in unweeded control), which was statistically on par with diclosulam *fb* hand weeding (T_6) and oxyfluorfen *fb* hand weeding (T_3) (96.8 % and 96 % lower than in unweeded control respectively). This might be attributed to the high efficiency of pre-emergence herbicides in suppressing the initial flushes of weed growth and the control of weeds which emerged later ensured by hand weeding. Stale seed bed (T_1) alone or on integration with oxyfluorfen (T_2) recorded comparatively higher values of weed dry matter production, which indicated the inefficiency of stale seed bed technique in upland conditions. The weed dry matter production in T_5 (imazethapyr + imazamox *fb* hand weeding), T_6 (diclosulam *fb* hand weeding) and T_3 (oxyfluorfen *fb* hand weeding) were 96 per cent and 87 per cent, 96 per cent and 86 per cent, and 95 per cent and 82 per cent lower than T_1 and T_2, respectively. This was in accordance with the findings of Tehria *et al.* (2015) who observed that herbicidal methods of weed control resulted in a lower weed dry matter production in pea as compared to stale seed bed. Unweeded control (T_8), which exhibited unchecked weed growth, registered the highest weed dry matter production (Fig. 6). Similar findings were reported by Kaur *et al.* (2009) and Singh *et al.* (2019) as well.

Nutrient removal by weeds is a function of weed dry matter production. It was found invariably the lowest in hand weeding (T_7), owing to the higher weed control achieved which ultimately resulted in low weed dry matter production (Figs. 7, 8 and 9). All the pre-emergence herbicidal treatments integrated with hand weeding recorded significantly lower nutrient removal by weeds, which was primarily due to the better control of weeds obtained, thereby reducing the weed biomass. The highest nutrient removal was recorded in unweeded control (T_8) as a result of high weed incidence, which subsequently decreased the available nutrient fraction in soil, making less nutrients available for uptake by the crop. Similar findings were reported by Kujur *et al.* (2015), who concluded that the nutrient removal by weeds was lower in all hand weeded and herbicidal treated plots when compared to the unweeded control

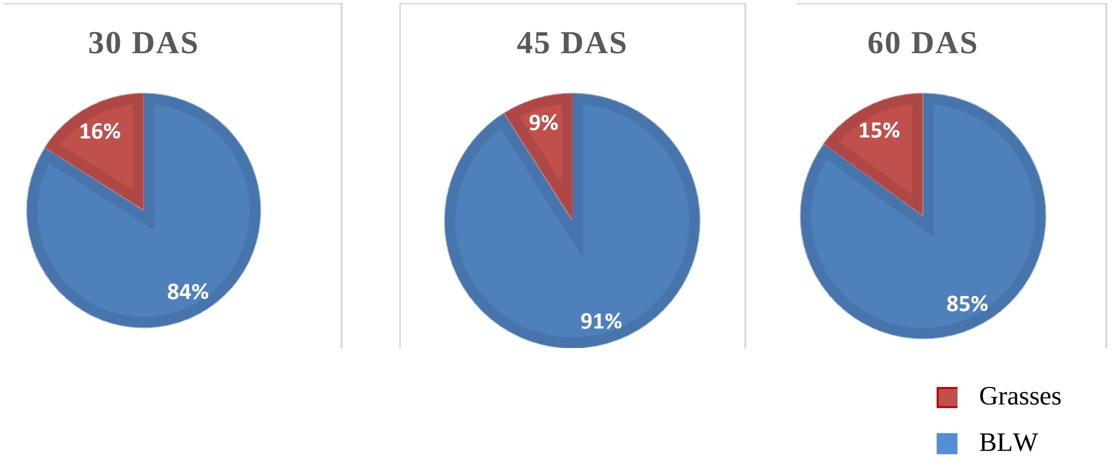

Fig. 2. Weed spectrum in the experimental field

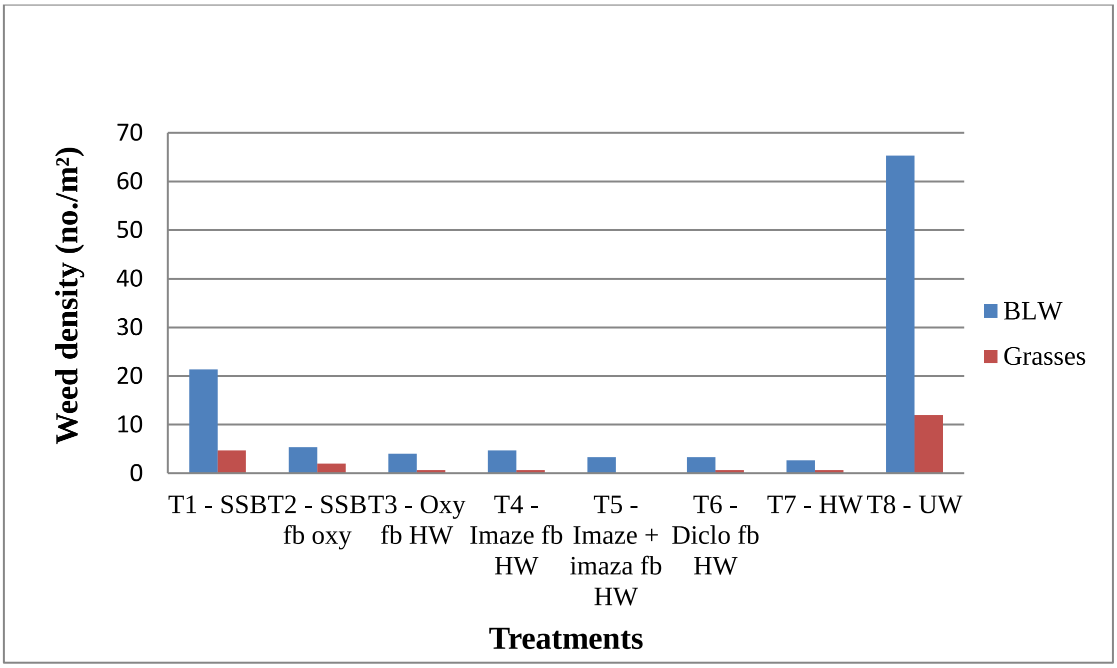

Fig. 3. Effect of integrated weed management practices on weed density at 30 DAS

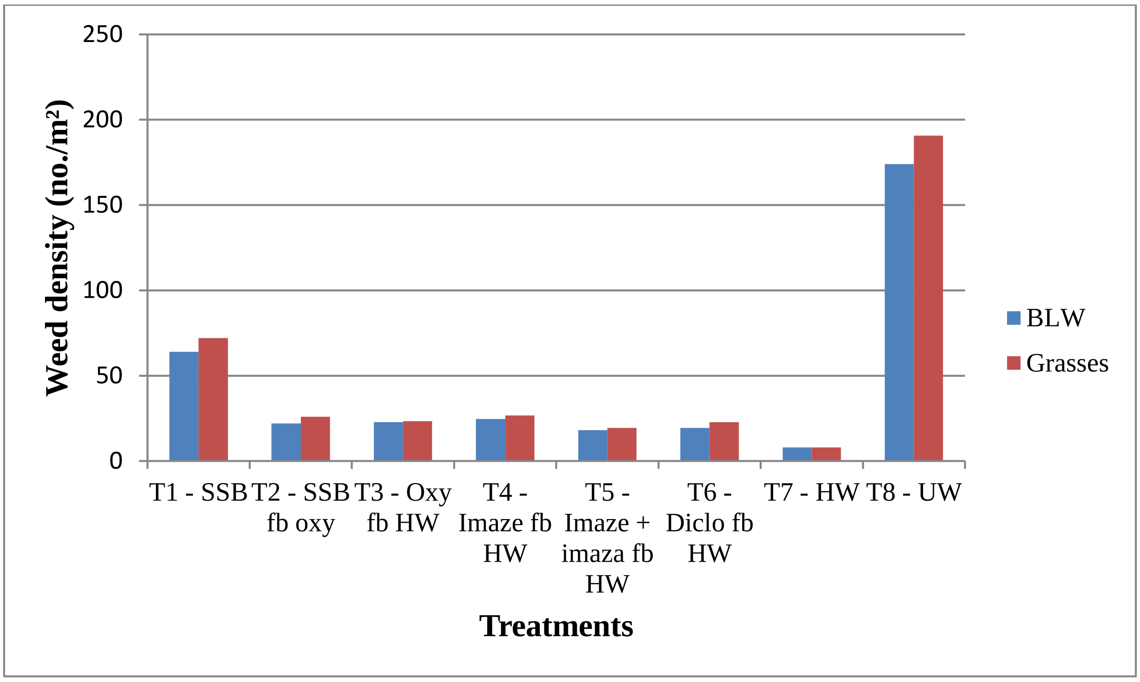

Fig. 4. Effect of integrated weed management practices on weed density at 45 DAS

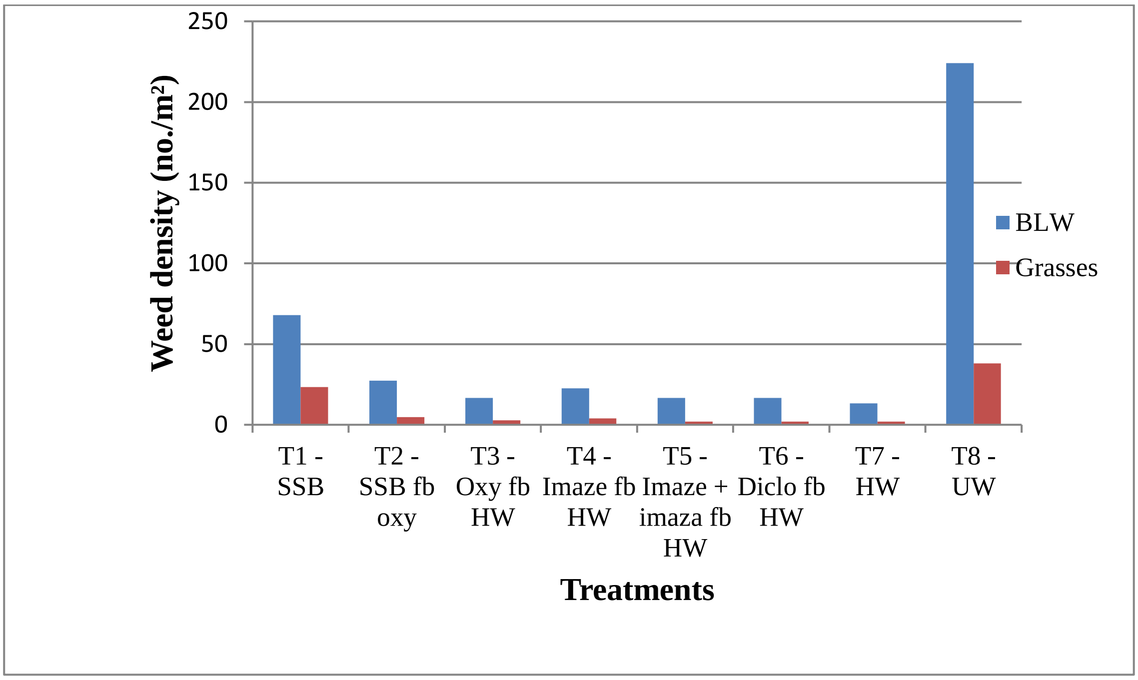

Fig. 5. Effect of integrated weed management practices on weed density at 60 DAS

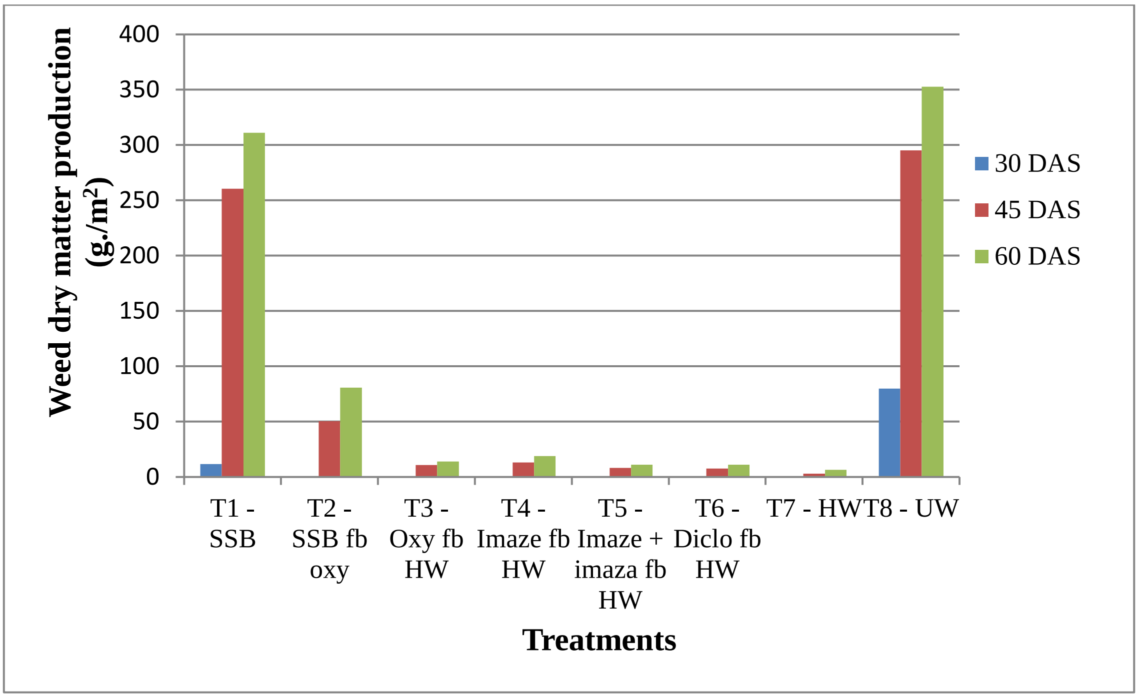

Fig. 6. Effect of integrated weed management practices on weed dry matter production

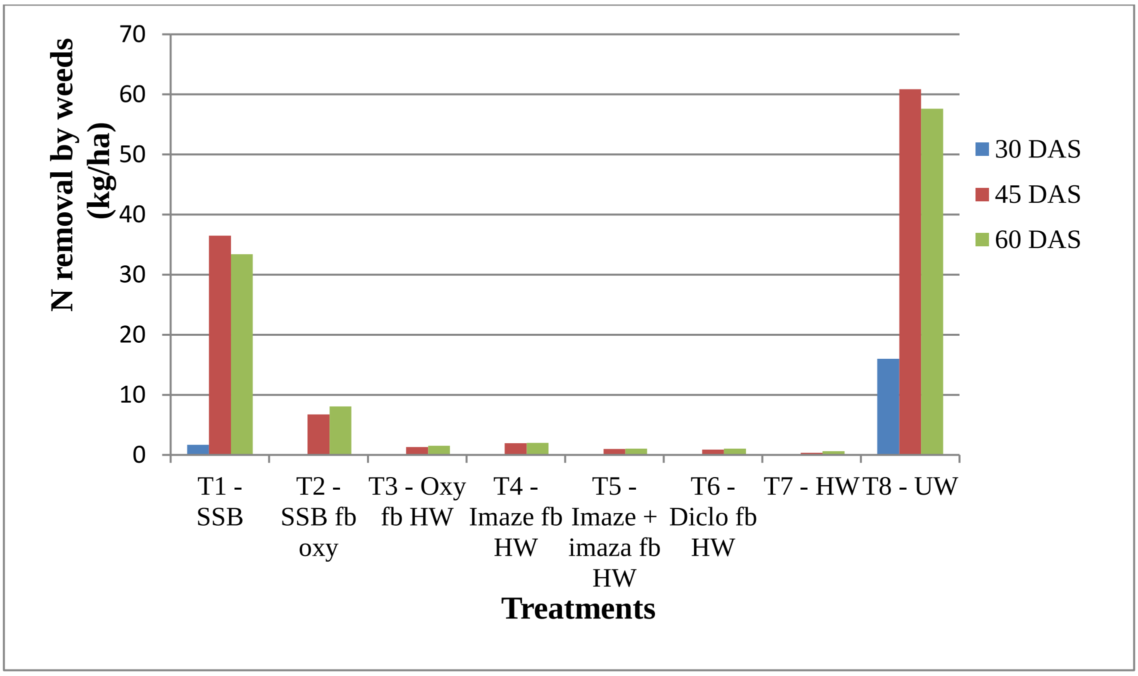

Fig. 7. Effect of integrated weed management practices on N removal by weeds

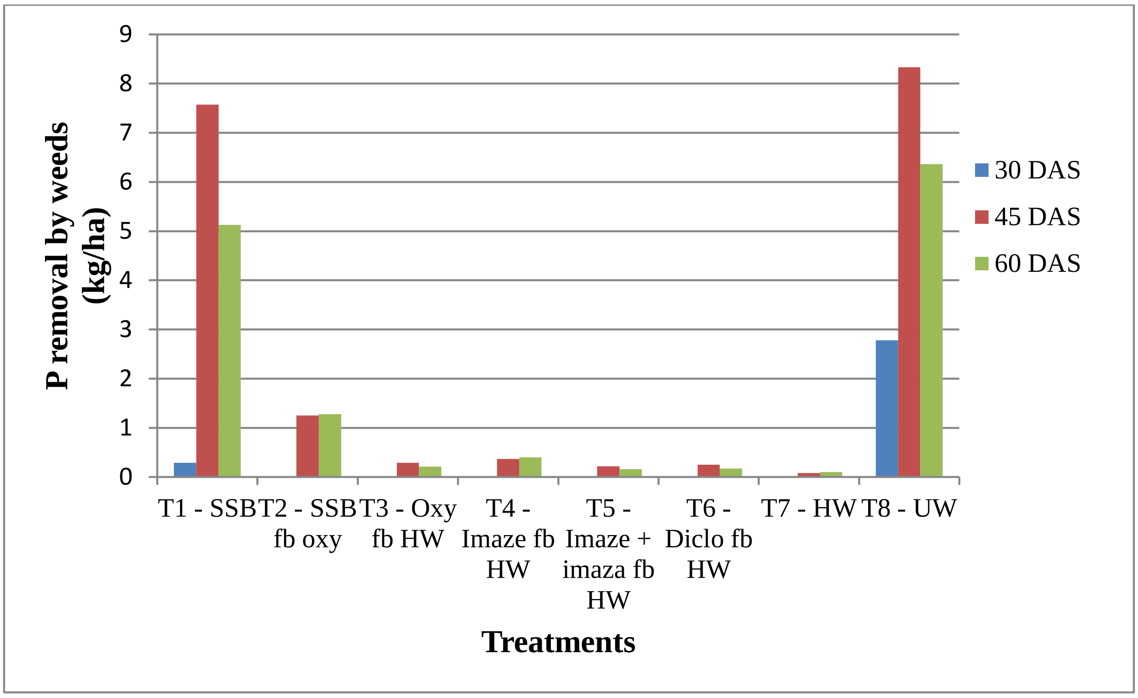

Fig. 8. Effect of integrated weed management practices on P removal by weeds

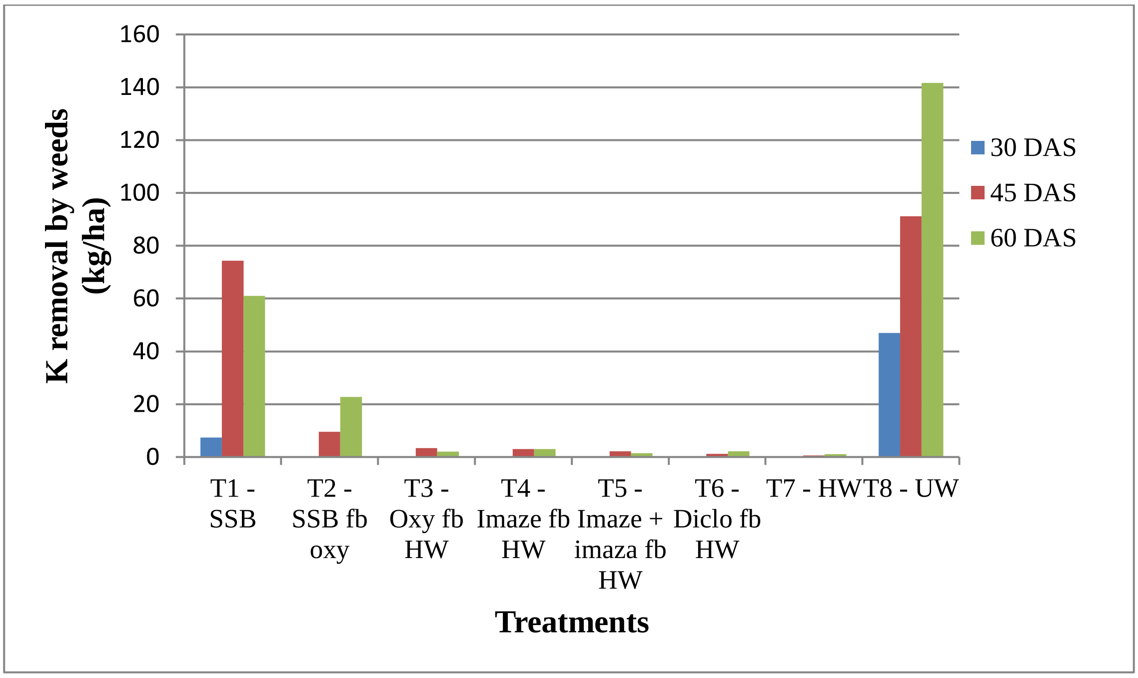

Fig. 9. Effect of integrated weed management practices on K removal by weeds

5.3 Weed Control Efficiency and Weed Index

All the integrated weed management practices involving pre-emergence herbicides followed by hand weeding resulted in very high weed control efficiencies of above 90 per cent, which might be due to the broad spectrum activity of the pre-emergence herbicides and the timely hand weeding undertaken. The highest WCE was observed in hand weeding (T_7) which was a direct effect of the periodical removal of weeds, which ultimately resulted in lowering the weed density as well as dry matter production (Fig 10). Results of Rao *et al.* (2018) and Singh *et al.* (2019) also substantiated the present findings. Among the chemical treatments, imazethapyr + imazamox *fb* hand weeding (T_5) recorded the highest WCE which was closely followed by diclosulam *fb* hand weeding (T_6). This was most likely due to the high efficacy of these herbicides in controlling the weeds of both broad leaved category and grasses, which in turn resulted in a lower dry matter production. At 30 DAS, stale seed bed (T_1) recorded a satisfactory WCE efficiency of 85.30 per cent, but it exhibited a sharp decline to 11.69 per cent at 45 DAS and 11.80 per cent at 60 DAS. It clearly indicated that the stale seed bed for 14 days was insufficient in providing season long weed control in green gram, because of which weed dry matter production was considerably high as observed at 45 DAS and 60 DAS. In upland situations, repeated staling might be more effective than a single stale seed bed. Accordingly, double stale seed bed could be taken up in areas of organic cultivation of pulses in order to achieve successful weed control. Gopinath *et al.* (2009) also found out that stale seed bed in garden pea recorded a low WCE of 53 per cent, whereas it was 84 per cent when hand weeding was carried out twice.

Weed index refers to the percentage decrement in the seed yield under a given treatment arising in response to the competition from weeds when compared to the seed yield achieved under hand weeded plots. Weed index was the lowest in imazethapyr + imazamox *fb* hand weeding (T_5), and then in diclosulam *fb* hand weeding (T_6) (Fig. 11). It may be attributed to the reduced crop-weed competition in these treatments owing to the high weed control efficiency, as a result of which seed yield in green gram was higher. The unchecked weed growth in unweeded control (T_8)

resulted in greater competition with the crop plants for both above ground and below ground resources, which adversely affected the seed yield of green gram, thereby registering the highest weed index. Similar observations were made by Mirjha *et al.* (2013) and Kumar *et al.* (2020).

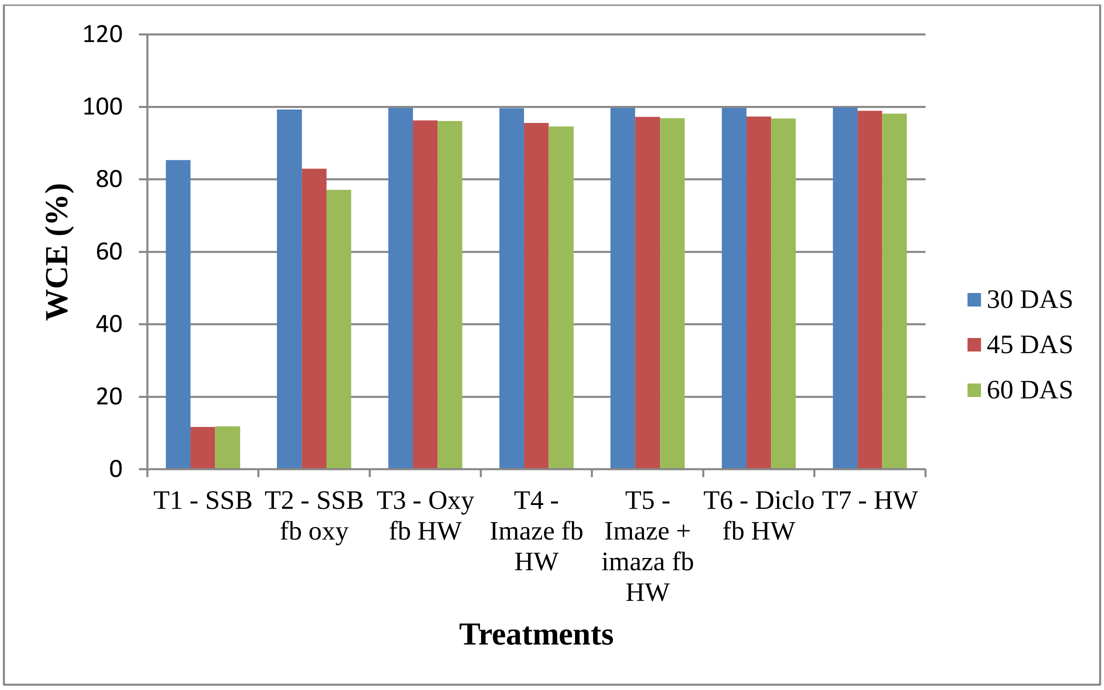

Fig. 10. Effect of integrated weed management practices on weed control efficiency

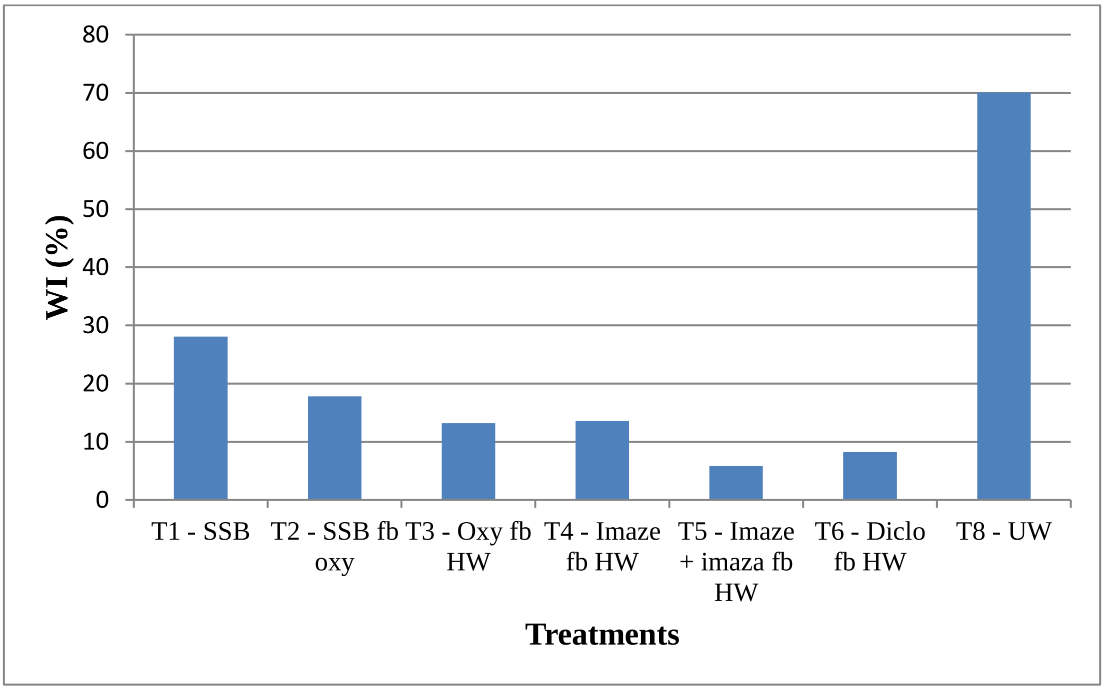

Fig. 11. Effect of integrated weed management practices on weed index

5.3 Response of crop to integrated weed management practices

The growth characters of green gram were significantly affected by any of the weed management practices (Figs. 12 and 13). The plant height and number of branches/plant was the highest in hand weeding (T_7) which was most likely due to the reduced competitive interaction of the crop with the weeds. This resulted in a more efficient utilization of resources like light, space, nutrients and moisture, which eventually led to an increase in the rate of photosynthesis and metabolic activities, thereby enhancing the overall growth. Plant height and number of branches were higher in all the stale seed bed and herbicide treated plots which might be due to the weed-free environment provided by these weed control treatments during the initial stages of crop growth. Sinchana (2020) reported that the plant height and number of branches in cowpea was higher in stale seed bed owing to the reduced crop-weed competition ensured during the initial stages of crop growth, which results in a more effective utilization of resources by the crop. Unweeded control (T_8) recorded significantly lower plant height and number of branches per plant which might have been the consequence of the high-crop weed competition. Singh *et al*. (2017) also stated that higher values of plant height and number of branches were obtained in green gram under weed management practices as compared to unweeded control.

The yield attributes were also significantly improved under weed management practices, which might be due to the congenial environment provided for the growth of green gram, which eventually resulted in enhanced development of the reproductive structures and greater translocation of photosynthetic products from source to sink. Accordingly, number of pods/plant was the highest in hand weeding (T_7) which was statistically on par with any of the integrated weed management practices followed (T_2 to T_6) (Fig. 16). Similarly, number of seeds/pod was observed to be the highest in diclosulam *fb* hand weeding (T_6), which was on par with hand weeding (T_7) as well as the other integrated weed management practices undertaken (T_2 to T_6) (Fig.14). However, weed management practices did not affect 100 seed weight, which was probably because it is primarily a varietal character. Values for all the yield attributes were found to be the lowest in unweeded control (T_8), which was most likely due to the increased competition of green gram with the weeds for resources available. This was in close conformity with the results of Singh *et al.* (2019), who concluded that significantly higher pods/plant and seeds/pod in green gram were noticed under herbicide treated or manually weeded plots over unweeded control, whereas 100 seed weight was not influenced.

The grain yield was found to be the highest in hand weeding (T_7), which can be attributed to the reduced weed density and biomass during critical stages of crop-weed competition as a result of periodical hand weeding, thereby providing conditions conducive for efficient crop growth, which led to an increased production of pods/plant and seeds/pod, and ultimately yield. Studies of Nandan *et al.* (2011) and Rao *et al.* (2018) also corroborated the present findings. Among the integrated weed management practices, the highest seed yield was recorded in imazethapyr + imazamox *fb* hand weeding (T_5), which might be due to the combined effect of both the herbicides and hand weeding in achieving maximum weed control, making more resources available to the crop plant, which eventually was reflected as an increase in grain yield. Tiwari *et al.* (2018) observed that the seed yield of black gram was the highest with the application of imazethapyr + imazamox followed by hand weeding at 35 DAS. It was again observed that diclosulam *fb* hand weeding (T_6) also produced comparable seed yields, indicating that the broad spectrum action of the herbicide coupled with timely hand weeding ensured satisfactory weed control at critical stages of crop-weed competition, because of which green gram recorded higher yield attributes and yield. Similar results were reported in soybean by Nainwal *et al.* (2010) who concluded that pre-emergence application of diclosulam followed by hand weeding resulted in the highest seed yield. Pre-emergence application of oxyfluorfen (T_3) and imazethapyr (T_4) when integrated with hand weeding also produced comparable seed yield. In unweeded control, significant quantities of nutrients and other resources were taken up by the weeds, and the stress created directly affected the growth and yield of green gram. This could be the probable reason for the lowest seed yield noted in unweeded control (T_8), which was 70 per cent less than the yield in hand weeded plots. Yield reduction of similar magnitude was noted in green gram by Singh *et al.* (1991) and Veeraputhiran *et al.* (2009) due to uncontrolled weed growth.

Weed management practices produced significant effect on haulm yield of green gram as well (Fig. 15). The highest haulm yield was registered in hand weeding (T_7), which was statistically on par with all the treatments where herbicide application was integrated with hand weeding (T_3 to T_6). It could be due to the higher weed control efficiencies observed in these treatments, which made more resources available for utilization by green gram, contributing to enhanced growth, seed and haulm yield in green gram. The lowest haulm yield in unweeded control (T_8) may be accounted for by the high crop-weed competition which rendered green gram less efficient in utilising the inputs effectively. Dash and Behera (2018) opined that both the grain yield and haulm yield of green gram was significantly increased when either physical or chemical weeding was employed.

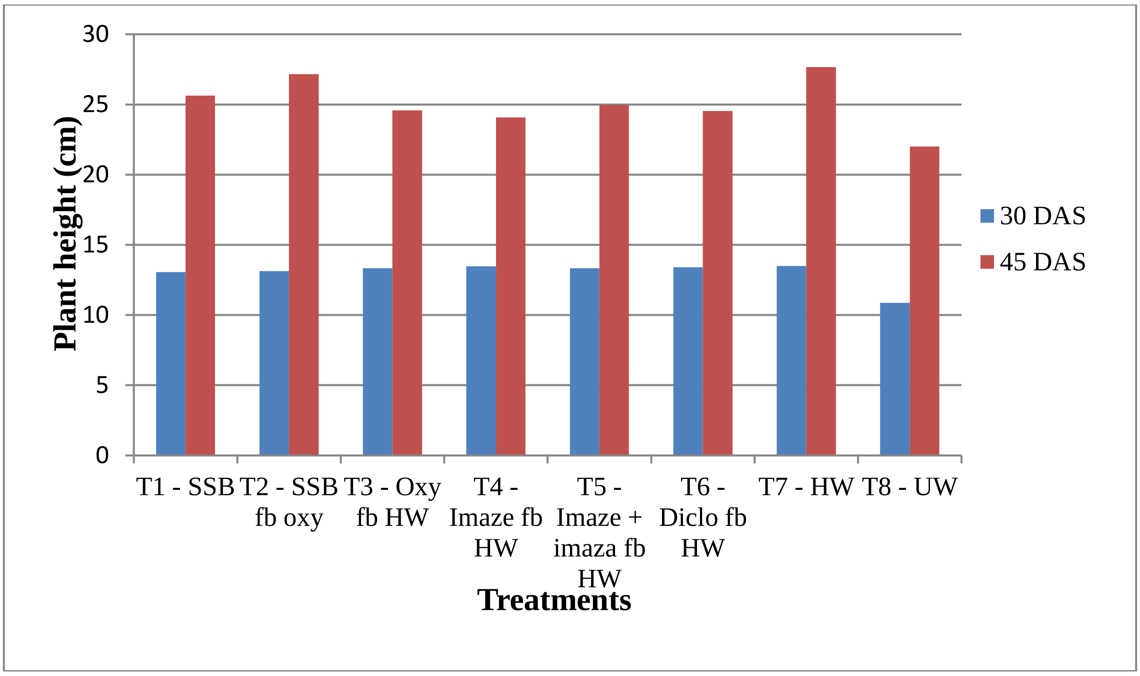

Fig. 12. Effect of integrated weed management practices on plant height of green gram

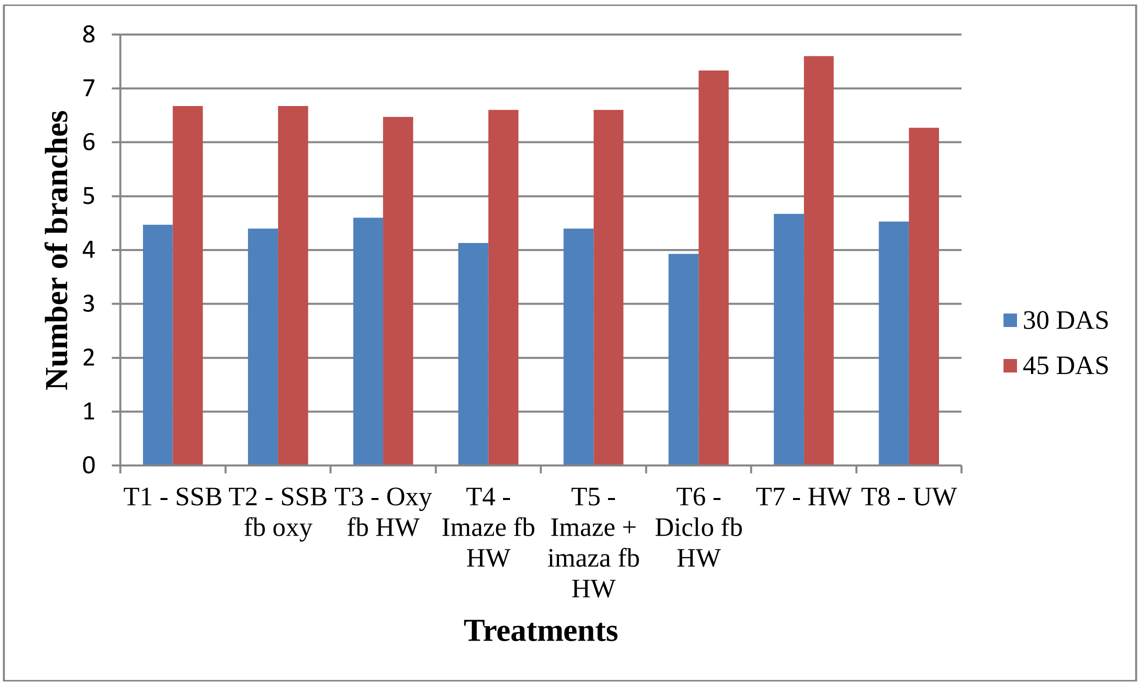

Fig. 13. Effect of integrated weed management practices on number of branches/plant of green gram

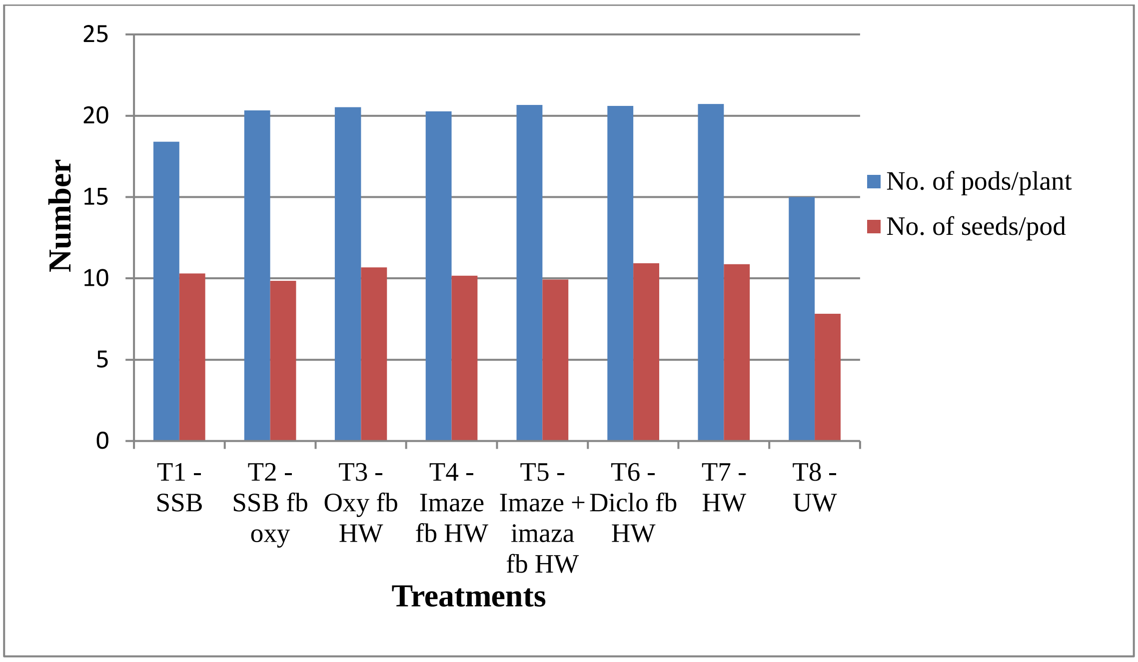

Fig. 14. Effect of integrated weed management practices on number of pods/plant and seeds/pod of green gram

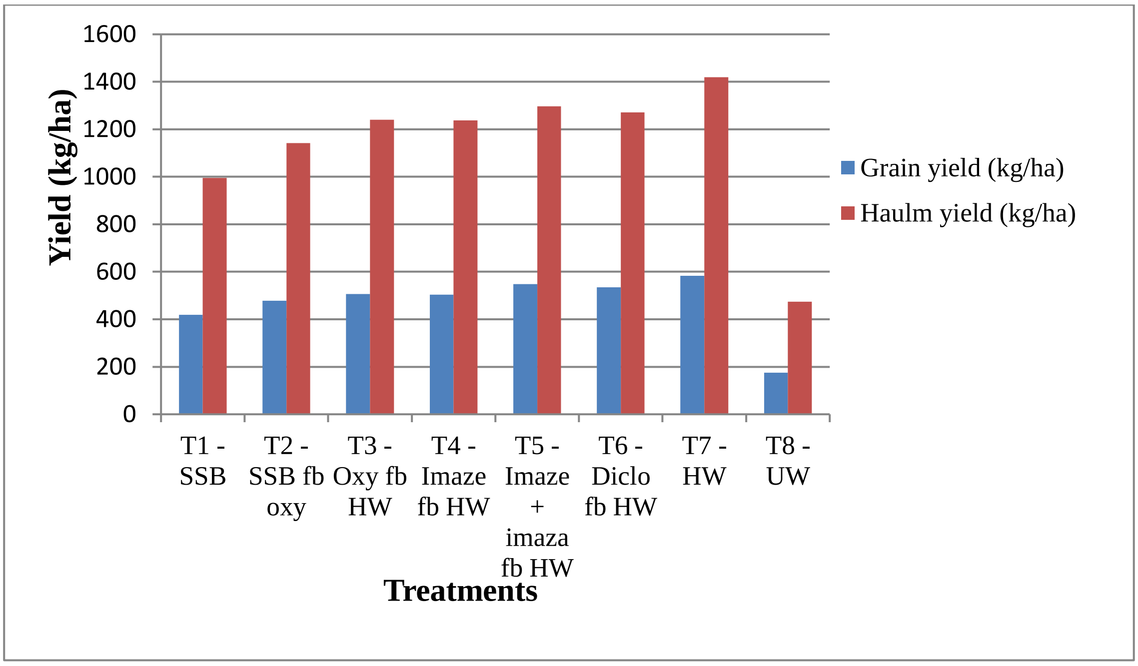

Fig. 15. Effect of integrated weed management practices on grain and haulm yield of green gram

5.4 Soil chemical properties as affected by integrated weed management practices

Soil pH, EC, organic carbon and available N were found unaffected by various weed management practices. However, available P was significantly higher in hand weeding (T_7) and was statistically on par with diclosulam *fb* hand weeding (T_6) and imazethapyr + imazamox *fb* hand weeding (T_5) (Fig. 16). Similarly, available K was found significantly higher in diclosulam *fb* hand weeding (T_6) which was on par with hand weeding (T_7), imazethapyr + imazamox *fb* hand weeding (T_5), oxyfluorfen *fb* hand weeding (T_3) and imazethapyr *fb* hand weeding (T_4) (Fig.18). The higher values of available nutrients might be attributed to the better weed control achieved in these treatments which led to a considerable reduction in nutrient removal by weeds, thus registering higher values for soil available nutrients. Malhi *et al.* (2020) observed that the adoption of chemical or physical weeding in black gram resulted in a significant reduction in nutrient uptake by weeds, as a result of which available N, P and K in the soil was increased. The lowest values of available nutrients were registered in unweeded control (T_8), which might have been the consequence of increased nutrient removal by weeds observed in this treatment. This could be correlated with the studies of Komal and Yadav (2015) and Jinger *et al.* (2016), who found out that the nutrient removal by weeds in green gram was the highest in unweeded control whereas it was significantly reduced with the adoption of integrated weed management practices.

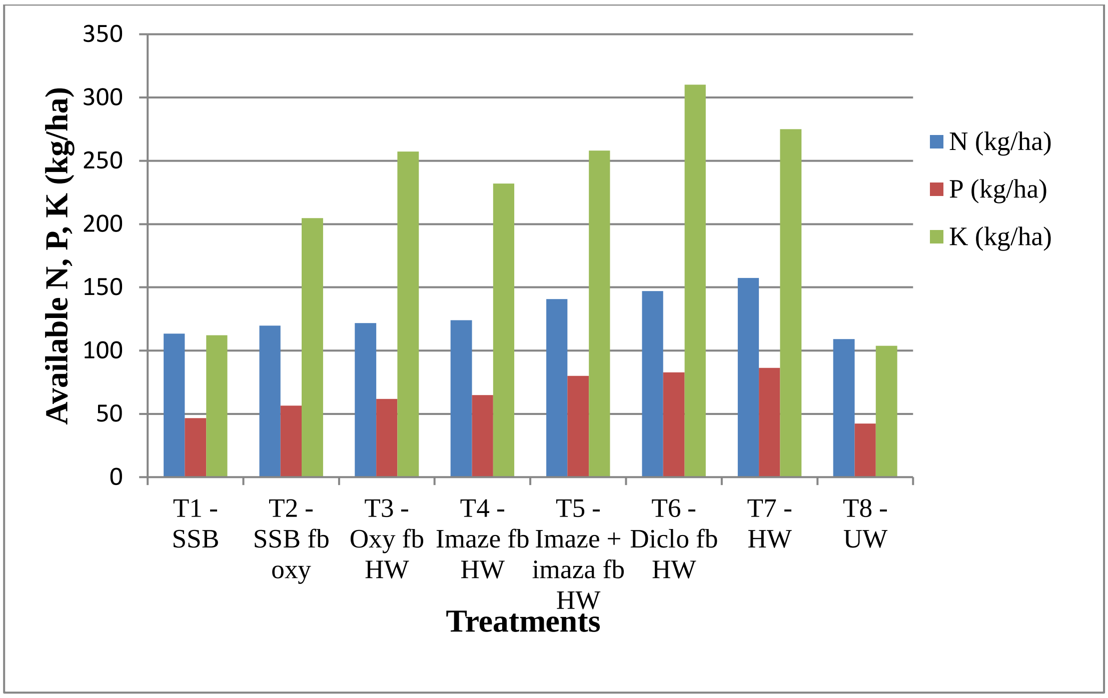

Fig. 16. Effect of integrated weed management practices on available N, P and K

5.5 Soil microbial population as affected by integrated weed management practices

The observations on total count of bacteria, fungi and actinomycetes showed a steady increase from pre-sowing to flowering and harvest, which might have been due to the increase in available nutrients in the soil. It was found that integrated weed management practices produced a significant effect on the total count of bacteria and fungi, but not on actinomycetes.

At flowering, the highest count of bacteria was observed in hand weeding (T_7) as compared to herbicide treated plots, which was most likely due to the toxic effect of the pre-emergence herbicides that created conditions unfavourable for the survival of soil bacteria. Singh *et al.* (2020) observed that the soil microbial load was significantly higher in hand weeded plots compared to those which received herbicidal treatments. At harvest also, bacterial population was the highest in hand weeding (T_7), but it was statistically on par with imazethapyr + imazamox *fb* hand weeding (T_5), unweeded control (T_8), oxyfluorfen *fb* hand weeding (T_3), stale seed bed (T_1), imazethapyr *fb* hand weeding (T_4) and stale seed bed *fb* oxyfluorfen (T_2) (Fig. 17). It might be due to the gradual degradation of pre-emergence herbicides in soil which led to a decrease in their final concentration. Singh and Singh (2020) stated that acute toxic effects of herbicides on soil microflora was noticed immediately after herbicide application in green gram, which diminished later due to subsequent decomposition of the chemical and a recovery of soil microbial population.

Total fungal count at flowering was the highest in unweeded control (T_8), which was statistically on par with hand weeding (T_7), imazethapyr + imazamox *fb* hand weeding (T_5) and stale seed bed (T_1) (Fig. 18). At harvest, although the highest fungal count was noticed in hand weeding (T_7), it was statistically on par with stale seed bed (T_1), unweeded control (T_8), imazethapyr *fb* hand weeding (T_4), stale seed bed *fb* oxyfluorfen (T_2), oxyfluorfen *fb* hand weeding (T_3) and imazethapyr + imazamox *fb* hand weeding (T_5), indicating that these chemicals did not produce any long-term effects on fungal population as well. Findings by Shruti *et al*. (2015) and

Mahajan *et al.* (2020) also affirmed that the initial inhibitory effects of oxyfluorfen, imazethapyr and imazethapyr + imazamox on soil microbial population were later diminished with the gradual degradation of these herbicides. However, the soil bacterial and fungal populations were significantly lower in diclosulam *fb* hand weeding (T_6), which might be due to higher persistence of diclosulam in soil that eventually developed prolonged toxic effect on soil microbes. Jakhar (2011) and Deepa (2015) also concluded that the application of diclosulam resulted in a reduction in the population of soil bacteria, fungi and actinomycetes.

Thus, it could be concluded that integrated weed management practices using pre-emergence oxyfluorfen, imazethapyr and imazethapyr + imazemox did not produce any prolonged inhibitory effects on soil microbial population, whereas the total count of soil bacteria and fungi was significantly reduced with the application of pre-emergence diclosulam.

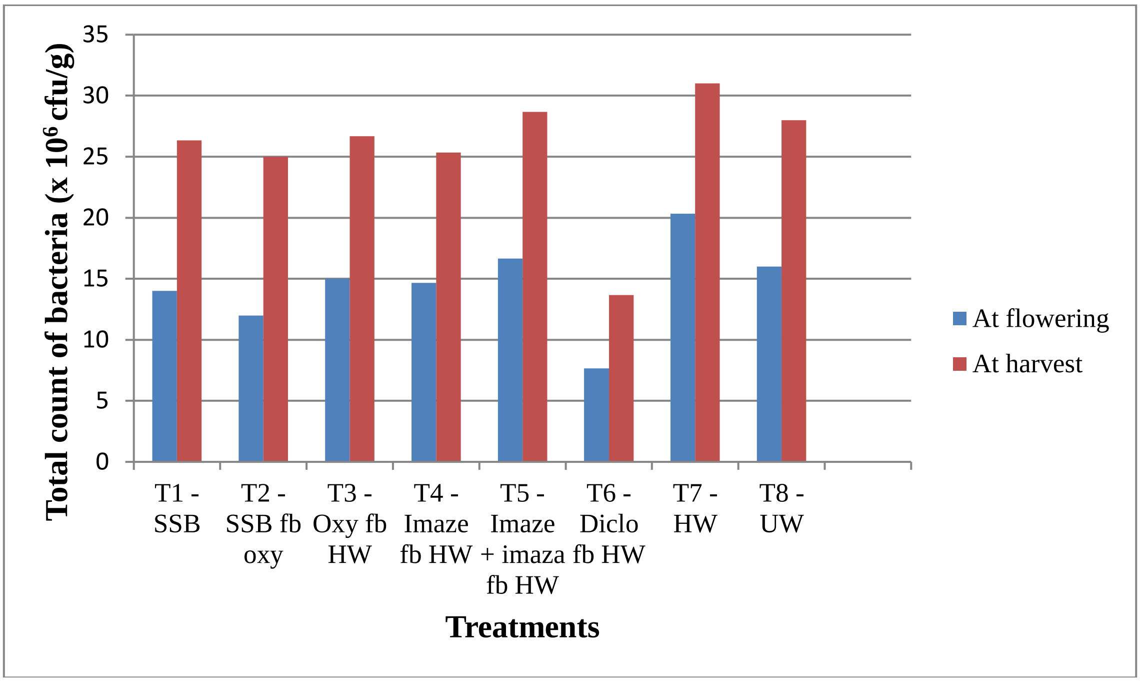

Fig. 17. Effect of integrated weed management practices on total count of bacteria

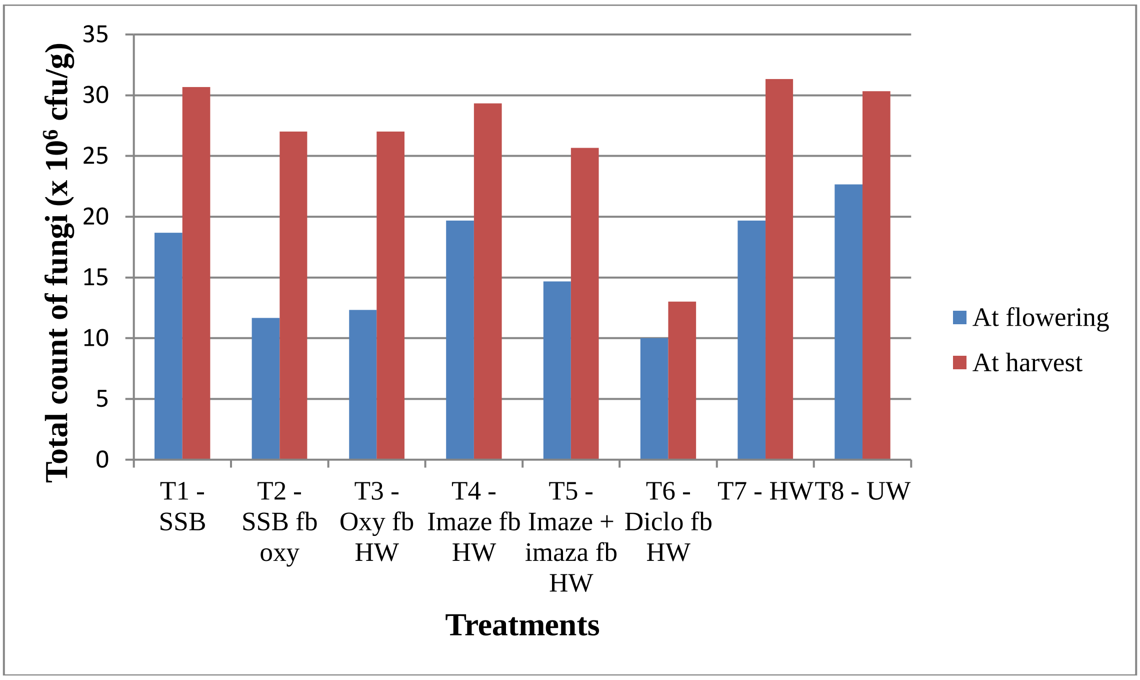

Fig. 18. Effect of integrated weed management practices on total count of fungi

5.5 Economics of cultivation

The cost of cultivation was highest (Rs. 37,638) in hand weeding (T_7), which was due to the high labour charges involved in manual weeding, while the lowest cost (Rs. 25,638) was incurred in unweeded control (T_8). This was in accordance with the findings of Singh and Singh (2020). Similarly, the gross returns (Rs. 43,699) was the highest in hand weeding (T_7), which was followed by imazethapyr + imazamox *fb* hand weeding (T_5) and diclosulam *fb* hand weeding (T_6), owing to the high yield obtained as a result of efficient weed control. These treatments recorded about 200 per cent higher gross returns as compared to unweeded control. However, net returns were highest in imazethapyr + imazamox *fb* hand weeding (T_5) (Rs. 9,126/ha), which was followed by diclosulam *fb* hand weeding (T_6) (Rs. 8,733/ha), which recorded 168 per cent and 165 per cent increase in net returns respectively, over unweeded control. Despite the high yield obtained under hand weeding (T_7), net returns were comparatively lower (Rs. 6,061/ha), owing to the high labour charges involved. Similarly, highest B:C ratio was registered in imazethapyr + imazamox *fb* hand weeding (T_5) (1.28), which was followed by diclosulam *fb* hand weeding (T_6) (1.27). This was because the application of pre-emergence herbicides *fb* hand weeding demand reduced labour requirements as compared with manual weeding, thereby reducing the total cost. Similar findings were reported by Rao *et al.* (2017) who confirmed that though the maximum gross returns were obtained in hand weeding, net returns and B:C ratio was not the highest in hand weeding. Thus, pre-emergence application of either imazethapyr + imazamox or diclosulam, followed by a single hand weeding at 25 DAS provided a suitable alternative to hand weeding in green gram when the labour charges were too high or manual labour was scarce.

However, as it was observed that diclosulam caused a significant reduction in soil microbial population, more research on the residual effect of the herbicide on soil microorganisms is required before its recommendation as a viable weed control measure in green gram.

Summary

6. SUMMARY

The research programme entitled “Integrated weed management in green gram [*Vigna radiata* (L.) Wilczek]” was designed with the objective of developing an integrated weed management strategy in green gram. The field trial was conducted from December 2020 to March 2021 at *Kotteppadam* rice field under Department of Agronomy, College of Agriculture, Vellanikkara.

The experiment was laid out in randomized block design (RBD), and included eight treatments in three replications, with a plot size of 20 sq.m. The weed management practices evaluated were: stale seed bed for 14 days followed by (*fb*) shallow digging (T_1), stale seed bed for 14 days *fb* shallow digging *fb* oxyfluorfen at 0-3 DAS (T_2), oxyfluorfen at 0-3 DAS *fb* hand weeding at 25 DAS (T_3), imazethapyr at 0-3 DAS *fb* hand weeding at 25 DAS (T_4), imazethapyr + imazamox at 0-3 DAS *fb* hand weeding at 25 DAS (T_5), diclosulam at 0-3 DAS *fb* hand weeding at 25 DAS (T_6) and hand weeding at 20 DAS and 40 DAS (T_7). An unweeded control (T_8) was also included.

Melochia corchorifolia, a broad leaved weed, was the predominant weed species identified, and accounted for more than 75 per cent of the total weed population. Other dominant broad leaved weeds were *Aeschynomene indica, Grangea maderaspatana, Phyllanthus amara, Heliotropium indicum, Mimosa invisa* and *Mimosa pudica*. Grasses included *Brachiaria mutica, Digitaria ciliaris, Echinochloa colona, Oryza sativa* and *Cynodon dactylon*.

At 30 DAS, effective control of both broad leaved weeds and grasses was achieved in all treatments where weed management practices were adopted. However, at 45 DAS and 60 DAS, stale seed bed recorded a very high weed density as compared with herbicide treated or hand weeded plots. Hand weeding resulted in highest reduction in weed density throughout the cropping period, whereas weed growth was highest in unweeded control. All the treatments where herbicide application was integrated with hand weeding emerged highly efficient in reducing the

density of both broad leaved weeds and grasses.

The weed dry matter production at 30 DAS was negligible in all the plots that received weed management practices except for the stale seed bed which recorded significantly higher weed dry matter production. At 45 DAS, the integration of any of the four pre-emergence herbicides with hand weeding (T_3 to T_6) resulted in a significant reduction in weed dry matter production, as compared with both the stale seed bed treatments (T_1 and T_2). At all stages of observations, the lowest weed dry matter production was observed in hand weeding, whereas it was highest in unweeded control. Treatments integrating pre-emergence herbicides with hand weeding were equally effective in reducing the weed dry matter production at 60 DAS also, with significantly lower dry matter production recorded in imazethapyr + imazamox *fb* hand weeding (11.04 g/m^2), diclosulam *fb* hand weeding (11.20 g/m^2) and oxyfluorfen *fb* hand weeding (13.87 g/m^2), while it was 352.81 g/m^2 in unweeded control.

Nutrient uptake by weeds was the highest in unweeded control, with removal of 16.02 kg, 2.78 kg and 46.94 kg N, P and K respectively per ha at 30 DAS, 60.89 kg, 8.33 kg and 91.15 kg N, P and K per ha respectively at 45 DAS, and 57.60 kg, 6.36 kg and 141.60 kg N, P and K respectively per ha at 60 DAS. At 30 DAS, the N removal by weeds was the lowest in hand weeding, and was statistically at par with all the integrated weed management practices (T_2 to T_6), whereas at 45 DAS and 60 DAS, the lowest N removal in hand weeding was statistically similar to all those treatments where herbicide application was integrated with hand weeding (T_3 to T_6). P removal by weeds was the lowest in hand weeding at all stages of observation, and was statistically on par with the integration of pre-emergence herbicides with hand weeding. At 30 DAS and 45 DAS, stale seed bed *fb* oxyfluorfen also produced comparable results. K removal was also the lowest in hand weeding, and was statistically on par with all the integrated weed management practices (T_2 to T_6). Stale seed bed recorded significantly higher nutrient removal by weeds at all stages of observation.

At 30 DAS, weed control efficiency was more than 99 per cent in all the integrated weed management practices adopted (T_2 to T_7), whereas it was 85 per cent when stale seed bed alone was adopted. Hand weeding registered the highest weed control efficiency of above 98 per cent at other stages of observation. All the integrated methods comprising of pre-emergence herbicides and hand weeding also resulted in weed control efficiencies of more than 94 per cent at both 45 DAS and 60 DAS. At 60 DAS, imazethapyr + imazamox *fb* hand weeding, diclosulam *fb* hand weeding and oxyfluorfen *fb* hand weeding all recorded weed control efficiencies greater than 96 per cent, and imazethapyr *fb* hand weeding had a WCE of 94.6 per cent. However, stale seed bed *fb* oxyfluorfen recorded a WCE of 77 per cent. Weed control efficiency was observed to be only 11 per cent at both 45 DAS and 60 DAS in treatments which included only stale seed bed. Weed index was observed to be the highest in unweeded control (70 %), whereas imazethapyr + imazamox *fb* hand weeding and diclosulam *fb* hand weeding registered lowest weed indices of 5.8 per cent and 8.2 per cent respectively.

At 30 DAS, the average plant height of green gram in the treatment plots T_1 to T_7 was 13.32 cm, while it was only 10.87 cm in unweeded control. At 45 DAS, the plant height was significantly higher in hand weeding (27.67 cm), and was statistically on par with stale seed bed *fb* oxyfluorfen (27.17 cm). Stale seed bed alone also recorded a comparatively higher plant height of 25.63 cm, whereas an average height of 24.53 cm was recorded in the remaining herbicidal treatments (T_3 to T_6). Unweeded control registered the lowest plant height of 22.00 cm at 45 DAS as well. At 30 DAS, the treatments had no significant effect on the number of branches/plants. However, at 45 DAS, significantly higher number of branches (8) was observed in hand weeding, which was closely followed by diclosulam *fb* hand weeding (7). Again, the number of branches was lowest in unweeded control (6).

Higher number of pods/plant and seeds/pod of green gram was observed in treatment plots T_2 to T_7 as compared with unweeded control and stale seed bed. An average of 20 pods was observed in those plots which received application of any of the pre-emergence herbicides integrated with either stale seed bed or hand weeding (T_2 to T_6), whereas stale seed bed alone recorded only 18 pods/plant. The number of seeds/pod was statistically on par in all the weed management practices (T_1 to T_7) with an average of 10 seeds/pod. The number of pods/plant (15) and seeds/pod (8) were the lowest in unweeded control. However, 100 seed weight in green gram remained unaffected by integrated weed management practices, probably due to the fact that it is mostly a varietal character.

Hand weeding registered the highest grain yield and haulm yield of 583 kg/ha and 1420 kg/ha respectively, which was on par with all the weed management practices where herbicide application was integrated with hand weeding. Grain yield (175 kg/ha) and haulm yield (474 kg/ha) were invariably the lowest in unweeded control.

The soil pH, EC and organic carbon were unaffected by integrated weed management practices. Available N, P and K contents in soil were found to be substantially increased after harvest as compared to the pre-experimental status, but soil available N remained unaffected by the integrated weed management practices. Available P was the highest in hand weeding (86 kg/ha), and was statistically on par with diclosulam *fb* hand weeding (83 kg/ha) and imazethapyr + imazamox *fb* hand weeding (80 kg/ha). Similarly, in the case of available K, the highest value was recorded in diclosulam *fb* hand weeding (310 kg/ha) which was statistically on par with hand weeding (275 kg/ha), imazethapyr + imazamox *fb* hand weeding (258 kg/ha), oxyfluorfen *fb* hand weeding (257 kg/ha) and imazethapyr *fb* hand weeding (232 kg/ha). Soil nutrient status was invariably the lowest in unweeded control with 109, 42 and 104 kg/ha of available N, P and K, respectively.

The total count of bacteria, fungi and actinomycetes showed a steady increase from before sowing to flowering and harvest, with comparatively lower populations observed in herbicide treated plots. However, the total count of actinomycetes was not influenced by integrated weed management practices. At flowering, soil bacterial population was the highest in hand weeding (20.33 x 10^6 cfu/g), and was statistically on par with imazethapyr + imazamox *fb* hand weeding, unweeded control, oxyfluorfen *fb* hand weeding, imazethapyr *fb* hand weeding and stale seed bed. Diclosulam *fb* hand weeding registered significantly lower bacterial count (7.67 x 10^6 cfu/g). Hand weeding recorded the highest bacterial population (31.00 x 10^6 cfu/g) at harvest as well, and was statistically on par with imazethapyr + imazamox *fb* hand weeding, unweeded control, oxyfluorfen *fb* hand weeding, stale seed bed, imazethapyr *fb* hand weeding and stale seed bed *fb* oxyfluorfen. Diclosulam *fb* hand weeding recorded a significantly lower bacterial count of 13.67 x 10^6 cfu/g. Soil fungal population at flowering was the highest in unweeded control (19.67 x 10^6 cfu/g), and was statistically on par with hand weeding, imazethapyr *fb* hand weeding, hand weeding and stale seed bed. Similarly, hand weeding recorded the highest fungal count (31.33 x 10^6 cfu/g) at harvest, which was statistically on par with treatments T_1 to T_5, and T_8. Soil fungal count was observed to be significantly lower in diclosulam *fb* hand weeding, both at flowering (10.00 x 10^6 cfu/g) and at harvest (13.00 x 10^6 cfu/g).

Though the gross returns were the maximum in hand weeding (Rs.43,699/ha), the highest net returns were obtained in imazethapyr + imazamox *fb* hand weeding (Rs. 9,126/ha) and diclosulam *fb* hand weeding (Rs. 8,733/ha). Similarly, B:C ratio was also the highest in imazethapyr + imazamox *fb* hand weeding (1.28), which was closely followed by diclosulam *fb* hand weeding (1.27). Thus, results of the study indicate that pre-emergence application of imazethapyr + imazamox, or diclosulam, followed by hand weeding can be recommended for integrated weed management in green gram.

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Appendix

APPENDIX

Monthly weather data during the cropping period

Month	Mean temperature (°C)		Relative humidity (%)	Total rainfall (mm)	Rainy days	Mean evaporation (mm/day)	Sunshine (hrs/day)
	Maximum	Minimum					
December, 2020	32.0	21.9	64.9	7.7	1.0	4.4	6.3
January, 2021	32.3	21.3	63.9	45.7	1.0	4.3	6.6
February, 2021	34.6	21.6	53.8	0	0	5.5	9.2
March, 2021	36.8	23.0	59.3	31.8	1.0	5.3	8.6

INTEGRATED WEED MANAGEMENT IN GREEN GRAM [*Vigna radiata* (L.) Wilczek]

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Weeds are known to cause substantial yield losses in green gram, owing to the slow initial growth of the crop and severe competition by weeds. Although hand weeding has been proved effective in reducing weed infestation, unavailability of timely labour and high labour costs have created practical difficulties in adopting manual weeding on a large scale, thus increasing the dependency on chemical weed control using herbicides. However, continuous use of herbicides results in problems like environmental contamination and resistance development. The present study entitled "Integrated weed management in green gram [*Vigna radiata* (L.) Wilczek]" was undertaken with the objective of developing an economically viable integrated weed management strategy that provided broad spectrum weed control in green gram.

The field experiment was carried out from December 2020 to March 2021 at *Kotteppadam* rice field under the Department of Agronomy, College of Agriculture, Vellanikkara. The experiment included eight treatments replicated thrice in a randomized block design (RBD). The treatments were: stale seed bed for 14 days followed by (*fb*) shallow digging (T_1), stale seed bed for 14 days *fb* shallow digging *fb* oxyfluorfen at 0-3 DAS (T_2), oxyfluorfen at 0-3 DAS *fb* hand weeding at 25 DAS (T_3), imazethapyr at 0-3 DAS *fb* hand weeding at 25 DAS (T_4), imazethapyr + imazamox at 0-3 DAS *fb* hand weeding at 25 DAS (T_5), diclosulam at 0-3 DAS *fb* hand weeding at 25 DAS, hand weeding at 20 DAS and 40 DAS (T_7) and unweeded control (T_8).

The major broad leaved weeds observed were *Melochia corchorifolia, Aeschynomene indica*, *Grangea maderaspatana*, *Phyllanthus amara*, *Heliotropium indicum, Mimosa invisa* and *Mimosa pudica*, whereas *Brachiaria mutica*, *Digitaria ciliaris, Echinochloa colona, Oryza sativa* and *Cynodon dactylon* were the predominant grasses.

Hand weeding resulted in the lowest weed density as well as weed dry matter production at all stages of observation. All the pre-emergence herbicides

integrated with hand weeding were also equally effective, among which imazethapyr+ imazamox *fb* hand weeding and diclosulam *fb* hand weeding recorded the highest weed control efficiency of 97 per cent. Similarly, nutrient removal by weeds was the lowest in hand weeding, which was statistically similar to all the treatments where herbicide application was integrated with hand weeding. Stale seed bed provided effective control of weeds only during the early stages of crop growth. Weed density, weed dry matter production, nutrient removal by weeds and weed index were invariably the highest in unweeded control.

Number of branches/plant, number of pods/plant, grain yield and haulm yield of green gram were higher in hand weeding and the treatments where herbicide application was integrated with hand weeding. Uncontrolled weed growth resulted in yield losses up to 70 per cent in green gram, which was reduced to 5.82 per cent and 8.22 per cent in imazethapyr + imazamox *fb* hand weeding and diclosulam *fb* hand weeding respectively. These treatments registered high grain and haulm yields of 549 kg and 1296 kg, and 535 kg and 1271 kg respectively.

Although the application of pre-emergence herbicides resulted in a reduction in the soil microbial count at flowering as compared to the untreated plots, the population recovered by harvest stage in the plots treated with oxyfluorfen, imazethapyr and imazethapyr + imazamox. However, diclosulam was found to have a pronounced inhibitory effect on the soil microbial population at harvest as well. Available N, P and K contents in soil were found the lowest in unweeded control.

Although the gross returns were the highest in hand weeding, imazethapyr + imazamox *fb* hand weeding and diclosulam *fb* hand weeding registered the highest net returns of Rs. 9,126/ha and Rs. 8,733/ha, respectively. Accordingly, B:C ratio was also the highest in imazethapyr + imazamox *fb* hand weeding (1.28) and diclosulam *fb* hand weeding (1.27). Thus, application of these two pre-emergence herbicides followed by hand weeding at 25 DAS proved highly successful in achieving season-long weed control in green gram, thereby enhancing the yields and fetching higher monetary returns.

സംഗ്രഹം

ചെറുപയറിലെ കളനിയന്ത്രണത്തിനായി ഒരു സംയോജിത കളപരിപാലനമാർഗം വികസിപ്പിക്കുക എന്ന ലക്ഷ്യത്തോടുകൂടി 2020 ഡിസംബർ മുതൽ 2021 മാർച്ച് വരെയുള്ള കാലയളവിൽ വെള്ളാനിക്കര കാർഷിക കോളേജിലെ അഗ്രോണോമി വിഭാഗത്തിനു കീഴിലുള്ള കൊട്ടേപ്പാടം നെൽവയലിൽ ഒരു പഠനം നടത്തുകയുണ്ടായി . പ്രസ്തുത പഠനത്തിൽ നടീൽനിലം ഒരുക്കിയതിനു ശേഷം വിതക്കുന്നതിന് മുൻപ് നൽകുന്ന പതിനാല് ദിവസത്തെ ഇടവേളയിൽ കളകളെ മുളക്കാൻ അനുവദിച്ച ശേഷം ചെറിയ തോതിൽ മണ്ണിളക്കി മുളച്ച കളകളെ നശിപ്പിക്കുക (T1), മേൽപ്പറഞ്ഞ അതേ രീതിയിൽ കളകളെ നശിപ്പിക്കുക, തുടർന്ന് ഹെക്ടറിന് 150 ഗ്രാം എന്ന തോതിൽ ഓക്സിഫ്ലൂർഫെൻ പ്രയോഗിച്ചതിനു ശേഷം മൂന്നു ദിവസത്തിനുള്ളിൽ വിതയ്ക്കുക (T2), ഹെക്ടറിന് 150 ഗ്രാം എന്ന തോതിൽ ഓക്സിഫ്ളുർഫെൻ പ്രയോഗിച്ചതിനു ശേഷം മൂന്നു ദിവസത്തിനുള്ളിൽ വിതയ്ക്കുക, പിന്നീട് 25 ദിവസത്തിനു ശേഷം കൈ കൊണ്ട് കള പറിച്ചു നീക്കുക (T3), ഹെക്ടറിന് 50 ഗ്രാം എന്ന തോതിൽ ഇമസെതാപൈർ പ്രയോഗിച്ചതിനു ശേഷം മൂന്നു ദിവസത്തിനുള്ളിൽ വിതയ്ക്കുക, 25 ദിവസത്തിനു ശേഷം കൈ കൊണ്ട് കള പറിച്ചു നീക്കുക (T4), ഹെക്ടറിന് 80 ഗ്രാം എന്ന തോതിൽ ഇമസെതാപൈർ + ഇമസമോക്സ് പ്രയോഗിച്ചതിനു ശേഷം മൂന്നു ദിവസത്തിനുള്ളിൽ വിതയ്ക്കുക, 25 ദിവസത്തിനു ശേഷം കൈ കൊണ്ട് കള പറിച്ചു നീക്കുക (T5), ഹെക്ടറിന് 18 ഗ്രാം എന്ന തോതിൽ ഡൈക്ലോസുലം പ്രയോഗിച്ചതിനു ശേഷം മൂന്നു ദിവസത്തിനുള്ളിൽ വിതയ്ക്കുക, 25 ദിവസത്തിനു ശേഷം കൈ കൊണ്ട് കള പറിച്ചു നീക്കുക (T6), വിതച്ച് ഇരുപതാം ദിവസവും നാല്പതാം ദിവസവും കൈ കൊണ്ട് കള പറിച്ചു നീക്കുക (T7), കളകൾ ഒട്ടും തന്നെ നീക്കം ചെയ്യാതെ വിളയെ വളരാൻ അനുവദിക്കുക (T8) എന്നിവയായിരുന്നു പരീക്ഷിച്ചത്.

ചെറുവുരം, നെല്ലിത്താളി, നിലംപാല, കീഴാർനെല്ലി, തേക്കട, തൊട്ടാവാടി, ആനത്തൊട്ടാവാടി തുടങ്ങിയ വീതിയുള്ള ഇലകളോടുകൂടിയ കളകളും മകരപുല്ല്, കർക്കിടകപ്പുല്ല്, കവട, കറുക എന്നീ പുല്ലുകളുമായിരുന്നു കൃഷിയിടത്തിലെ പ്രധാന കളകൾ.

കൈകൊണ്ട് കള പറിച്ചു നീക്കുന്ന രീതി എല്ലാത്തരം കളകളെയും നിയന്ത്രിക്കുന്നതിൽ മികവ് പുലർത്തുന്നതോടൊപ്പം ഉയർന്ന വിളവ്

രേഖപ്പെടുത്തുകയും ചെയ്തു. എന്നിരുന്നാലും, വർധിച്ച കൂലിച്ചിലവുകൾകാരണം സാമ്പത്തികലാഭം നന്നേ കുറവായിരുന്നു. അതേസമയം, ഇമസെതാപൈർ + ഇമസമോക്സ് അല്ലെങ്കിൽ ഡൈക്ലോസുലം പ്രയോഗിച്ചതിനു ശേഷം വിതക്കുകയും, ശേഷം ഇരുപത്തഞ്ചാം ദിവസം കൈകൊണ്ട് കള പറിച്ചു നീക്കുകയും ചെയ്യുന്നത് ചെറുപയറിലെ കളനിയന്ത്രണത്തിന് ഫലപ്രദമാണെന്നും അതുവഴി വിളവ് വർധിപ്പിക്കുകയും ഉയർന്ന വരുമാനം ലഭ്യമാക്കുകയും ചെയ്യുന്നതായി നിരീക്ഷിക്കപ്പെട്ടു.