WEED MANAGEMENT IN CABBAGE
(*Brassica oleracea* var. *capitata* L.)

By

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(2016-11-045)

THESIS

Submitted in partial fulfilment of the requirement for the degree of

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DECLARATION

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Introduction

1. INTRODUCTION

Cabbage is an important cool season annual vegetable crop belonging to the family Brassicaceae. It is from a group of plants known as the cole crops which also includes cauliflower, broccoli, kale, collards, kohlrabi, and Brussels sprouts. Among these, cabbage is one of the world's most widely grown vegetables. It is native to western Europe and Mediterranean region. Cabbage and kale were the first cole crops to be domesticated. It is an introduced vegetable crop in India and has been adopted all over the country, ranking second in area and production. Cabbage is a biennial plant, grown as an annual vegetable crop for its dense-leaved heads. It is well adapted to cool season, with an optimum temperature requirement of 15-20^{0}C for growth and head development. Traditionally it is grown largely in the northern, eastern, and coastal areas of India. In Kerala, its cultivation was earlier restricted to the hill tracts of Idukki and Wayanad districts. But with the introduction of tropical varieties and hybrids the cultivation of this crop has spread to the tropical plains also (Narayanankutty *et al.*, 2012).

Cabbage is a rich source of Vitamin A, B and C, and it also contains potassium, calcium, phosphorus and sodium. It is a good source of protein. Cabbage leaves are low in calories, fat and carbohydrates. They contain β-carotene (provitamin-A), ascorbic acid, riboflavin, niacin and thiamine. Cabbage is one of the good sources of sulphur containing amino acids. Glucosinolates such as sinigrin, progoitrin and glucobrassicin are found in cabbage.

Cabbage is commonly used as salad, vegetable, soup, processed product as well as dehydrated vegetable. Sauerkraut is a preserve made from cabbage. It also has some medicinal properties and is good for digestion. It was used against ailments like diarrhoea, gout, stomach and celiac troubles in ancient times. Cabbage leaves are prescribed for fever, cough, skin diseases, peptic ulcers and haemorrhoids in ayurvedic medicine.

Major cabbage growing states in India are West Bengal, Odisha, Bihar, Assam, Madhya Pradesh, Gujarat, Jharkhand, Chhattisgarh, Haryana, and Uttar Pradesh. In Kerala, it is grown in an area of 198 ha (GOK, 2017). In India, area under cabbage production shows an increasing trend over the years but its productivity is seen to be varying. This might be due to the changing climate, water problems and also weed problems.

Cabbage requires heavy manuring and frequent irrigations. This creates conducive conditions for germination and growth of weeds, which reduce cabbage yield by 45-80 per cent (Chadha, 2001). So, weed free environment should be ensured during the initial stages of crop for the healthy growth of plants. Considerable research work has been carried out in India on various aspects of cabbage cultivation, but the problem of weeds needs special attention, as weeds when present in the field affect the yield and quality of the crop.

Weed competition during the initial stages of the crop may lead to reduced growth and yield of cabbage and can add to the cost of farm operations, thereby increasing the cost of cultivation. For profitable cultivation of cabbage, early control of weeds is necessary as longer period of crop weed competition greatly reduces crop growth and economic yield. Yield reduction may be not only due to competition, but also by the increased infestation by insect pests. Moreover, cabbage is relatively a new crop in plains, and information on weed problems in cabbage in this area is lacking.

Because of the popularity of the crop among farmers, there is heavy demand for cheap and efficient methods of weed control in cabbage. Manual weeding is the most effective method of weed control in cabbage, but due to the time, labour and cost factors involved, it is not very acceptable. Taking these factors into consideration, the present project is proposed to assess the efficacy of different weed management technologies involving both chemical and non-chemical methods. The specific objective of this study was to evolve a weed management package for cabbage suited to the plains of Kerala.

Review of literature

2. REVIEW OF LITERATURE

Cabbage (*Brassica oleracea* L. var. *capitata*) is an important cole crop. Cabbage is highly nutritive and contains moisture (92.4g), protein (1.3g), fat (0.2g), carbohydrates (5.4g), energy (24kcal), calcium (49mg), phosphorus (29mg), Iron (0.4mg), β-carotene (1200μg), thiamine (0.05mg), riboflavin (0.05mg), niacin (0.03mg) and vitamin-C (47mg) per 100g of edible portion (Chakrabarti, 2001). It is consumed by people all over the world and is of great demand.

Weeds are a major problem in cabbage and cause considerable yield loss to the crop. So it is important to manage the weeds for good growth and yield of crop.

2.1 Weed flora

2.1.1 Weed flora in Asian countries including India

Patel *et al.* (1995) reported *Amaranthus spinosus, Cyperus rotundus, Chenepodium album, Amaranthus viridis* and *Portulaca oleracea* as the prominent weeds in cabbage field at Anand, Gujrat.

According to Nandal *et al.* (2005) the prominent weed species present in cabbage field in Himachal Pradesh were *Cyperus didymus* (41%), *Poa annua* (21.8%), *Cyperus rotundus* (11.2%), *Medicago denticulata* (4.7%) and *Ageratum conyzoides* (4.6%).

Arora *et al.* (2006) reported *Coronopus didymus* and *Melilotus indica* as major weeds and *Parthenium hysterophorus, Rumex dentatus etc* as minor weeds of cabbage in and around Delhi.

Kumar *et al.* (2014) reported *Cynodon dactylon,, Parthenium hysterophorus, Digitaria arvensis, Cyperus rotundus, Dactyloctenium aegyptium* as the prominent weed species in cabbage fields at Rajendranagar, Hyderabad.

Ishikawa *et al.* (2002) found *Rorippa islandica*, *Chenopodium album*, *Persicaria longiseta* and *Parsicaria nepalensis* as the prominent weeds in direct-seeded cabbage fields in the Tokachi district of Hokkaido, Japan.

2.1.2 Weed flora in Europe, Australia and other parts of the world

Brandsaeter *et al.* (1998) recorded *Viola arvensis*, *Spergula arvensis*, *Galeopsis tetrahit*, *Chenopodium album*, *Lamium purpureum* and *Stellaria media* as the most prevalent weeds in cabbage fields.

Tei *et al.* (2005) reported *Digitaria* spp., *Echinochloa crus-galli, Amaranthus* spp., *Elymus repens, Setaria* spp., *Chenopodium* spp., *Datura stramonium, Polygonum* spp., *Mercuriallis annua, Portulaca oleraceae* and *Solanum nigrum* as the most important and frequent species in spring-summer cabbage, and *Cirsium arvense, Matricaria* spp., *Stellaria media, Senecio vulgaris, Sonchus* spp., *Fumaria officinalis* and cruciferous weeds in autumn-winter cabbage crops.

Karkanis *et al.* (2011) found redroot pigweed (*Amaranthus retroflexus*), field bind weed (*Convolvulus arvensis*), jimson weed (*Datura stramonium*), common purslane (*Portulaca oleracea*), venice mallow (*Hibiscum trionum*), black nightshade (*Solanum nigrum*) and barnyard grass (*Echinochloa crus-galli*) to be the common weed species in cabbage field.

Al-Khatib *et al.* (1995) reported that common lambsquarters (*Chenopodium album*), shepherd's purse (*Capsella bursa-pastoris*), common chickweed (*Stellaria media*), pineapple-weed (*Matricariam atricarioides*), hedge mustard (*Sisymbrium *officinale*), common groundsel (*Senecio vulgaris* L.), redroot pigweed (*Amaranthus retroflexus*), henbit (*Lamium amplexicule*), and purple deadnettle (*Lamium purpureum*) were the major weeds present in cabbage.

Wszelaki *et al.* (2007) reported that *Portulaca oleracea, Chenopodium album, Echinochloa crus-galli, Agropyron repens,* and *Oxalis europaea* occurred in more than 95 per cent of the plots in the field of 'Bravo' cabbage in the year 2002.

Henderson (1996) found sowthistle (*Sonchus oleraceus*), bittercress (*Coronopus didymus*), fat hen (*Chenopodium album*), small-flowered mallow (*Malva parviflora*), and burr medic as occurring weeds in cabbage.

Kuerschner (1988) observed that in transplanted cabbage (*Brassica oleracea* L. var. *capitata*), weed flora was dominated by species common in vegetable fields, like *Euphorbia hirta, Phyllanthus amarus, Physalis angulata, Portulaca oleracea, Brachiaria subguadripara* and *Digitaria* spp.

2.2 Critical period of crop weed competition in vegetable crops

Weed control during the critical period of weed competition will result in highest economic returns and also avoid significant yield losses. The crop yield level obtained by weeding during this period is almost similar to that obtained by the full season's weed free conditions.

Kuerschner (1988) reported that weed competition reduced biomass and yields in cabbage if weed growth was allowed for more than two weeks after transplanting or if weeding stopped before four weeks after transplanting. Yield losses averaged 72 per cent in plots left unweeded until four weeks after transplanting, and 40 per cent if weeding was not continued beyond four weeks after transplanting.

In cauliflower, the critical period of weed competition occurred at 0-38 days after transplanting. Weed competition for 14 days after transplanting resulted in reduced average head yield by 41per cent (Qasem, 2009). Miller and Hopen (1991) observed that under natural weed stands, the critical weed control period in seeded cabbage was 2 weeks and 4 weeks in 1988 and 1989 respectively.

Horng (1980) reported that keeping the field weed free for at least 4 weeks after transplanting is required to prevent yield reduction in cabbage. Porwal and Singh (1993) observed that most critical stage of crop-weed competition in cauliflower was up to 50 days after transplanting, and competition during this period resulted in significant reduction in curd yield.

In vegetables, the critical period of crop weed competition are: cauliflower (30), cabbage (30-45), potato (25-30), onion (30-75), carrot (20-40), brinjal (20-60), cumin (15-30), turnip (15-20), peppers (30-45) and okra (15-30) days after sowing respectively (Rana *et al.*, 2011).

2.3 Yield loss due to weeds

Weeds compete with crop plants for water, nutrients, light and space thereby lowering the crop yields. Apart from competition for nutrients they also harbour insect pests and disease causing organisms that attack and damage crop plants. The losses due to weeds depend upon the type of weed flora, density, agro-climatic conditions, soil fertility, moisture status, soil type and crop type.

Marketable yield of drilled cabbage was reduced by between 47 and 100 per cent when weeds remained throughout the growing season (Roberts *et al.*, 1976).

Lawson and Wiseman (1978) reported that yields of transplanted spring cabbage were reduced by at least two-thirds in unweeded as compared with weed-free plots, thus causing economic damage to the crop. Weed competition reduced total biomass and seed yield of cabbage by more than 50 per cent while comparing weedy with weed free control (Al-Khatib *et al.*, 1995).

Weaver (1984) reported that yield of cabbage was reduced if weeds were allowed in the plots for longer than 4-5 weeks after transplanting.

Cabbage yield was reduced by 52 per cent and 71 per cent under velvet leaf densities of 1.2 and 3.6 plants per m^2 during 1988 and reduced by 76 per cent and 92 per cent during 1989 respectively. No yield reduction was found when velvet leaf was seeded 4 or 6 week after cabbage whereas a reduction in yield was seen when they were seeded 0, 1 and 2 weeks after cabbage (Miller and Hopen, 1991).

Qasem and Hill (2003) studied the competition effects of *Chenopodium album* and *Senecio vulgaris* on cabbage (*Brassica oleracea* var. *capitata*) and lettuce (*Lactuca sativa* L.). They observed that weeds significantly reduced growth of both crops and lowered accumulation of nitrogen, phosphorus, potassium, calcium and magnesium.

In cauliflower, due to weed competition, shoot dry weight was reduced by 74.8 per cent and head weight by 76.1 per cent compared to weed-free control (Qasem, 2007).

2.4 Methods of weed control

2.4.1 Mechanical methods

In cabbage and tomato, observations taken 50 days after treatment showed that flaming treatment provided greater weed control of up to 80 per cent (Wszelaki *et al.*, 2007). Cover crop combined with roto tilling reduced weed biomass by 89 per cent when compared with untreated monoculture in white cabbage (Brandsaeter, 1998).

Semiday (1997) reported that cabbage yield produced from hand weeded check (39980kg/ha) was similar to the yield obtained from cabbage treated with ciomazone at two rates (1.12 and 2.24kg a.i./ha), and oxyfluorfen at 0.56kg a.i./ha.

Golian *et al.* (2016) observed that weed infestation was effectively reduced under polypropylene and biodegradable foil mulches as well as hand weeding. In case of mechanical weeding, the weed control effect was short-lived as re-emergence of weeds were seen soon after the treatment. The number and weight of weeds were reduced when cover crops were cut into small pieces and left on the soil surface whereas when cover crops were incorporated into soil results were similar to the unweeded check. The highest yields were obtained for red cabbage grown in polypropylene and in biodegradable foil, and lowest from cover crops.

Golian and Anyszka (2016) studied the effect of various weed management practices (mechanical treatments, mechanical treatments with biostimulator, mulches - black non-woven polypropylene and biodegradable films and hand weeding) on chinese cabbage and transplanted leek. Hand weeded and mulched treatments gave the best results. Weeds were completely absent in Chinese cabbage and reduced by 98.9 to 99.5 per cent in transplanted leek grown under mulches. Highest yield was obtained from the plots covered by polypropylene and biodegradable films.

Kohut *et al.* (2013) found that in red cabbage, mechanical weeding and hand weeding resulted in best weed control. Among mulched treatments propylene mulching gave the best control as well as highest yield.

Solarization

Hamooh and Alsolaimani (2014) reported that soil solarization with transparent polyethylene sheets (10 microns) amended with 30 t/ha of animal manure at different months decreased weed fresh weight and significantly enhanced cabbage head, stem and root characters. Soil solarization during August-September resulted in increased cabbage head length and diameter by 29.6 and 21.7 per cent respectively and yield at a rate of 81.5 per cent compared to control.

Campiglia *et al.* (2000) reported that solarization with clear polyethylene (CPE) mulch significantly reduced the weed density and total weed biomass by over 93 per cent and 92 per cent respectively in the cauliflower and fennel harvest. The CPE mulch increased yield by up to 47 per cent and 91 per cent in cauliflower and fennel respectively.

Mulching

According to Lament (1993), musk melons, water melons, honey dews, squash, cucumbers, tomatoes, peppers, egg plant, sweet corn, okra, and cole crops can be grown successfully using plastic mulches, and mulching produced significant increases in earliness, total yield, and quality.

Patterson (1998) reported the effect of different types of polyethylene film mulches on emergence and growth of purple nut sedge. Translucent polyethylene film mulches reduced or eliminated the shoot emergence compared to a conventional, opaque, white/black polyethylene film mulch in green house experiments. In field experiments, translucent mulches reduced emergence and growth by 70-88 per cent compared to opaque mulch.

Easmin *et al.* (2009) reported that polythene mulching resulted in production of tallest chinese cabbage plant (44.50 cm) with plant spread of 58.28cm. Shortest plant of 37.60cm height and spread of 49.58cm was recorded in no mulch *i.e.*, control. Similarly no mulch treatment required more days to start head formation (45.37) whereas least number of days to start of head formation was seen in polythene mulch (41.17). Black polythene mulch resulted in highest marketable yield of chinese cabbage (123.27t/ha) and lowest yield (76.51t/ha) was recorded in no mulch.

Masarirambi *et al.* (2013) observed that mulch type significantly affected growth and yield of 'Savoy' baby cabbage, weed infestation and moisture conservation on a loamy soil. At 7 weeks after transplanting the plant height for no mulch (23.2cm) was lower than white plastic (26cm) and sawdust (27.3cm) treatments. The plots mulched with white plastic (41.15t/ha) or sawdust (38.69t/ha) showed no significant difference in yield of cabbage heads while the control (22.06 t/ha) produced relatively lower yield of 'Savoy' baby cabbage.

Salim *et al.* (2008) reported that there was a positive impact of mulch on yield and yield attributes of cauliflower. Three varieties of cauliflower (Poushali, Snow crown and IPSA-1) were cultivated with or without polyethylene mulch and highest marketable yield (31.32t/ha) was obtained from hybrid variety Snow crown with mulch, which was 35.16 per cent higher than without mulch.

Bana *et al.* (2012) observed that black plastic mulch treated plot showed excellent weed control in cauliflower. They also recorded higher growth (plant height, spread and number of leaves), quality (compactness, colour and per cent protein content of curd) and yield for this treatment.

Experimenting with cauliflower, Moniruzzaman *et al.* (2007) reported that highest per hectare curd yields of 30.38 and 29.40 tons were obtained from treatments having weekly irrigation and black polythene mulch in 2000-2001 and 2001-2002, respectively. Absence of irrigation and mulching resulted in reduced curd yields.

2.4.2 Cultural methods

Karkanis *et al.* (2011) studied the effects of plant density and row arrangement on weed flora and yield of cabbage. The crop was planted at single rows (60cm x 40cm with 41,700 plant/ha, 70cm x 30cm with 42,850 plants/ha and 50cm x 34cm with 58,900 plants/ha) and paired rows (58,800 plants/ha). It was observed that paired- rows cabbage provided a better weed control and yield than single rows pattern, at lower cabbage density.

Jung-Lai *et al.* (2014) reported that for chinese cabbage, soybean, hot pepper and corn the weed suppression rates of false seedbed treatment in the spring crop were 65 to 73 per cent, 50 to 55 per cent, 9 to 55 per cent and 8 to 33 per cent, respectively. For stale seedbed treatments the suppression rates were 18 to 39 per cent, 40 to 77 per cent and 37 to 38 per cent for chinese cabbage, spinach and carrot respectively.

2.4.3 Chemical methods

In cabbage, oxyfluorfen at 0.75kg a.i./ha effectively controlled both dicot and monocot weeds (including *Cyperus* spp.) without affecting the crop yields adversely (Leela, 1982).

In a weed management trial in cabbage, Nandal *et al.* (2005) obtained higher yield of cabbage under weed free treatment and among herbicidal treatments, maximum yield was recorded with oxadiazon at 1.0kg/ha followed by oxadiazon at 0.75 + pendimethalin at 0.75kg/ha.

Nandawar *et al.* (2006) reported that in cabbage pre-plant and pre-emergence application of oxyfluorfen at 0.20kg/ha in combination with hand weeding at 30 DAT was most effective in controlling annual weeds, followed by oxyfluorfen at 0.20kg/ha alone.

In broad leaf weed control with trifluralin, oxyfluorfen, pendimethalin, clopyralid, pyridate, and metolachlor in cabbage grown for seeds, no single herbicide controlled broad leaf weeds adequately except for pendimethalin at 1.92 and 3.84kg/ha. Combinations of trifluralin + oxyfluorfen, pendimethalin + clopyralid, and oxyfluorfen + pyridate effectively controlled weeds (Al-Khatib *et al.*, 1995).

Frost and Hingston (2004) reported that oxadiargyl at 400g a.i./ha effectively controlled a range of broadleaf and grass weeds including *Amaranthus powellii*, *Chenopodium album, Nicandra physaloides, Solanum nigrum, Eleusine indica* and *Echinochloa crus-galli.* Transplanted vegetables such as cabbage, cauliflower, broccoli, lettuce and capsicum showed high tolerance to oxadiargyl (200 and 400g a.i./ha) applied pre-transplant.

Alachlor and oxyfluorfen at all concentrations and butachlor at 2kg a.i./ha gave significantly good control of weeds up to 60 days when compared to hand weeded control in cabbage (Leela, 1985).

Semidey (1997) reported a reduction in weed density by more than 67 per cent in cabbage treated with ciomazone (1.12 and 2.24kg a.i./ha), oxyfluorfen (0.28 and 0.56kg a.i./ha), and prometryn (2.0 and 4.0kg a.i./ha) during 1992-93 and 1994 respectively.

Treatments of oxyfluorfen at 0.43 kg/ha as pre transplant treatment, followed by several sequential post emergence grass herbicides (sethoxydim,fluazifop-butyl and haloxyfop-methyl) as post over the top (POT) treatments, provided excellent broad leaf and grass control in transplanted cabbage, and oxyfluorfen treatments alone gave 86 to 89 per cent control of grass species (Bhowmik and McGlew, 1986).

Henderson (1996) studied the effects of herbicides (metolachlor, pendimethalin, propachlor and oxyfluorfen) on cabbage. It was observed that pre-emergence application of oxyfluorfen herbicide gave excellent control of bittercress (*Coronopus didymus*), small-flowered mallow (*Malva parviflora*) and fat hen (*Chenopodium album*) with no crop damage. Metolachlor gave better control of bittercress than pendimethalin/propachlor mixtures, whereas fat hen and small-flowered mallow were effectively controlled by pendimethalin/propachlor. Oxyfluorfen applied before transplanting was the best herbicide option, due to higher yields, effective weed control, least cost and least seed bank contribution.

Herbst and Derr (1990) observed that broccoli treated with herbicides (oxyfluorfen 0.7kg a.i/ha, pyridate 0.28 and 0.56kg a.i./ha, and BAS 514 0.14kg a.i./ha) produced yields similar to the cultivated check.

Sikkema *et al.* (2007a) reported that oxyfluorfen, sulfentrazone, dimethenamid-p, and dimethenamid-p plus sulfentrazone applied pre-transplant at the proposed and twice the proposed use dose in broccoli, cabbage, and cauliflower did not cause any visual injury, and did not reduce number of heads produced, head weight or yield and all had an acceptable level of crop safety for use at the proposed dose in broccoli, cabbage, and cauliflower.

Pre-planting application of chlorthal-dimethyl (10kg/ha), pendimethalin (4.6 l/ha), nitrofen (1.4 l/ha) and trifluralin (1.5 l/ha) were effective in controlling weeds and it was observed that post-planting treatment of oxyfluorfen (2 l/ha) increased head yield of cauliflower and was best in controlling weeds and reduced their shoot dry weight by 65.5 per cent compared with the weed-infested control (Qasem, 2007).

In cauliflower, application of pendimethalin and fluchloralin at lower dose of 0.75kg/ha supplemented with one hand weeding at 30 days after transplanting resulted in lowest weed biomass with weed control efficiency of more than 90 per cent compared to higher rate of application of pendimethalin at 1.5kg/ha and fluchloralin at 1.0kg/ha. In terms of average curd weight, total curd yield and net returns, pendimethalin at 1.5kg/ha was observed to be the best (Kumar *et al.,* 2015a).

Mal *et al.* (2005) reported that among the different weed control treatments (viz., weedy check, hand weeding, pendimethalin and oxadiazon each at 1.0 and 1.5kg/ha), pendimethalin at 1.5kg/ha resulted in maximum reduction in weed population and weed dry matter.

Gilreath and Gilreath (1983) studied the effect of oxyfluorfen (0.5 lb a.i./acre pre plant incorporated), DCPA (8 lb a.i./acre post transplant), napropamide (2 lb a.i./acre post transplant) and propachlor (5 and 10 lb a.i./acre post transplant) for their efficacy and phytotoxicity in fall transplanted broccoli (Atlantic) and cauliflower (Early Snowball A). All treatments excepting DCPA showed acceptable grass and broad leaf weed control. Broccoli yields were reduced by DCPA application. There was a reduction in the size of cauliflower curds in DCPA treatment compared to the hoed check, oxyfluorfen and propachlor (10 lb a.i/acre) treatments did not influence broccoli head size. Napropamide, oxyfluorfen, and both rates of propachlor were the most acceptable herbicidal treatments.

Widaryanto and Roviyanti (2017) reported that in broccoli a significant reduction in weed dry weight upto 56 days after transplanting was observed when oxyfluorfen was applied at the rate of 480g a.i./ha.

Herbicide toxicity

In cabbage, ciomazone (1.12kg a.i./ha) and oxyfluorfen (0.28kg a.i./ha) resulted in 15 to 25 per cent injury when evaluated after three weeks and 2 to 10 per cent after six weeks (Semidey, 1997).

Bellinder and Warholic (1988) reported that incorporation of metolachlor resulted in significant injury and yield reduction in cabbage. Post-transplant applications of metolachlor caused foliar flecking without any reduction in yield.

Reis *et al.* (2017) conducted a study to evaluate the selectivity of various herbicides, S-metolachlor (1,740 and 768g/ha), clomazone (720 and 360g/ha), oxyfluorfen (240 and 96g/ha), flumioxazin (40g/ha) and oxyfluorfen + flumioxazin (240 + 20 and 96 + 20g/ha) applied before and after transplant of seedlings and S-metolachlor + flumioxazin (768 +20g/ha), applied after transplant. A satisfactory weed control was obtained from all treatments, but most of them showed toxic effects in cabbage with an exception for oxyfluorfen (applied before transplant), and flumioxazin and S-metolachlor (applied after transplant).

Pereir *et al.* (1971) conducted an experiment to study the cabbage plant characteristics which made the cabbage cutivar 'Hybelle' tolerant and the cultivar 'Rio Verde' susceptible to the herbicide nitrofen. They observed that plants with fewer cuticles were more susceptible, regardless of cultivar and 'Hybelle' had more wax per unit surface than 'Rio Verde'. The amount of cuticular wax on the leaves at the time of nitrofen application decides the mechanism of intraspecific selectivity of cabbage.

Cabbage, broccoli and cauliflower were evaluated for their tolerance to oxyfluorfen (560 and 1120g a.i./ha), dimethenamid-p (750 and 1500g a.i./ha), sulfentrazone (100 and 200g a.i./ha), and a tank-mix of dimethenamid-p plus sulfentrazone (750+100 and 1500+200g a.i./ha). These herbicides when applied pre-transplant caused minimal visual injury (2% or less) to the crops without affecting their yield (Sikkema *et al.*, 2007a).

Sikkema *et al.* (2007b) evaluated the tolerance of cabbage to S-metolachlor applied pre- transplant incorporated (800g a.i./ha), pre-transplant (1600g a.i./ha) and post-transplant (2400g a.i./ha). The crop did not show any effect on visual injury, marketable head production, marketable head weight and yield of cabbage when S-metolachlor was applied at different timings.

Gorske and Hopen (1978) reported that application of nitrofen (3.36kg/ha) reduced the fresh weight of cabbage cultivars Hybelle (tolerant) and Rio Verde (susceptible) to 82 and 62 per cent, and oxyfluorfen (0.15kg/ha) resulted in 60 and 27 per cent reduction respectively. Applications of nitrofen at 3.36kg/ha reduced the fresh weight of cabbage cultivar Hybelle to the same extent as 100g/ha oxyfluorfen and 70g/ha in Rio Verde.

Harrison and Farnham (2013) carried out experiments to compare the tolerance of broccoli cultivars (Captain, Green Magic, Legacy, and Patron) and cabbage cultivars (Bravo, SC 100, Stone Head, and Vantage Point) to clomazone. Application of clomazone as pre-transplant at 0.25 lb/acre caused moderate chlorosis to the susceptible cultivars, Bravo and Patron. When clomazone was applied at 0.50 and 1.0 lb/acre, most cultivars exhibited chlorosis at 2 weeks after transplanting (WAT) but the tolerant cultivars recovered at 6 WAT.

The response of various herbicides were studied in bok choy (*Brassica rapa* L. *chinesis*), napa (*Brassica rapa* L. *pekinensis*), and Chinese broccoli (*Brassica oleracea* var. *alboglabra*) to assess crop tolerance and weed control. Crop vigour was reduced with pre transplant applications of metolachlor and oxyfluorfen (0.5 lb/acre) and the post transplant application of thiobencarb (16 lb/acre). All herbicides provided acceptable early grass control. Yields of chinese broccoli and napa were reduced by the pre emergence application of cinmethylin at 0.75 lb/acre (Shuler *et al.*, 1987).

Harrison *et al.* (1998) conducted experiments to assess the feasibility of using metolachlor (pre emergence application) in direct-seeded collard and kale cultivars. In was observed that in greenhouse and field experiments, metolachlor at 0.75 and 1.5 kg/ha caused injury and reduced the seedling weights of some cultivars. However, under field conditions, yield reduction was seen only at doses of 3.0kg/ha. Metolachlor at 1.5kg/ha or lower can be used safely in direct-seeded collard and kale by avoiding susceptible cultivars.

2.4.4 Integrated weed management

Kumar *et al.* (2014) reported that pre-emergence application of oxyfluorfen at 0.25kg a.i./ha followed by soil covering with black polythene mulch recorded highest yield (32 t/ha), profitability and weed control efficiency (72.63%) in cabbage.

Hoyt *et al.* (1996) studied the effect of conventional tillage (100% cultivated) and strip tillage (25% cultivated and 75% residue) system with various herbicide treatments on transplanted cabbage to evaluate weed control and cabbage yield. Commercially acceptable (>80%) control of carpet weed, red root pigweed, large crab grass, swine cress, and common lambsquarters was found with oxyfluorfen at 0.3kg a.i./ha, and oxyfluorfen at 0.2 kg a.i./ha plus napropamide at 1.1kg a.i./ha, DCPA at 9kg a.i./ha and napropamide at 1.1kg a.i./ha, under both tillage system.

Dillard *et al.* (2004) found that in cabbage herbicides provided good weed control but non-chemical practices (mulching, cultivation) were also equally effective in controlling *Ambrosia artemisiifolia*, which was associated with reduced yield in cabbage. They suggested that weed populations can be managed by effectively combining rotational crop schemes with non-chemical control measures.

2.5 Effect of weed management on soil microflora

Adhikary *et al.* (2014) studied the effect of herbicides (pendimethalin, propaquizafop and oxyfluorfen) on soil microbial populations in chilli. They observed that there was inhibition of microbial growth upto 15 days after application but thereafter no inhibition was observed. They presumed that microorganisms were involved in degradation process and the degraded herbicides were used as carbon rich substrates for the growth of microbial population.

Garg *et al.* (2007) observed an increase in fungal and bacterial counts under banana leaf mulch treatment. Black polyethylene mulch resulted in highest bacterial load but least fungal load after control in guava orchard soil.

Bera and Ghosh (2013) reported that immediately after the application of herbicide, there was a decrease in soil microflora (bacteria, actinomycetes and fungi) but after their persistence period, the microbial population recovered and sometimes even exceeded the initial count. At harvest, the population of bacteria was higher than that of control.

According to Bhagat *et al.* (2016) mulched soil samples gave higher microbial population. The treatment having rice straw mulch at 6t/ha and 100 per cent recommended dose of nitrogen resulted in maximum bacterial population (75×10^7 cfu/g soil), plant growth promoting rhizobacteria count (63×10^5 cfu/g soil) and fungal population (69×10^3 cfu/g soil) under potato cultivation.

Khuntia *et al.* (2013) observed that in rice, application of various herbicides (butachlor, pretilachlor, oxadiargyl, metsulfuron methyl + chlorimuron ethyl and pyrazosulfuron ethyl) resulted in significant reduction in microbial population upto 15 days after application but later on they recovered. Among all treatments, hand weeding resulted in significant increase in the population of total bacteria in soil.

Das *et al.* (2016) reported that in pigeon pea, herbicide treatments showed an increase in microbial population by 41.3 to 88.3 per cent over weedy check and 23.7 to 64.8 per cent over two hand weedings. The microorganisms degrade the herbicides and use them as a source of biogenic elements for their own physiological processes.

Das *et al.* (2015) found that in transplanted rice, initially (upto 15 days after application) the microbial population decreased in herbicide applied treatments. However, at 60 days after application 21.74 to 93.56 per cent higher population of total bacteria, 15.79 to 34.12 per cent higher population of actinomycetes and 18.47 to 71.23 per cent higher population of fungi were observed.

Kaur *et al.* (2014) studied the effect of sixteen weed control treatments, viz. pendimethalin (0.75kg/ha), thiobencarb (1.50kg/ha), butachlor (1.50kg/ha), anilofos (0.375kg/ha), oxadiargyl (0.09kg/ha), pretilachlor (0.75kg/ha) and pyrazosulfuron-ethyl (0.015kg/ha) applied as pre-emergence and each followed by bispyribac sodium (0.025kg/ha) at 30 days after sowing, two hand weedings and unweeded control on soil microorganisms. They found that herbicides have no detrimental effect on soil health at the applied doses and microbial populations in the herbicide treated plots were similar to unweeded and hand weeded plots.

Podder *et al.* (2017) observed that in onion, although soil micro flora reduced at the initial stage of herbicide application, in the later stages it exceeded the initial population. It was seen that at 60 days after application, herbicidal treatments recorded 50.49 to 97.57 per cent higher bacterial population than control. Similar results were observed in case of fungi and actinomycetes where the herbicidal treatments recorded higher population than control at 60 days after application.

Bhatt (2016) observed that the bacterial, fungal and actinomycetes population in herbicide treated plots was more or less similar to the unsprayed control plots in later stages *i.e.* 20 days after herbicide application, indicating that herbicides have no detrimental effect on soil health at applied doses.

2.6 Economics of weed control

Rana *et al.* (2017) reported that integrated application of oxyfluorfen at 0.25 kg/ha (pre-plant incorporated) followed by black polythene mulch in cabbage resulted in highest gross returns of Rs. 165800 and benefit cost ratio of 3.17.

Rajkumara *et al.* (2010) reported that weed free check resulted in significantly higher gross returns (Rs.113200/ha) and net returns (Rs. 91020/ha) followed by weed free period upto 120 days after sowing in onion. B:C ratio obtained from weed free check (5.11) was on par with that of weed free period up to 120 days after sowing (4.60).

Mondal *et al.* (2005) observed that in onion, oxyfluorfen (100g/ha) supplemented with one hand weeding at 25 DAT gave the maximum net return (Rs. 33650/ha) which was followed by fluchloralin (750g/ha) + HW (Rs.31983/ha), pendimethalin (750g/ha) + HW (Rs.31450/ha) and oxyfluorfen (200g/ha) (Rs.31400/ha). Weedy check resulted in a net loss of Rs.3900/ha.

According to Singh *et al.* (2017) among herbicidal applications oxyfluorfen at 0.30kg/ha was found most effective for most of the characters (plant height, average weight of bulb, diameter of bulb, plant population and bulb yield) studied in onion and a maximum benefit: cost ratio (2.92) was recorded in the same treatment.

Kumar *et al.* (2015b) opined that highest net returns of Rs. 382196 and B:C ratio of 4.63 was obtained in two hand weedings (30 and 60 DAT) closely followed by pendimethalin at 1.5 kg a.i./ha in tomato.

Trials conducted in onion under blue coloured polythene mulch and black polythene mulch showed the highest B:C ratio of 6.92 and 6.80 respectively (Pramanick *et al.*, 2006).

Black plastic mulch in onion resulted in maximum net return of Rs 162588/ha and cost benefit ratio of 1:2.66 followed by oxyfluorfen 23.5% EC + one hand weeding at 30 days after transplanting + quizalofop ethyl 5% EC at 60 days after transplanting and oxyfluorfen 23.5% EC + one hand weeding at 40-60 days after transplanting which resulted in cost benefit ratios of 1:2.86 and 1:2.79 respectively (Urraiya *et al.*, 2018).

Vishnu *et al.* (2015) opined that for onion highest gross (Rs. 327200/ha) and net return (Rs. 287471/ha) was obtained under weed free treatment. Highest B:C ratio of 7.12 was recorded under weed free treatment which was followed by the treatment two hand weedings at 25-30 and 45-50 days after transplanting, with B:C ratio of 6.74.

Materials & methods

3. MATERIALS AND METHODS

A field experiment on "Weed management in cabbage (*Brassica oleracea* var. *capitata* L.)" was carried out at Centre for Hi-tech Horticulture and Precision Farming, Vellanikkara, Thrissur from November 2017 to March 2018. The details of the materials used and the methodology adopted are described in this chapter.

3.1 General details

3.1.1 Location

Geographically the field is situated at $10^0 31'$ latitude and $76^0 13'$ longitude, at an altitude of 40.3 m above mean sea level.

3.1.2 Climate and weather conditions

The area enjoys typical warm humid climate. The mean weekly averages of important meteorological parameters observed during the experimental period are presented in Appendix 1.

3.1.3 Soil

The soil is laterite and is acidic in reaction with a pH of 6.56. The physico-chemical characteristics of the soil are depicted in Table 1.

3.1.4 Season and variety

The experiment was conducted from November 2017 to March 2018. Cabbage hybrid NS 183 of Namdhari Seeds Pvt. Ltd. was used for the experiment. It is a good uniform vigorous hybrid, maturing in 60 to 65 days with attractive dark bluish green foliage and good wrapper leaves. Head is round to semi round in shape, very compact with excellent firmness and density, having good field holding capacity and disease tolerance.

Table 1. Physico-chemical characteristics of the soil

Particulars	Content	Method used
A) Particle size analysis		
Sand (%)	66.38	International Pipette Method (Piper, 1966)
Silt (%)	19.60	
Clay (%)	14.02	
pH	6.56	Soil water suspension of 1:2.5 (Jackson, 1958)
B) Available nutrients		
Organic C (%)	1.08	Walkley and Black method (Walkley and Black, 1934)
Available N (kg/ha)	176.4	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg/ha)	45.88	Ascorbic acid reduced molybdo phosphoric blue colour method (Bray and Kurtz, 1945; Watanabe and Olsen, 1965)
Available K (kg/ha)	325.92	Neutral normal ammonium acetate extractant using flame photometry (Jackson, 1958)

3.1.5 Cropping history of the experimental site

The experimental site was under vegetable cultivation during the previous year.

3.2 Experimental details

3.2.1 Design and layout

The experiment was laid out in randomized block design (RBD) with eight treatments and three replications. The plot size was 6m x 2.4m and spacing adopted was 60cm x 60cm. The layout plan of experiment is given in Fig. 1.

3.2.2 Treatments

T_1: Pre emergence herbicide application of oxyfluorfen (0.20kg/ha) + 1 hand weeding at 30 days after planting

T_2: Pre emergence herbicide application of pendimethalin (1.50kg/ha) + 1 hand weeding at 30 days after planting

T_3 : High density planting with spacing of 0.6m x 0.3m + 1 hand weeding at 25 days after planting

T_4 : Mulching with coconut fronds (2 layers)

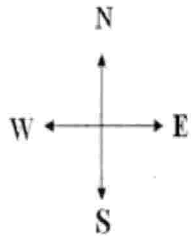
T_5 : Mulching with black and silver polythene (30 microns gauge)

T_6 : Stale seed bed followed by glyphosate application + 1 hand weeding at 30 days after planting

T_7 : Hand weeding (25 and 50 days after planting)

T_8 : Unweeded control

Fig. 1. Layout of experimental field



T2	T3	T4	T1	R_3
T8	T7	T6	T5	
T4	T8	T7	T3	R_2
T1	T5	T2	T6	
T6	T1	T8	T4	R_1
T3	T7	T5	T2	

3.2.3 Cultural practices

Land preparation

Land was ploughed with a tractor drawn disc plough and the soil was pulvarized using a rotavator. Beds of length 6m, width 2.4m and height 0.1m were taken.

Mulching

Mulching was done in two treatments, with coconut fronds and polythene sheets. In coconut frond mulching treatment, coconut fronds were spread in 2 layers over the entire bed completely covering the soil. In polythene mulching, 30 micron gauge silver-black polythene sheets were used for covering the beds. Holes of approximately 6cm diameter were punched at a spacing of 0.6m x 0.6m.

Planting

Twenty five days old seedlings were transplanted at a spacing of 0.6m x 0.6m. After transplanting, seedlings were given initial protection by shading for 3 days. Gap filling was done within a week after transplanting to ensure optimum plant population. There were 40 plants per treatments per replication in all the treatments but in high density planting there were 80 plants.

Manures and fertilizers

Fertilizers and manures were applied as per Package of Practices Recommendations of KAU (2016). FYM @ 25 t/ha was applied as basal during land preparation. $N:P_2O_5: K_2O$ were applied @ 150:100:125 kg/ha by fertigation.

Irrigation

Drip irrigation was carried out. Drip irrigation system was installed in the field prior to planting. The water source for drip system was a storage tank located near the experimental site and water was pumped to the irrigation line from the storage tank. Immediately after transplanting, 20 minutes drip irrigation was given for better establishment of the crop.

After cultivation

Earthing up was done one month after planting. Weeding was carried out as per treatment requirement.

Harvesting

Harvesting was done when heads reached marketable stage.

3.3 Observations

3.3.1 Observations on crop

From each treatment per replication 5 plants were selected randomly, tagged and observations were recorded.

Plant height (cm)

The height of the plant was recorded from the ground level to the topmost leaf apex.

Stalk length (cm)

It was recorded at marketable stage as length of plants from ground level to the first non wrapping leaves.

No. of wrapping leaves

Number of wrapping leaves from each sample plant was recorded at harvest stage and average was worked out.

No. of non wrapping leaves

Non wrapping leaves from each sample plant was recorded at harvest stage and average was worked out.

Plant spread (cm)

It was recorded as the average distance between two outer leaves of the plant.

Days to 50% head formation

It was recorded as the number of days from transplanting to putting forth of head by 50 per cent of the plants.

Days to 50% head maturity

Number of days from transplanting to producing marketable heads by 50 per cent plants was recorded as days to 50 per cent head maturity.

Head compactness

Head compactness was recorded as follows

1. Very compact
2. Compact
3. Medium compact
4. Loose
5. Others

Head length (cm)

At marketable stage, average length of head was recorded.

Head breadth (cm)

Average breadth of head was recorded at marketable stage.

Core length (cm)

Core length was measured from the sample plants and average was worked out. Mature head was cut vertically and the core length was measured.

Gross head weight (kg/plant)

It was recorded as the weight of the head before removal of the non wrapping leaves and stalk at marketable stage.

Net head weight (kg/plant)

It was recorded as the weight of the head after removal of the non wrapping leaves and stalk at marketable stage.

Head index

It is the average ratio of head length to head width.

Yield (t/ha)

Net weight of marketable heads recorded.

3.3.2 Observations on weeds

Weed count

From each plot, species wise weed count was taken at 25 and 50 DAP using a 50cm x 50cm ($0.25m^2$) quadrant. The quadrant was placed randomly at two different spots within each plot, weeds were uprooted, species wise weed count were taken and expressed on per m^2 basis.

Weed dry matter production

Weeds within the quadrants of 0.25 m^2 area in each plot were uprooted, cleaned, air dried and then oven dried at 80 ± 5^0C and dry weight was recorded in g/m^2 at 25 DAP and 50 DAP.

Weed control efficiency (WCE)

Weed control efficiency was calculated using the formula suggested by Mani *et al.* (1973).

$$WCE = \frac{\text{Weed dry weight in unweeded plot} - \text{Weed dry weight in treated plot}}{\text{Weed dry weight in unweeded plot}} \times 100$$

Weed index (WI)

Weed index was worked out using the formula suggested by Gill and Kumar (1969).

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

X= Yield in treatments with least weeds

Y= Yield from treatment plot

The least weed incidence was observed in mulching with silver-black polythene sheet treatment, so the yield obtained from this treatment was taken as X value for computing the weed index.

3.3.3 Chemical analysis

Soil analysis

Initial and final status of major nutrients in the soil was estimated. Soil samples were collected and soil analysis was done for pH, organic carbon, available N, available P and available K using standard procedures. Before analysis, air dried samples were passed through 0.5 mm sieve for analyzing the status of organic carbon and through 2 mm sieve for analysis of major nutrients.

Plant analysis

The N, P and K contents of weeds at 50 DAP were analyzed using standard procedures. Total N content was determined by microkjeldal digestion and distillation method. Diacid digestion of plant samples was done and P content was determined by vanadomolybdo phosphoric yellow colour method. Flame photometer was used to estimate the potassium content in the diacid digest. The uptake of N, P and K was calculated as the product of nutrient content and weed dry weight and expressed in kg/ha.

Table 2: Methods used for the analysis of plant samples

Sl. No.	Parameter	Method and reference
1.	N	Microkjeldahl digestion and distillation method (Jackson, 1958)
2.	P	Vanadomolybdo phosphoric yellow colour method (Bray and Kurtz, 1945; Watanabe and Olsen, 1965)
3.	K	Flame photometry (Jackson, 1958)

3.3.4 Soil microbial load

The population of bacteria, actinomycetes and fungi in soil were enumerated at planting and harvest. The media used are presented in Table 3.

Table 3: Media used for enumeration of microorganisms in soil

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

3.3.5 Pest and disease incidence

Incidence of pest and diseases was observed, recorded and timely control measures were adopted.

3.4 Economics

Gross expenditure was computed by considering prevailing labour charges, cost of inputs and extra treatment costs. The price of cabbage calculated based on local market rate was taken as total receipts for computing gross return. The ratio of gross return to total expenditure gave the benefit cost ratio.

3.5 Statistical analysis

The data were subjected to analysis of variance using the statistical package WASP 2. Data on weed count and weed biomass were subjected to square root transformation ($\sqrt{x}$ +0.5) to make the analysis of variance valid (Gomez and Gomez,1984).

Plate 1. Field view at 60 DAP

Results

4. RESULTS

The field experiment on "Weed management in cabbage (*Brassica oleracea* var. *capitata* L.)" was conducted from November 2017 to March 2018 at Centre for Hi-tech Horticulture and Precision Farming, Vellanikkara, Thrissur and the results of the study are presented below.

4.1 Studies on weeds

4.1.1 Weed spectrum

Major weeds found in the experimental field were broad leaf weeds which comprised of *Trianthema portulacastrum, Oldenlandia* sp., *Cleome* spp. *etc*., among which *Oldenlandia* sp. was highest in number. *Eleusine indica* was the dominant grass species followed by *Digitaria* sp. *Cyperus iria* was the only sedge observed in the field and the population of sedges was very low compared to other groups.

4.1.2 Weed density

Total and species wise weed count was taken at 25 and 50 days after planting (DAP) (Tables 4 and 5). As expected, weed density was more in untreated/ unmulched plots at 25 DAP. Polythene mulching permitted no weed growth. Plots treated with pendimethalin gave good control of weeds with only 12.67 weeds/m^2 and this was followed by oxyfluorfen treatment (26/m^2). Coconut leaf mulching and stale seed bed were equally effective at this stage of crop growth with weed density of 79.33/m^2 and 72.67/m^2, respectively.

Number of broad leaf weeds in coconut frond mulching and stale seed bed were 40.67/m^2 and 30.00/m^2 respectively. The number in pre-emergence herbicide applied plots varied from 12/m^2 in oxyfluorfen to 8/m^2 in pendimethalin.

Population of monocot weeds were less than that of broad leaf weeds in the experimental field. Comparing different treatments, monocot population was higher under high density planting (58/m^2). The number of monocot weeds in untreated/ unmulched plots and in stale seed bed recorded higher values. Plots under oxyfluorfen and pendimethalin recorded weed count of 8/m^2 and 4.67/m^2 respectively. *Cyperus iria* was the only sedge observed and its population ranged from zero to 12/m^2, the highest being in coconut frond mulching. Plots under high density planting (T_3) and oxyfluorfen (T_2) recorded a sedge population of 8.67 and 6/m^2 respectively. There were no sedges in other treatments.

At 50 DAP, higher weed counts were observed in high density planting (87.33), unweeded control (75.33) and hand weeding (65.33). Dicot and sedge weed density was also highest in high density planting, whereas grass weeds were significantly lower. Coconut frond mulching recorded a weed count of 50/m^2. The total weed density in pre emergence herbicide applied plots were on par (Table 5).

Polythene mulching was not subjected to statistical analysis as no weed count could be realized because of the specific nature of treatment.

4.1.3 Weed dry weight

Data on weed dry weight are presented in Table 6. The data shows progressive increases in dry weight from 25 DAP to 50 DAP from 163g/m^2 to 626g/m^2 in unweeded control. Weed dry weight in unweeded control was statistically higher than those in all other treatments. High density planting (T_3) and hand weeding (T_7) which recorded higher weed dry weights of 143g/m^2 and 137g/m^2 respectively were on par at 25 DAP. At 50 DAP, high density planting was superior to hand weeding with less than half of the weed dry matter production under hand weeding.

Table 4: Species wise weed count at 25 DAP (No./m^2) as influenced by various weed management practices

Treatment	Weed count at 25 DAP (No./m^2)										
	Trianthema sp.	*Cleome* spp.	*Oldenlandia* sp.	Other dicots	Total dicots	*Eleusine* sp.	*Digitaria* sp.	Other Monocots	Total monocots	Total Sedges	Total weed count
T_1 (Oxy+ 1HW)	*1.761^{d} (2.67)	1.290^{de} (1.33)	0.998^{d} (0.67)	2.687^{de} (7.33)	3.431^{e} (12.00)	2.264^{e} (4.67)	0.707^{e} (0.00)	1.805^{cd} (3.33)	2.813^{d} (8.00)	2.529^{c} (6.00)	5.082^{d} (26.00)
T_2 (Pendi + 1HW)	1.290^{de} (1.33)	1.581^{cd} (2.00)	0.707^{d} (0.00)	2.150^{e} (4.67)	2.828^{f} (8.00)	1.290^{f} (1.33)	0.707^{e} (0.00)	1.805^{cd} (3.33)	2.150^{e} (4.67)	0.707^{d} (0.00)	3.557^{e} (12.67)
T_3 (HDP+ 1HW)	5.207^{a} (26.67)	4.881^{a} (23.33)	7.057^{b} (49.33)	6.266^{b} (39.33)	11.775^{ab} (138.67)	7.105^{a} (50.00)	1.581^{cd} (2.00)	2.449^{b} (6.00)	7.615^{a} (58.00)	3.024^{b} (8.67)	14.329^{a} (205.33)
T_4 (Coconut frond mulching)	2.902^{c} (8.00)	0.998^{e} (0.67)	4.593^{c} (20.67)	3.345^{c} (11.33)	6.369^{c} (40.67)	4.665^{d} (21.33)	1.290^{d} (1.33)	1.955^{bc} (4.00)	5.161^{c} (26.67)	3.528^{a} (12.00)	8.897^{c} (79.33)
#T_5 (Polythene mulching)	-	-	-	-	-	-	-	-	-	-	-
T_6 (SSB *fb*. Gly + HW)	0.707^{e} (0.00)	1.941^{c} (3.33)	4.142^{c} (16.67)	3.152^{cd} (10.00)	5.475^{d} (30.00)	5.634^{b} (31.33)	3.132^{a} (9.33)	1.414^{d} (2.00)	6.526^{b} (42.67)	0.707^{d} (0.00)	8.523^{c} (72.67)
T_7 (2 HW)	4.600^{b} (20.67)	3.536^{b} (12.00)	8.151^{a} (66.00)	7.070^{a} (50.00)	12.191^{a} (148.67)	5.324^{bc} (28.00)	2.264^{b} (4.67)	3.363^{a} (11.33)	6.620^{b} (44.00)	0.707^{d} (0.00)	13.875^{a} (192.67)
T_8 (UWC)	4.734^{ab} (22.00)	1.941^{c} (3.33)	7.190^{b} (51.33)	7.065^{a} (50.00)	11.254^{b} (126.67)	4.947^{cd} (24.00)	1.941^{bc} (3.33)	2.150^{bc} (4.67)	5.655^{c} (32.00)	0.707^{d} (0.00)	12.596^{b} (158.67)

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

Polythene mulching was not subjected to statistical analysis as no weed count could be realized at both 25 and 50 DAP

Oxy- Oxyfluorfen, Pendi- Pendimethalin, HDP- High density planting, HW- Hand weeding, SSB- Stale seed bed, Gly- Glyphosate, UWC- Unweeded control

Table 5: Species wise weed count at 50 DAP (No./m^2) as influenced by various weed management practices

Treatment	Weed count at 50 DAP (No./m^2)										
	Trianthema sp.	*Cleome* spp.	*Oldenlandia* sp.	Other dicots	Total dicots	*Eleusine* sp.	*Digitaria* sp.	Other monocots	Total monocots	Total Sedges	Total weed count
T_1 (Oxy+ 1HW)	*0.707^d (0.00)	1.774^b (2.67)	0.707^e (0.00)	3.735^b (14.00)	4.077^d (16.67)	2.150^{bc} (4.67)	0.707^d (0.00)	0.707^c (0.00)	2.150^e (4.67)	1.774^b (2.67)	4.897^d (24.00)
T_2 (Pendi + 1HW)	0.707^d (0.00)	1.344^c (1.33)	0.998^e (0.67)	4.071^b (16.67)	4.309^d (18.67)	1.805^c (3.33)	1.052^c (0.67)	2.112^a (4.00)	2.818^d (8.00)	0.707^c (0.00)	5.515^d (26.67)
T_3 (HDP+ 1HW)	1.559^b (2.00)	2.676^a (6.67)	4.740^b (22.00)	6.412^a (41.33)	8.471^a (72.00)	2.444^{ab} (6.00)	1.344^c (1.33)	1.559^b (2.00)	3.048^{cd} (9.33)	2.544^a (6.00)	9.329^a (87.33)
T_4 (Coconut frond mulching)	3.027^a (8.67)	1.774^b (2.67)	3.230^c (10.00)	3.735^b (14.00)	5.944^c (35.33)	2.702^{ab} (7.33)	2.271^{ab} (4.67)	0.707^c (0.00)	3.458^{bc} (12.00)	1.761^b (2.67)	7.069^c (50.00)
#T_5 (Polythene mulching)	-	-	-	-	-	-	-	-	-	-	-
T_6 (SSB *fb*. Gly + HW)	0.707^d (0.00)	1.052^c (0.67)	1.904^d (3.33)	2.537^c (6.67)	3.215^e (10.67)	1.577^c (2.67)	0.707^d (0.00)	0.707^c (0.00)	1.577^f (2.67)	0.707^c (0.00)	3.613^e (13.33)
T_7 (2 HW)	1.052^c (0.67)	1.774^b (2.67)	5.699^a (32.00)	4.081^b (16.67)	7.210^b (52.00)	2.698^{ab} (7.33)	1.954^b (3.33)	1.774^b (2.67)	3.648^{ab} (13.33)	0.707^c (0.00)	8.081^b (65.33)
T_8 (UWC)	2.912^a (8.00)	1.774^b (2.67)	5.625^a (31.33)	4.161^b (17.33)	7.690^b (59.33)	2.825^a (8.00)	2.544^a (6.00)	1.559^b (2.00)	3.999^a (16.00)	0.707^c (0.00)	8.671^{ab} (75.33)

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

Polythene mulching was not subjected to statistical analysis as no weed count could be realized at both 25 and 50 DAP

Oxy- Oxyfluorfen, Pendi- Pendimethalin, HDP- High density planting, HW- Hand weeding, SSB- Stale seed bed, Gly- Glyphosate, UWC- Unweeded control

Table 6: Effect of treatments on weed dry weight at 25 and 50 DAP

Treatments	25 DAP (g/m^2)	50 DAP (g/m^2)
T_1: Oxyfluorfen (0.20kg/ha) + 1 HW at 30 DAP	*4.764[e] (22.8)	4.966[e] (24.67)
T_2 : Pendimethalin (1.50kg/ha) + 1 HW at 30 DAP	3.103[f] (9.8)	3.464[f] (12)
T_3: High density planting with spacing of 0.6m x 0.3m + 1 HW at 25 DAP	11.960[b] (143.07)	6.126[d] (37.53)
T_4: Mulching with coconut fronds (2 layers)	8.521[c] (72.73)	17.874[b] (320.53)
#T_5 : Mulching with black and silver polythene	-	-
T_6 : Stale seed bed *fb.* glyphosate application + 1 HW at 30 DAP	7.756[d] (60.2)	3.676[f] (13.53)
T_7 : Hand weeding (25 and 50 days after planting)	11.704[b] (137)	8.852[c] (78.4)
T_8:Unweeded control	12.790[a] (163.6)	25.018[a] (626.27)

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

Polythene mulching was not subjected to statistical analysis as no weed count could be realized at both 25 and 50 DAP

DAP- Days after planting

HW- Hand weeding

Pendimethalin (9.8g/m^2) and oxyfluorfen (22.8g/m^2) recorded lower dry weight at 25 DAP. Mulching with coconut fronds and stale seed bed technique recorded weed dry weight of 73g/m^2 and 60g/m^2 respectively at 25 DAP. At 50 DAP, lower weed dry matter was observed under pendimethalin and stale seed bed treatment with 12g/m^2 and 14g/m^2 which were on par. Oxyfluorfen registered a little higher value of 25/m^2 and was significantly inferior to pendimethalin treatment and stale seed bed. Polythene mulching was not subjected to statistical analysis as no weeds were present both at 25 and 50 DAP.

4.1.4 Nutrient removal by weeds

The data on nutrient removal by weeds at 50 DAP is given in Table 7. Unweeded control recorded highest uptake of N, P and K. The N removal ranged from 153.10kg/ha in unweeded control to zero in polythene mulching where there were no weeds. Mulching with coconut fronds and hand weeding resulted in an uptake of 74.24 and 24.28kg/ha respectively. High density planting and oxyfluorfen application registered comparable values. The treatments pendimethalin and stale seedbed recorded lower uptake.

P removal also followed a similar pattern to that of N uptake, with highest P uptake by unweeded control and no removal under polythene mulching. Coconut frond mulching and hand weeding resulted in uptake of 14.42 and 4.12kg/ha respectively. P uptake in plots under high density planting (1.75kg/ha), oxyfluorfen (1.21kg/ha), pendimethalin (0.65kg/ha), and stale seedbed (0.58kg/ha) were statistically on par.

Highest K uptake of 189.48kg/ha was observed in unweeded control, whereas no uptake was registered under polythene mulching due to no weed growth. The second highest uptake was recorded from coconut frond mulching (98.78kg/ha)

Table 7: Effect of treatments on uptake of N, P and K by weeds

Treatment	Nutrient uptake (kg/ha)		
	Nitrogen	Phosphorus	Potassium
T_1: Oxyfluorfen (0.20kg/ha) + 1 HW at 30 DAP	*9.24^{de}	1.21^{d}	8.99^{de}
T_2 :Pendimethalin (1.50kg/ha) + 1 HW at 30 DAP	3.52^{e}	0.65^{d}	3.680^{ef}
T_3: High density planting with spacing of 0.6m x 0.3m + 1 HW at 25 DAP	11.17^{d}	1.75^{d}	10.420^{d}
T_4: Mulching with coconut fronds (2 layers)	74.24^{b}	14.42^{b}	98.78^{b}
#T_5 : Mulching with black and silver polythene	-	-	-
T_6 : Stale seed bed *fb.* glyphosate application + 1 HW at 30 DAP	3.69^{e}	0.58^{d}	3.45^{f}
T_7 : Hand weeding (25 and 50 days after planting)	24.28^{c}	4.12^{c}	23.11^{c}
T_8: Unweeded control	153.10^{a}	16.67^{a}	189.48^{a}

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

Polythene mulching was not subjected to statistical analysis as no weed count could be realized

DAP- Days after planting

HW- Hand weeding

which was followed by hand weeding. The treatments, high density planting and oxyfluorfen had comparable values. Lower uptake of K was noticed in stale seedbed and pendimethalin, which were on par.

4.1.5 Weed control efficiency

The data on weed control efficiency at 25 and 50 DAP are presented in Table 8. Both at 25 and 50 DAP, black polythene mulch (T_5) recorded a weed control efficiency of 100 per cent as no weeds were found in that treatment, and under unweeded control (T_8), since no weed management was adopted, weed control efficiency was zero. At 25 DAP, pendimethalin (T_2) and oxyfluorfen (T_1) recorded a weed control efficiency of 94 and 86 per cent respectively. It was followed by stale seedbed technique with a weed control efficiency of 63 per cent. High density planting (T_3) recorded a lower weed control efficiency of 12 per cent.

At 50 DAP, weed control efficiency of pendimethalin (98%), stale seed bed technique (98%), oxyfluorfen (96%) and high density planting (93%) were comparable. It was followed by hand weeding which registered a weed control efficiency of 87 per cent. Lower weed control efficiency was recorded in coconut frond mulching (49%).

4.1.6 Weed index

Data on weed index is given in Table 9. Pendimethalin applied plots recorded lower weed index of 39.52 per cent. Treatments, stale seed bed (T_6), hand weeding (T_7) and oxyfluorfen (T_1) registered comparable values of 48.28 per cent, 53.28 per cent and 55.77 per cent respectively. Unweeded control (T_8), coconut frond mulching (T_4) and high density planting (T_3) recorded higher weed index values with the highest being recorded under unweeded control (94.59 %).

Table 8: Effect of treatments on weed control efficiency

Treatments	Weed control efficiency (%)	
	25 DAP	50 DAP
T_1: Oxyfluorfen (0.20kg/ha) + 1 HW at 30 DAP	86.04	96.06
T_2 : Pendimethalin (1.50kg/ha) + 1 HW at 30 DAP	94.04	98.08
T_3: High density planting with spacing of 0.6m x 0.3m + 1 HW at 25 DAP	12.49	93.00
T_4: Mulching with coconut fronds (2 layers)	55.52	48.96
T_5 : Mulching with black and silver polythene	100	100
T_6 : Stale seed bed *fb.* glyphosate application + 1 HW at 30 DAP	63.16	97.83
T_7 : Hand weeding (25 and 50 days after planting)	16.26	87.43
T_8:Unweeded control	0.00	0.00

DAP- Days after planting

HW- Hand weeding

Table 9: Effect of treatments on weed index

Treatments	Weed index (%)
T_1: Oxyfluorfen (0.20kg/ha) + 1 HW at 30 DAP	55.77
T_2 :Pendimethalin (1.50kg/ha) + 1 HW at 30 DAP	39.52
T_3: High density planting with spacing of 0.6 m x 0.3m + 1 HW at 25 DAP	66.67
T_4: Mulching with coconut fronds (2 layers)	81.42
T_5 : Mulching with black and silver polythene	0.00
T_6 : Stale seed bed *fb.* glyphosate application + 1 HW at 30 DAP	48.28
T_7 : Hand weeding (25 and 50 days after planting)	53.28
T_8:Unweeded control	94.59

DAP- Days after planting

HW- Hand weeding

4.2 Soil analysis

4.2.1 Soil pH

The data on soil pH are depicted in Table 10. The soil was slightly acidic in nature. There was an increase in soil acidity after the experiment in all treatments, as compared to pre experimental soil. All treatments except mulching with coconut fronds and oxyfluorfen were on par.

4.2.2 Soil organic carbon

The data on soil organic carbon and major nutrients are presented in Table 10. There was no significant difference between treatments with respect to soil organic carbon content.

4.2.3 Available N, P and K

The content of available N in polythene mulching (264.6kg/ha), oxyfluorfen (260.4kg/ha), stale seed bed (256.2kg/ha), high density planting (252kg/ha) and pendimethalin (247.8kg/ha) treatments were statistically on par (Table 10). Coconut frond mulching recorded an available N content of 222.6kg/ha. The least available N was noticed in unweeded control (163.8 kg/ha) which was followed by hand weeding (193.2kg/ha).

The available P content was higher in plastic mulching and pendimethalin treated plots. The treatments stale seed bed (T_6) and oxyfluorfen (T_1) recorded available P content of 64.29 and 61.36 kg/ha respectively. The treatments with hand weeding and high density planting were statistically on par (61.11 and 60.24kg/ha). The least content of available P was noticed in unweeded control (50.66kg/ha).

Table 10: Effect of different treatments on soil pH, soil organic carbon and available nutrients in soil

Treatments	pH	Soil organic carbon (%)	Available nutrients (kg/ha)		
			N	P	K
T_1: Oxyfluorfen (0.20kg/ha) + 1 HW at 30 DAP	*6.16^{bc}	0.95	260.40^{a}	61.36^{cd}	328.91^{bc}
T_2: Pendimethalin (1.50kg/ha) + 1 HW at 30 DAP	6.43^{ab}	1.08	247.80^{a}	72.10^{a}	477.49^{a}
T_3: High density planting with spacing of 0.6m x 0.3m + 1 HW at 25 DAP	6.45^{a}	1.02	252.00^{a}	60.24^{cde}	281.49^{c}
T_4: Mulching with coconut fronds (2 layers)	5.95^{c}	1.02	222.60^{b}	51.81^{de}	278.88^{c}
T_5 : Mulching with black and silver polythene	6.37^{ab}	1.19	264.60^{a}	78.07^{a}	354.29^{b}
T_6 : Stale seed bed *fb.* glyphosate application + 1 HW at 30 DAP	6.38^{ab}	1.14	256.20^{a}	64.29^{bc}	339.36^{bc}
T_7: Hand weeding (25 and 50 days after planting)	6.27^{ab}	1.10	193.20^{c}	61.11^{cde}	331.15^{bc}
T_8:Unweeded control	6.36^{ab}	0.99	163.80^{d}	50.66^{e}	275.52^{c}
Pre experiment	6.56	1.08	176.4	45.88	325.92

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

DAP- Days after planting

HW- Hand weeding

Higher K content of 477.49kg/ha was noticed in pendimethalin applied treatment followed by plastic mulching (354.29kg/ha). The treatments, stale seed bed technique (339.36kg/ha), hand weeding (331.15kg/ha) and oxyfluorfen (328.91kg/ha) were statistically on par. Unweeded control (275.52kg/ha), mulching with coconut fronds (278.88kg/ha) and high density planting (281.49kg/ha) recorded the lowest status of available K.

4.2.4 Soil microbial load

Data on soil microbial load are given in Table 11. Irrespective of the treatments, population of bacteria, fungi and actinomycetes registered higher values at the times of harvest as compared to pre-experiment period. However there was no significant difference in soil microbial load (bacteria, fungi and actinomycetes) between treatments after harvest.

4.3 Plant observations

4.3.1 Plant height

Plant height was recorded at 30 DAP and at harvest (Table 12). Plant height at 30 DAP were found to be non significant between treatments.

At harvest, plant height was more in plastic mulching (44.66cm). The plant height in the treatments, pendimethalin (40cm), hand weeding (39.18cm), oxyfluorfen (39.1cm), stale seed bed (36.33cm), coconut frond mulching (36.03cm) and high density planting (34.23cm) were statistically on par. Unweeded plots recorded the lowest plant height of 26.67cm.

Table 11: Effect of treatments on soil microbial load at harvest

Treatments	Population (cfu/g)		
	Bacteria ($x 10^5$)	Fungus ($x 10^3$)	Actinomycetes ($x 10^5$)
T_1: Oxyfluorfen (0.20 kg/ha) + 1 HW at 30 DAP	*11.75 (138.16)	7.40 (54.83)	3.74 (14.00)
T_2 :Pendimethalin (1.50kg/ha) + 1 HW at 30 DAP	11.39 (129.66)	6.93 (48.00)	3.46 (12.00)
T_3: High density planting with spacing of 0.6m x 0.3m + 1 HW at 25 DAP	11.83 (139.83)	7.07 (50.00)	3.99 (16.00)
T_4: Mulching with coconut fronds (2 layers)	12.09 (146.50)	7.57 (57.33)	4.08 (16.66)
T_5 : Mulching with black and silver polythene	11.78 (141.50)	7.27 (53.16)	3.60 (13.00)
T_6 : Stale seed bed *fb.* glyphosate application + 1 HW at 30 DAP	11.45 (131.00)	6.90 (47.66)	3.51 (12.33)
T_7: Hand weeding (25 and 50 days after planting)	11.92 (142.50)	7.42 (55.16)	3.78 (14.33)
T_8:Unweeded control	11.59 (134.50)	7.39 (54.67)	3.59 (13.00)
Pre experiment	114	40	11

*$\sqrt{x+0.5}$ transformed values, original values in parentheses.

DAP- Days after planting

HW- Hand weeding

4.3.2 Plant spread

Plant spread was recorded at 30 DAP and at harvest. At 30 DAP (Table 13), highest plant spread was recorded in polythene mulching (41.77cm). The plant spread in plots with stale seed bed (35.47cm), hand weeding (34.13cm) and coconut frond mulching (32.27cm) were statistically on par. High density planting and oxyfluorfen sprayed plots recorded a plant spread of 31.53 and 31.27cm respectively. The lowest plant spread was recorded in unweeded control (26.57cm) and pendimethalin (26.10cm).

At harvest also, highest plant spread was recorded in polythene mulching (65.26cm). The treatments, pendimethalin, stale seed bed, hand weeding and oxyfluorfen were on par and recorded a plant spread of 51.11, 50.47, 47.31 and 46.83cm respectively. High density planting and coconut frond mulching recorded a plant spread of 38.63 and 32.90cm respectively. Unweeded control recorded the lowest plant spread (27.17cm).

4.3.3 Number of wrapping leaves per head

The highest number of wrapping leaves (4.53) was observed in polythene mulched plots followed by hand weeding (3.73) (Table 13). The number of wrapping leaves in plots applied with oxyfluorfen (3.60), pendimethalin (3.60), stale seedbed (3.60) and coconut fronds (3.53) were statistically on par. The plot under high density planting recorded 3.20 wrapping leaves per head. Lowest number of wrapping leaves was observed in unweeded control (2.87).

4.3.4 Number of non wrapping leaves per head

The number of non wrapping leaves per head in plots with hand weeding (22.60), stale seed bed (22.40), oxyfluorfen (22.00), pendimethalin (21.47) and

Table 12: Effect of treatments on plant height

Treatments	Plant height (cm)	
	30 DAP	Harvest
T_1: Oxyfluorfen (0.20kg/ha) + 1 HW at 30 DAP	11.033	*39.10[ab]
T_2: Pendimethalin (1.50kg/ha) + 1 HW at 30 DAP	10.267	40.00[ab]
T_3: High density planting with spacing of 0.6m x 0.3m + 1 HW at 25 DAP	10.700	34.23[b]
T_4: Mulching with coconut fronds (2 layers)	12.033	36.03[b]
T_5 : Mulching with black and silver polythene	13.833	44.66[a]
T_6 : Stale seed bed *fb.* glyphosate application + 1 HW at 30 DAP	11.353	36.33[b]
T_7 : Hand weeding (25 and 50 days after planting)	12.333	39.18[ab]
T_8:Unweeded control	11.933	26.67[c]

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

DAP- Days after planting

HW- Hand weeding

Table 13: Effect of treatments on plant spread, no. of wrapping leaves and non wrapping leaves

Treatments	Plant spread (cm)		No. of wrapping leaves	No. of non wrapping leaves
	30 DAP	Harvest		
T_1: Oxyfluorfen (0.20kg/ha) + 1 HW at 30 DAP	*31.27^{bcd}	46.83^{b}	3.60^{bc}	22.00^{a}
T_2 :Pendimethalin (1.50kg/ha) + 1 HW at 30 DAP	26.10^{d}	51.11^{b}	3.60^{bc}	21.47^{a}
T_3: High density planting with spacing of 0.6m x 0.3m + 1 HW at 25 DAP	31.53^{bc}	38.63^{c}	3.20^{cd}	16.00^{b}
T_4: Mulching with coconut fronds (2 layers)	32.27^{b}	32.90^{c}	3.53^{bc}	15.87^{b}
T_5 : Mulching with black and silver polythene	41.77^{a}	65.26^{a}	4.53^{a}	21.33^{a}
T_6 : Stale seed bed *fb.* glyphosate application + 1 HW at 30 DAP	35.47^{b}	50.47^{b}	3.60^{bc}	22.40^{a}
T_7: Hand weeding (25 and 50 days after planting)	34.13^{b}	47.31^{b}	3.73^{b}	22.60^{a}
T_8 :Unweeded control	26.57^{cd}	27.17^{d}	2.87^{d}	13.47^{b}

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

DAP- Days after planting

HW- Hand weeding

polythene mulching (21.33) were statistically on par (Table 13). High density planting (16.00), coconut frond mulching (15.87) and unweeded control (13.47) gave lowest number of non wrapping leaves.

4.4 Observations at harvest

4.4.1 Stalk length

Stalk length was recorded at harvest (Table 14). Highest stalk length was observed in high density planting and was followed by pendimethalin and coconut fronds which were statistically on par. The treatment, hand weeding and oxyfluorfen recorded stalk lengths of 8.79 and 8.75cm respectively and were on par. Polythene mulching (8.50cm) and stale seedbed (7.99cm) recorded lower stalk length and the lowest was found in unweeded control (6.97cm).

4.4.2 Days to 50% head formation

The minimum number of days to achieve 50 per cent head formation was observed under polythene mulching (43.00), which was followed by pendimethalin (49.33) oxyfluorfen, stale seed bed and hand weeded plots which were statistically on par (Table 14). High density planting took 60 days to obtain 50 per cent head formation and it was on par with coconut frond mulching. Unweeded control took most number of days to attain 50 per cent head formation.

4.4.3 Days to 50% head maturity

The lowest number of days to achieve 50 per cent head maturity was observed under polythene mulching (63.00), which was followed by pendimethalin (70.00), oxyfluorfen (71.67), stale seedbed (72.22) and hand weeded (72.67) plots which were statistically on par (Table 14). High density planting took 79 days to obtain 50 per

Table 14: Effect of treatments on stalk length, days to 50% head formation and days to 50% head maturity

Treatments	Stalk length (cm)	Days to 50% head formation	Days to 50% head maturity
T_1: Oxyfluorfen (0.20kg/ha) + 1 HW at 30 DAP	*8.75^{abc}	51.33^{c}	71.67^{c}
T_2 : Pendimethalin (1.50kg/ha) + 1 HW at 30 DAP	9.43^{ab}	49.67^{c}	70.00^{c}
T_3: High density planting with spacing of 0.6m x 0.3m + 1 HW at 25 DAP	10.60^{a}	58.33^{b}	78.33^{b}
T_4: Mulching with coconut fronds (2 layers)	9.40^{ab}	60.00^{b}	80.00^{ab}
T_5 : Mulching with black and silver polythene	8.50^{bc}	43.33^{d}	63.00^{d}
T_6 : Stale seed bed *fb.* glyphosate application + 1 HW at 30 DAP	7.99^{bc}	51.67^{c}	72.33^{c}
T_7: Hand weeding (25 and 50 days after planting)	8.79^{abc}	52.00^{c}	72.67^{c}
T_8:Unweeded control	6.97^{c}	67.00^{a}	85.00^{a}

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

DAP- Days after planting

HW- Hand weeding

cent head maturity and it was followed by coconut frond mulching. Unweeded control took highest days to attain 50 per cent head maturity.

4.4.4 Head compactness

The cabbage heads were medium compact to compact in all treatments except in unweeded control where it was found to be medium compact (Table 15).

4.4.5 Head length

Observation on head length was recorded at the time of harvest (Table 16). Polythene mulching registered the highest value for head length (13.95cm). Pendimethalin and stale seed bed recorded comparable values (11.72cm and 10.53cm respectively). Hand weeding and oxyfluorfen recorded head lengths of 10.46 and 10.20cm respectively. Head lengths of 9.20cm and 8.60 cm was registered by high density planting and coconut frond mulching respectively. Lowest length of 5.83cm of was reported in unweeded control.

4.4.6 Head breadth

Observations on head breadth were also recorded at the time of harvest. Polythene mulching registered the highest value for head length (12.57cm) which was followed by pendimethalin with a breadth of 10.60cm (Table 16). Stale seedbed, hand weeding and oxyfluorfen recorded values of 9.70, 9.40 and 9.37cm respectively. The treatment, high density planting (8.43cm) and coconut frond mulching (7.23cm) registered comparable values. Lowest head breadth (4.73cm) was reported in unweeded control.

4.4.7 Core length

Highest core length was recorded in polythene mulching (6.49cm), followed by pendimethalin with 6.23cm (Table 16). The treatment, stale seedbed and hand weeding recorded core lengths of 5.93 and 5.79cm respectively and were on par. Oxyfluorfen (5.52cm), high density planting (5.31cm) and coconut frond mulching (5.13cm) registered comparable values. Lowest core length (3.67cm) was recorded in unweeded control.

4.4.8 Gross head weight

The per plant gross head weight was recorded at harvest and the data are presented in Table 17. Highest weight of 1987.27g was observed in polythene mulching which was followed by pendimethalin (1400.53g), stale seedbed (1218.07g), hand weeding (1156.00g) and oxyfluorfen (1174.13g) treatments which were statistically on par. The treatment, high density planting and coconut frond mulching registered head weights of 770.80g and 609.73g respectively and were on par. Unweeded control recorded the lowest weight (286.60g).

4.4.9 Net head weight

Net head weight was recorded as the weight of the head after removal of the non wrapping leaves and stalk at marketable stage. The per plant net head weight was recorded at harvest (Table 17). Highest net head weight of 858.47g was observed in polythene mulching which was followed by pendimethalin treatment with a net head weight of 523.40g. The treatments, stale seed bed (435.13g) and hand weeding (402.67g) registered comparable values. Oxyfluorfen and high density planting recorded net head weights of 376.20g and 291.53g respectively. Lowest head weight was observed in unweeded control (49.40g).

Table 15: Effect of treatments on head compactness

Treatments	Head compactness
T_1: Oxyfluorfen (0.20kg/ha) + 1 HW at 30 DAP	Medium compact to compact
T_2 : Pendimethalin (1.50kg/ha) + 1 HW at 30 DAP	Medium compact to compact
T_3: High density planting with spacing of 0.6m x 0.3m + 1 HW at 25 DAP	Medium compact to compact
T_4: Mulching with coconut fronds (2 layers)	Medium compact to compact
T_5 : Mulching with black and silver polythene	Medium compact to compact
T_6 : Stale seed bed *fb.* glyphosate application + 1 HW at 30 DAP	Medium compact to compact
T_7: Hand weeding (25 and 50 days after planting)	Medium compact to compact
T_8:Unweeded control	Medium compact

DAP- Days after planting

HW- Hand weeding

Table 16: Effect of treatments on head length, head breadth and core length

Treatments	Head length (cm)	Head breadth (cm)	Core length (cm)
T_1: Oxyfluorfen (0.20kg/ha) + 1 HW at 30 DAP	*10.20^{cd}	9.37^{bc}	5.52^{bc}
T_2 :Pendimethalin (1.50kg/ha) + 1 HW at 30 DAP	11.72^{b}	10.60^{b}	6.23^{ab}
T_3: High density planting with spacing of 0.6m x 0.3m + 1 HW at 25 DAP	9.20^{de}	8.43^{cd}	5.31^{c}
T_4: Mulching with coconut fronds (2 layers)	8.60^{e}	7.23^{d}	5.13^{c}
T_5 : Mulching with black and silver polythene	13.95^{a}	12.57^{a}	6.49^{a}
T_6 : Stale seed bed *fb.* glyphosate application + 1 HW at 30 DAP	10.53^{bc}	9.70^{bc}	5.93^{abc}
T_7: Hand weeding (25 and 50 days after planting)	10.46^{c}	9.40^{bc}	5.79^{abc}
T_8:Unweeded control	5.83^{f}	4.73^{e}	3.67^{d}

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

DAP- Days after planting

HW- Hand weeding

4.4.10 Head index

Head index is the average ratio of head length to head breadth. Unweeded control recorded a head index value of 1.26 and it was followed by the value 1.23 under coconut frond mulching (Table 17). The treatment, polythene mulching and hand weeding recorded head index value of 1.12. The head index values of treatment, pendimethalin (1.11), oxyfluorfen (1.10), high density planting (1.10) and stale seedbed (1.09) were on par.

4.4.11 Yield

Data on cabbage yield is given in Table 17. Highest yield of 16.83t/ha was obtained from the treatment T_5 *i.e* polythene mulched plots, followed by T_2, pendimethalin applied plots (10.26t/ha). Treatment, stale seed bed (T_6), hand weeding (T_7) and oxyfluorfen (T_1) gave comparable yields of 8.53, 7.90 and 7.44t/ha respectively. Lowest yield was recorded under unweeded control (0.97t/ha). The next low yielding treatments were coconut frond mulching (T_4) and high density planting (T_3).

4.5 Correlation studies

The correlation coefficients for yield with weed dry matter production at 25 and 50 days after planting, crop growth parameters like plant height, plant spread, number of wrapping and non-wrapper leaves and yield attributes *viz.* head length and head breadth are furnished in Table 18. These were arrived at from the individual values of all treatments in each replication.

Weed dry matter production both at 25 and 50 DAP gave a significant negative correlation with yield. Plant height, plant spread and number of wrapping and non-wrapper leaves were positively correlated with yield and gave significantly high values. With plant spread, the correlation was very high. Similarly head length and head breadth gave very high positive correlation.

4.6 Incidence of pest, disease and physiological disorders

Painted bug (*Bagrada hilaris*) and army worm (*Spodoptera litura)* were the two major pests found in the experimental field. The incidence of painted bug was observed during the initial growth stages whereas, *Spodoptera litura* was seen in the later stages. Cypermethrin (50g/ha) was used for the control of painted bug and chlorantranilprole (25g/ha) was used for the control of spodoptera. No diseases and physiological disorders were recorded during the experimental period.

4.7 Economics

The data regarding B:C ratio are presented in Table 19. The highest B:C ratio of 2.17 was obtained in polythene mulch (T_5). The second highest B:C ratio was obtained from pendimethalin applied plots (1.63) which was followed by stale seed bed with a B:C ratio of 1.34. Hand weeded plots recorded a B:C ratio of 1.18, similar to oxyfluorfen applied treatment (1.18). High density planting and coconut frond mulching recorded B:C ratios of 0.90 and 0.52 respectively. The least B:C ratio of 0.23 was observed in unweeded control.

Table 17: Effect of treatments on gross head weight, net head weight, head index and yield

Treatments	Gross head weight (g/plant)	Net head weight (g/plant)	Head index	Yield (t/ha)
T_1: Oxyfluorfen (0.20kg/ha) + 1 HW at 30 DAP	*1174.13^{b}	379.20^{cd}	1.10^{c}	7.44^{cd}
T_2 : Pendimethalin (1.50kg/ha) + 1 HW at 30 DAP	1400.53^{b}	523.40^{b}	1.11^{c}	10.26^{b}
T_3: High density planting with spacing of 0.6m x 0.3m + 1 HW at 25 DAP	770.80^{c}	291.53^{d}	1.10^{c}	5.72^{d}
T_4: Mulching with coconut fronds (2 layers)	609.73^{c}	163.93^{e}	1.23^{ab}	3.21^{e}
T_5 : Mulching with black and silver polythene	1987.27^{a}	858.47^{a}	1.12^{bc}	16.83^{a}
T_6 : Stale seed bed *fb.* glyphosate application + 1 HW at 30 DAP	1218.07^{b}	435.13^{bc}	1.09^{c}	8.53^{bc}
T_7: Hand weeding (25 and 50 days after planting)	1156.00^{b}	402.67^{c}	1.12^{bc}	7.90^{c}
T_8:Unweeded control	286.60^{d}	49.40^{f}	1.26^{a}	0.97^{f}

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

DAP- Days after planting

HW- Hand weeding

Table 18. Correlation coefficients for yield with weed dry matter production, crop growth parameters, and yield attributes

Weed parameters	**Correlation coefficients**
Weed dry weight at 25 DAP	-0.683**
Weed dry weight at 50 DAP	-0.695**
Crop growth parameters	**Correlation coefficients**
Plant height	0.765**
Plant spread	0.961**
No. of non wrapping leaves	0.791**
No. of wrapping leaves	0.649**
Yield attributes	**Correlation coefficients**
Head length	0.946**
Head breadth	0.945**

**Significant at 1% level

Table 19: Effect of treatments on Benefit:Cost ratio

Treatments	Cost of cultivation /ha (lakh Rs)	Income /ha (lakh Rs)	Net returns/ha (lakh Rs)	B : C ratio
T_1: Oxyfluorfen (0.20kg/ha) + 1 HW at 30 DAP	1.889	2.232	0.343	1.18
T_2 : Pendimethalin (1.50kg/ha) + 1 HW at 30 DAP	1.893	3.078	1.185	1.63
T_3: High density planting with spacing of 0.6m x 0.3m + 1 HW at 25 DAP	1.895	1.713	-0.182	0.90
T_4: Mulching with coconut fronds (2 layers)	1.835	0.963	-0.872	0.52
#T_5 : Mulching with black and silver polythene	2.326	5.049	2.722	2.17
T_6 : Stale seed bed *fb.* glyphosate application + 1 HW at 30 DAP	1.907	2.559	0.652	1.34
T_7: Hand weeding (25 and 50 days after planting)	2.007	2.370	0.363	1.18
T_8: Unweeded control	1.283	0.291	-0.992	0.23

*Labour charges (Men- Rs 600/day and women Rs. 450/day)

*Cost of polythene sheet – Rs. 7/m^2

*Cost of herbicides: Pendimethalin Rs.470/L, Oxyfluorfen Rs.589/250ml, Glyphosate Rs. 315/800 ml

*Sale price of cabbage-Rs. 30/kg

DAP- Days after planting

HW- Hand weeding

Plate 2. Oxyfluorfen applied plot (T_1) at 50 DAP

Plate 3. Pendimethalin applied plot (T_2) at 50 DAP

Plate 4. High density planting (T_3) at 50 DAP

Plate 5. Coconut frond mulched plots (T_4) at 50 DAP

Plate 6. Mulching with silver-black polythene sheet (T_5) at 50 DAP

Plate 7. Stale seed bed technique (T_6) at 50 DAP

Plate 8. Hand weeded treatment (T_7) at 50 DAP

Plate 9. Unweeded control (T_8) at 50 DAP

Plate 10. Cabbage head under polythene mulching

Plate 11. Cabbage head under unweeded control

Discussion

5. DISCUSSION

The experiment entitled "Weed management in cabbage" (*Brassica oleracea* var. *capitata* L.) was conducted at the Centre for Hitech Horticulture and Precision farming, Vellanikkara, during 2017-18. The results obtained from the experiment, presented in the previous chapter, are discussed below.

5.1 Studies on weeds

5.1.1 Effect of weed management practices on weed growth

During the crop period, 28 weed species were observed in the field (Appendix 2). Predominant grasses seen in the plots were *Eleusine indica* and *Digitaria ciliaris.* Important broad leaf weeds included *Trianthema portulacastrum, Oldenlandia* sp., *Cleome viscosa, Cleome burmanii, Boerhaavia diffusa, Euphorbia hirta* and they accounted for 78.76 per cent of total weeds in unweeded control (Tables 4, 5 and Fig. 2). *Cyperus iria* was the only sedge found in the experimental area.

No weeds were recorded under black polythene mulching throughout the crop growth period and was the most effective treatment in controlling weeds. Masarirambi *et al.* (2013) also reported that weed infestation was lowest when savoy baby cabbage was grown under plastic mulch.

Application of herbicides limited both weed count and weed dry matter largely. Pre emergence application of pendimethalin at 1.5 kg/ha was more effective than oxyfluorfen (0.2 kg/ha) application. In pre emergence applied treatments (T_1 and T_2) weed count ranged from 12.67 to 26 per m^2 at 25 days after planting. Broad leaf weeds were found to be greater in number than grass weeds in both the treatments. According to Kumar *et al.* (2017) efficacy of pendimethalin and oxyfluorfen was higher against grasses than broad leaf weeds. This also due to the fact that broad leaf weeds dominated the area and contributed much to the weed seed bank which helped in their persistence. However, compared to unweeded control, there was a significant reduction in both grasses and broad leaf weeds due to the herbicidal activity on germinating weed seeds.

The weed dry matter production was also low with pendimethalin (9.8g/m^2) and oxyfluorfen (22.8g/m^2) treatments (Table 6 and Fig. 3). Hand weeded treatment registered higher weed count and dry matter at 25 days after planting since weed count was taken before weeding was carried out on the 25th day. Coconut frond mulching reported a lower weed count and dry matter at 25 days after planting. This may be because of the physical barrier provided by the coconut fronds. However, at 50 days after planting, this treatment registered higher weed density and dry matter. The weeds which germinated and emerged out through the mulch continued to grow and by this time, the coconut fronds had started disintegration. Muhammed (2015) reported higher weed dry matter with coconut frond mulching in okra cultivation at 60 days after sowing.

Similarly, treatment T_3, *i.e.,* high density planting, reported a higher weed dry weight (143.07g/m^2), next only to unweeded control at 25 days after planting, but at 50 days after planting it had a weed dry matter production (37.53g/m^2) which was less than hand weeding (78.4g/m^2), though weed density was the highest. Closer planting might have resulted in plant covering the entire soil surface and shading the germinated weeds, preventing further development. Similar result was obtained by Patel (1995), where closer planting of cabbage at 30cm x 30cm gave a lower weed dry matter than normal spacing. At 50 days after planting, pendimethalin and stale seed bed reported lower weed dry matter of 12g and 13.53g per m^2 respectively. Jung-Lai *et al.* (2014) observed that the weed suppression rate of stale seedbed treatment was 18 to 39 per cent in Chinese cabbage.

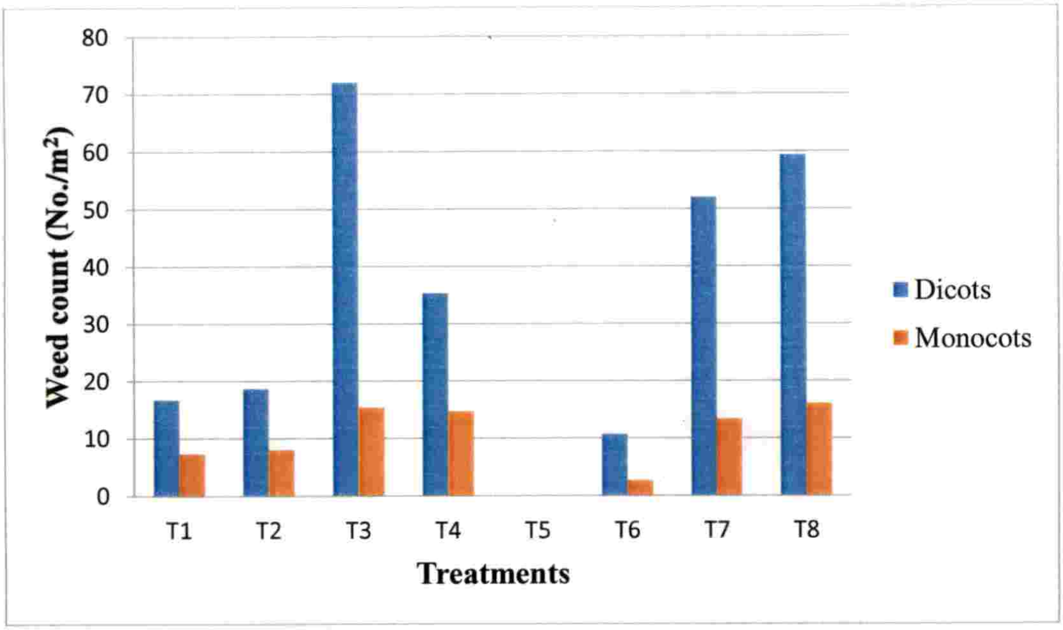


Fig. 2. Effect of treatments on weed count at 50 DAP

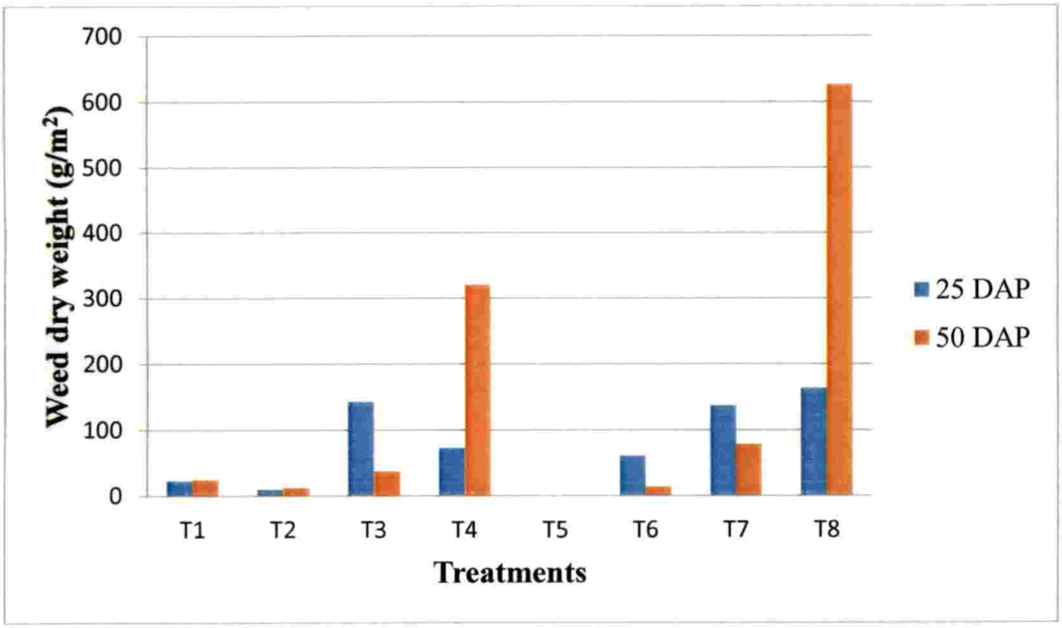


Fig. 3. Effect of treatments on weed dry weight at 25 and 50 DAP

5.1.2 Nutrient removal by weeds

Mulching with black polythene resulted in no weed growth hence there was no nutrient uptake by weeds (Table 7). The nutrient uptake by weeds increased as the weed dry matter production increased with time. Unweeded control which recorded the highest dry matter production showed an increased nutrient removal. Similar results were obtained by Patel (1994) in cabbage who observed higher N, P and K uptake in unweeded control. Mulching with coconut fronds recorded the second highest nutrient removal by weeds, as the weed dry matter was found to be higher in this treatment.

5.2 Weed control efficiency and weed index

Mulching with black polythene resulted in highest weed control efficiency and unweeded control gave the lowest weed control efficiency both at 25 and 50 days after planting. Bana *et al.* (2012) made similar observations while trying different herbicidal and mulching treatments in cauliflower. They reported highest weed control efficiency in black polythene mulching, and weedy check recorded the lowest weed control efficiency.

Application of pre emergence herbicides along with one hand weeding gave higher weed control efficiency of upto 94 per cent at 25 days after planting and upto 98 per cent at 50 days after planting. Pendimethalin gave better efficiency than oxyfluorfen, both at 25 and 50 days after planting. Kumar *et al.* (2015a) observed a weed control efficiency of greater that 90 per cent when pendimethalin was applied along with a hand weeding at 30 days after transplanting or two hand weedings at 30 and 60 days after transplanting in cauliflower. Reis *et al.* (2017) reported effective weed control by pre transplant applied oxyfluorfen both at 15 and 30 days after application in cabbage. High density planting and hand weeding registered higher weed control efficiency at 50 days after transplanting. Patel (1995) observed a higher weed control efficiency of 84.83 per cent in narrow spaced (30cm x 30cm) cabbage crop compared to normal spaced crop, both given a hand weeding at 21 days after transplanting.

Coconut frond mulching could not control weeds effectively and weed control efficiency reduced from 55.52 per cent at 25 DAP to 48.96 per cent at 50 DAP. This was due to the emergence of weeds through the coconut fronds and their profuse growth due to the better soil moisture and addition of organic matter through mulching. Throughout the crop growth period unweeded control registered lowest weed control efficiency as no control measures were adopted.

In case of weed index, it was found that even manual weeding resulted in 53.28 per cent reduction in yield as complete weed control was not possible. Highest weed index of 94.59 per cent was recorded in unweeded control. The second highest was in coconut frond mulching where it was 81.42 per cent. Similar results were obtained by Chathoth (2014) who reported higher weed index values of 83.12 per cent and 64.16 per cent in unweeded and coconut frond mulching respectively under weed management studies in ashgourd. Pre emergence application of pendimethalin and oxyfluorfen resulted in weed index values of 39.52 and 55.77 per cent respectively.

5.3 Effect of weed management practices on soil chemical properties

The initial status was pH 6.56 and after the experiment the pH ranged from 5.95 to 6.45 (Table 10 and Fig. 6). Both before and after the experiment the soil was slightly acidic in all treatments except in treatment T_4, which showed a moderately acidic pH of 5.95. Reduced pH values may be due to the addition of acid forming fertilizers and decomposition of organic residues by microorganisms.

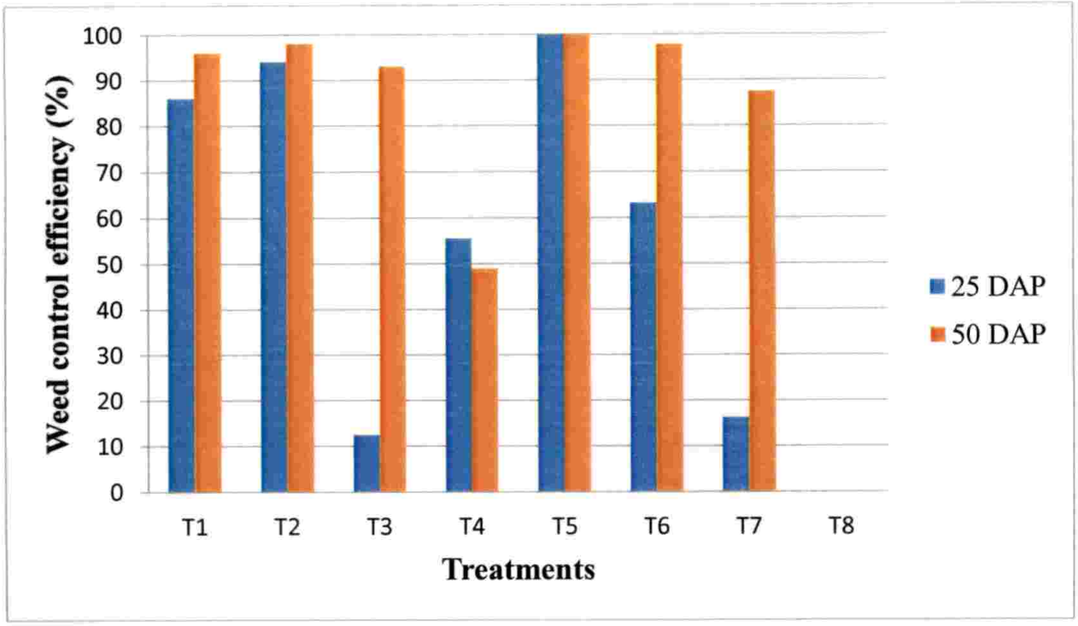


Fig. 4. Effect of treatments on weed control efficiency at 25 and 50 DAP

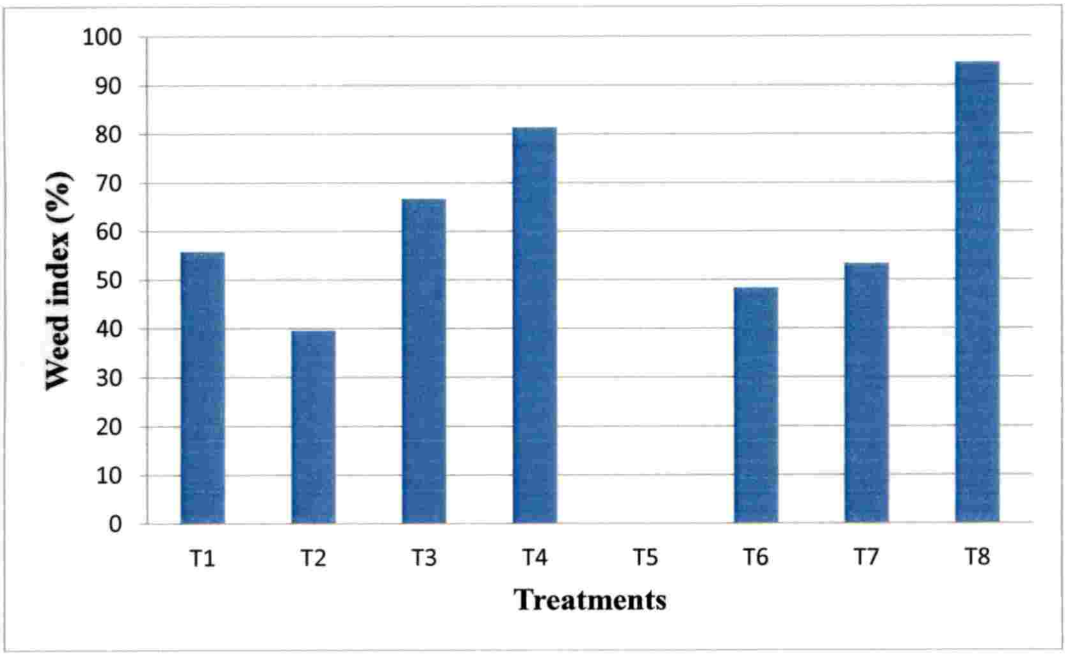


Fig. 5. Effect of treatments on weed index (%)

The soil organic carbon content after the experiment ranged from 0.95 to 1.19 per cent and the pre- experiment content was 1.08 per cent. There was no significant difference in organic carbon per cent before and after the experiment and also between the treatments (Table 10).

Nutrient status of pre experimental soil presented in Table 10 and Fig. 7 indicate low content of available N and high figures for P and K. After the experiment, the available N status of soil increased in all the treatments, except for unweeded control and the available P status of soil increased in all the treatments.

The available K increased in all treatments except for unweeded control (T_8), coconut frond mulching (T_4) and high density planting (T_3). In general, unweeded control recorded lower content of all the major nutrients. This may be because of the higher nutrient removal by weeds. Sekhar (2017) also reported a lower status of available nutrients in unweeded control.

Nutrient content were highest in plots with minimum weed infestation ie under polythene mulching and pendimethalin application, indicating the influence of weed infestation on reduction of soil available nutrients.

Among all the treatments, polythene mulch recorded highest soil content of both available N and P, and second highest available K. This may be because of the absence of weed growth in polythene mulching, which otherwise would have resulted in loss of nutrients by weed uptake. Enhanced mineralization of nutrients under black polythene mulches may be another reason for higher content of nutrients. Lalitha *et al.* (2010) reported that in polythene mulching, mineralization of organic N resulted in high soil mineral N content (NO^{3-} and NH^{4+}) and increased the availability of soil nitrogen. Release of soluble nutrients like NO^{3-}, NH^{4+}, Ca^{2+}, Mg^{2+}, K^+ and fulvic acid to the soil by breakdown of organic material results in increased soil nutrient availability under polythene mulching.

5.4 Effect of treatments on soil microbial load

Initial bacterial, fungal and actinomycetes population in the soil was 114 x 10^5, 40 x 10^3 and 11 x 10^5cfu/g of soil (Table 11). At the time of harvest population of bacteria, fungi and actinomycetes were higher than that before starting of the experiment. This may be due to the continuous supply of water and nutrients throughout the crop growth period by way of fertigation.

The population of bacteria ranged from 129.66 to 146.50 x 10^5cfu/g of soil at harvest. Higher count was observed in coconut frond mulching. Garg *et al.* (2007) observed higher bacterial and fungal populations under mulched treatments compared to unmulched treatment. Mulched soils contain higher moisture content compared to unmulched treatment. Pre emergence herbicide applied plots (T_1 and T_2) also showed higher counts than initial observation. Poddar *et al.* (2017) observed that at 60 days after application of herbicides, 50.49 to 97.57 per cent higher bacterial population was observed in herbicide applied treatments than control.

The fungal population increased towards harvest in all treatments and there was no significant difference in fungal population between the treatments. Fungal population higher than the initial population was found in herbicide treated plots and the fungal count in oxyfluorfen treated plots exceeded the control. Bera and Ghosh (2013) reported that immediately after the application of herbicide, there was a decrease in soil microflora but after their persistence period, the microbial population recovered and sometimes even exceeded the initial count. Kaur *et al.* (2014) observed that herbicides had no detrimental effect on soil health at the recommended doses and microbial populations in the herbicide applied plots were similar to unweeded and hand weeded plots.

Actinomycetes population in soil also showed a similar trend and increased from planting towards harvest. There was no significant difference in actinomycetes

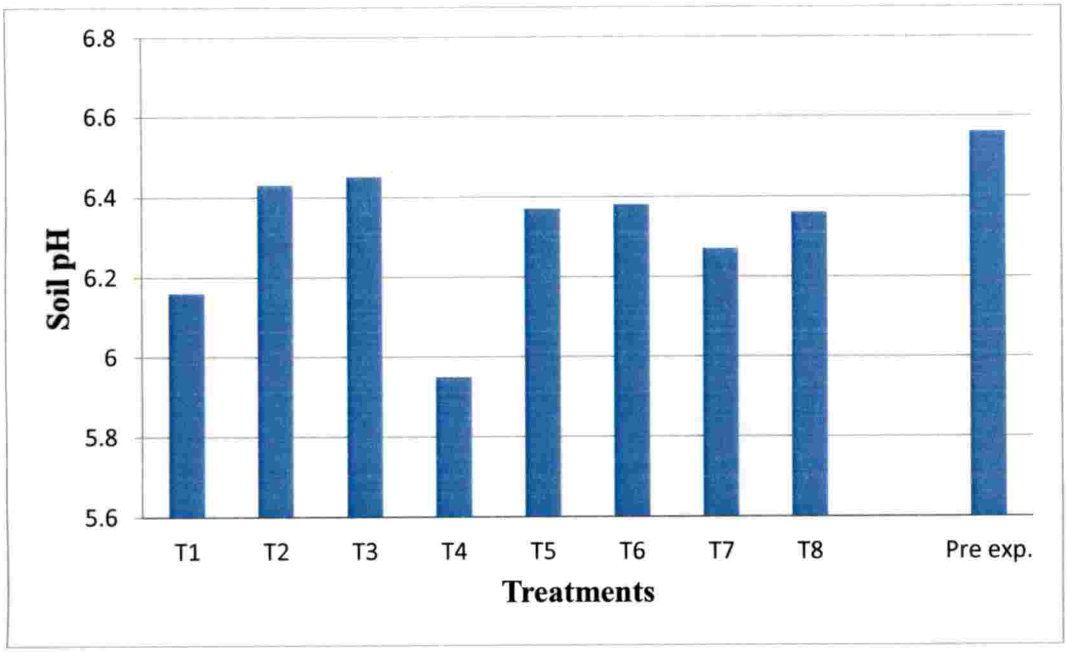


Fig. 6. Effect of treatments on soil pH

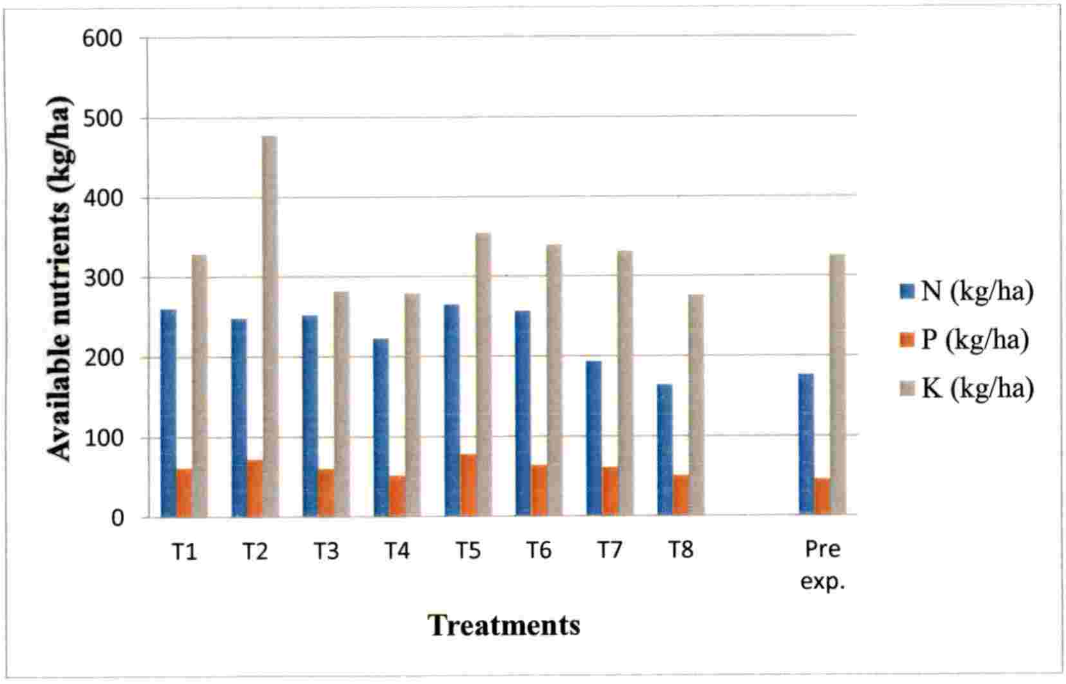


Fig. 7. Effect of treatments on available nutrients in soil

population between the treatments.

5.5 Studies on crop

5.5.1 Effect of weed management practices on crop growth characteristics

The height of cabbage plants ranged from 10.27 to 13.83cm at 30 DAP and 26.26 to 44.66cm at harvest (Table 12 and Fig. 8). At 30 DAP, there was no significant difference in height between treatments. Polythene mulching claimed the highest plants throughout the crop growth period. According to Ferdous *et al.* (2017), cauliflower plants grown under plastic mulch were taller than that without mulch. Height of cauliflower plant was superior in plots where weeds were lower in number since there was no crop-weed competition for light, nutrients, space and moisture (Mal *et al.,* 2005). At 30 DAP, pre emergence application of pendimethalin registered the least height (10.27cm) but at harvest it recorded height (40cm) comparable with polythene mulching. The reduced height might be due to the toxic effect of herbicide on crop, preventing plant cell division and elongation in susceptible species. Unweeded control recorded the least plant height of 26.67cm at harvest. This may be due to the severe competition between weeds and crop. Bana *et al.* (2012) reported similar results in cauliflower where plastic mulching resulted in maximum plant height while weedy check producing minimum.

Plant spread, both at 30 DAP and at harvest was found to be highest in polythene mulched treatment (Table 13 and Fig. 9). Easmin *et al.* (2009) reported similar results. In Chinese cabbage, they observed highest plant spread under black polythene mulching. This might be due to less weed competition and increased moisture content in soil under polythene mulching. At 30 DAP lowest plant spread was reported under pendimethalin treatment but at harvest it recorded a higher plant spread next to polythene mulching. Al-Khatib *et al.* (1995) observed stunting,

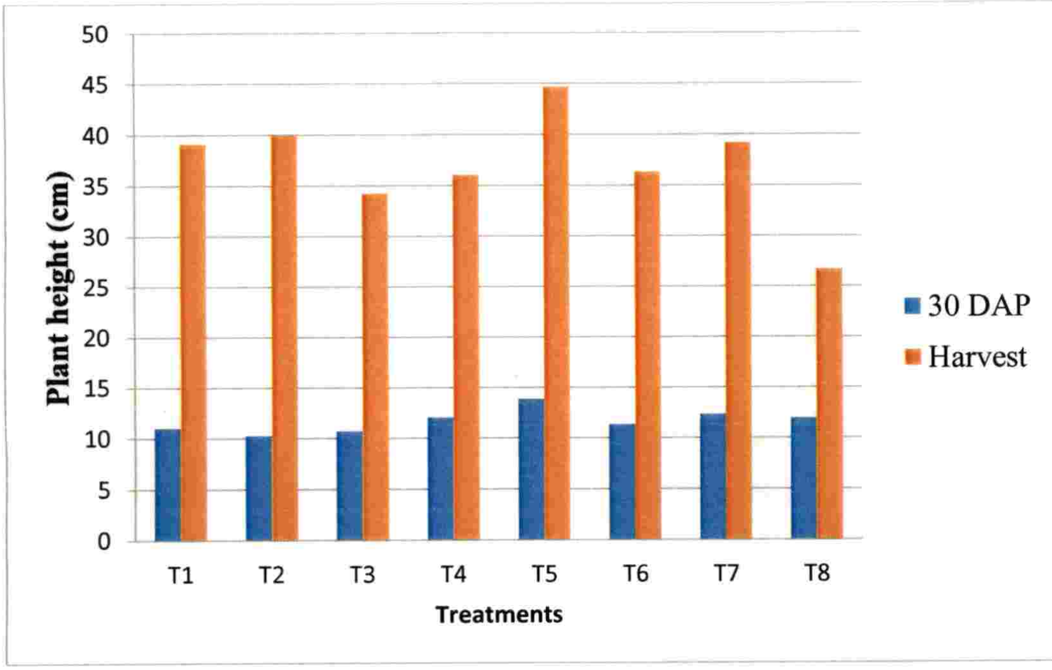


Fig. 8. Effect of treatments on plant height

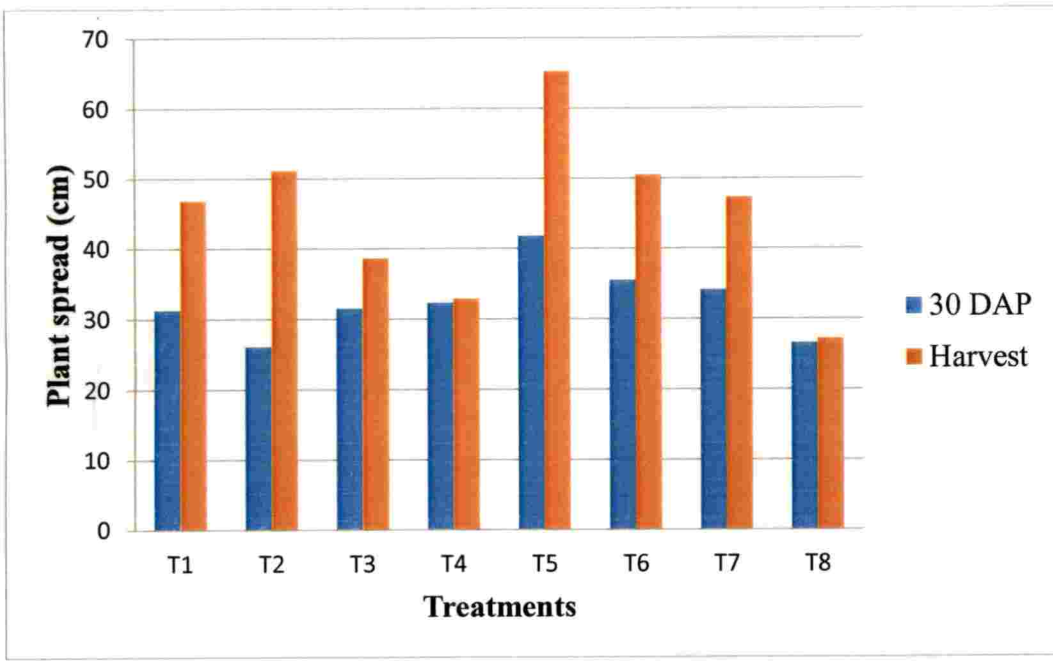


Fig. 9. Effect of treatments on plant spread

downward cupping and crinkling of cabbage leaves due to pendimethalin application during initial stages, from which the plants recovered 100 days after transplanting (DAT). At harvest, lowest plant spread was reported in unweeded control.

The number of non wrapping leaves ranged from 13.47 to 22.60. High density planting (16.00), coconut frond mulching (15.87) and unweeded control (13.47) gave lower number of wrapping leaves, most probably because of the severe weed competition resulting in reduced plant growth. Patel *et al.* (1995) also found lowest number of non wrapping leaves in unweeded control in cabbage.

Higher stalk length (10.60cm) was reported in high density planting as the plants competed with each other for light. The unweeded control recorded lowest stalk length (6.97cm) where the crop was smothered by weeds and growth was severely affected.

5.5.2 Effect of weed management practices on yield parameters

Polythene mulching reported the minimum number of days to attain 50% head formation and maturity and unweeded control the greatest (Table 14 and Fig. 10). Easmin *et al.* (2009) found similar results in Chinese cabbage where no-mulch treatment required more number of days to start head formation (45.37) whereas polythene mulching registered the lowest number. In the present experiment, polythene mulching was followed by the treatment, pre emergence application of pendimethalin and oxyfluorfen, stale seed bed and hand weeding which had comparable values. Within these, application of pendimethalin recorded the least number of days to attain 50 per cent head formation and maturity. Similar results were reported by Bana *et al.* (2012) in cauliflower. They observed that black plastic mulch treated plot recorded least number of days to reach curd initiation and maturity and among the herbicide + hand weeding combinations, the pendimethalin (1.5kg/ha)

+ one hand weeding gave early curd initiation and maturity. Cabbages from all the treatments produced medium compact to compact heads except in unweeded control.

Weed management practices significantly influenced the cabbage yield. Highest values for head length, head breadth, core length, and gross and net head weight were reported in polythene mulching. The increase in yield was 94.59 per cent in polythene mulching as compared to unweeded check (Fig. 11). This is in agreement with observations of Salim *et al.* (2008), who found that plastic mulching increased marketable yield and yield attributes in cauliflower. Plastic mulch helps in suppressing weeds and improving soil properties like soil temperature, bulk density, aggregate stability, moisture content and nutrient availability (Lalitha *et al.*, 2010).

Maida (2014) also reported higher yield attributes and curd yield in cauliflower under polythene mulching. Similar results were reported by Masarirambi *et al.* (2013) in savoy baby cabbage, and Lament (1993) in vegetables. The second best treatment was T_2, *i.e.* application of pendimethalin with one hand weeding at 30 DAP. Unweeded control gave the lowest cabbage yield and yield attributes. Arora *et al.* (2006) observed that among different treatments (hoeing, pendimethalin and pendimethalin + hoeing), highest cabbage yields were obtained from treatment where pendimethalin (1kg/ha) and one hoeing was given and lowest in unweeded control. Patel (1995) and Patel (1994) also reported similar results. Among different chemical treatments, pendimethalin + one hand weeding gave the highest yield in cabbage and the least yield was from unweeded control. Bana *et al.* (2012) reported lower yield of cauliflower under weedy check. Poor yield in weedy check plot may be ascribed to more crop-weed competition. Stale seedbed, hand weeding and oxyfluorfen application recorded comparable values. Coconut frond mulching registered lower yield. Higher weed growth seen in coconut frond mulching may have influenced crop growth adversely and thereby yield. Chathoth (2014) and Muhammed (2015) reported lower yields in ash gourd and okra respectively under coconut frond

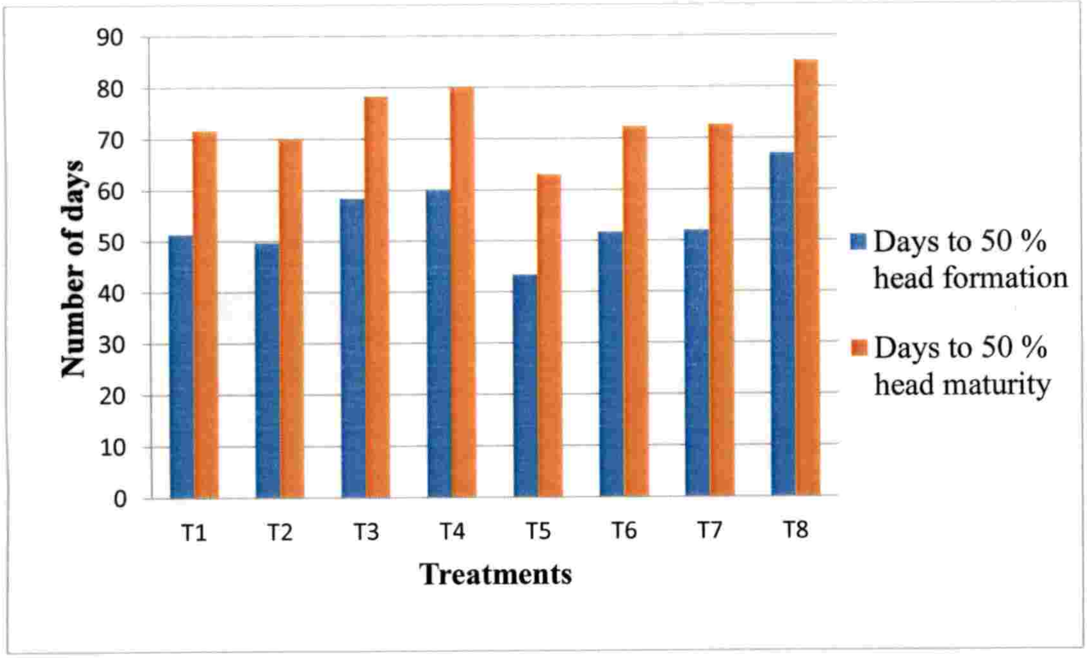


Fig. 10. Effect of treatments on days to 50 % head formation and 50 % head maturity

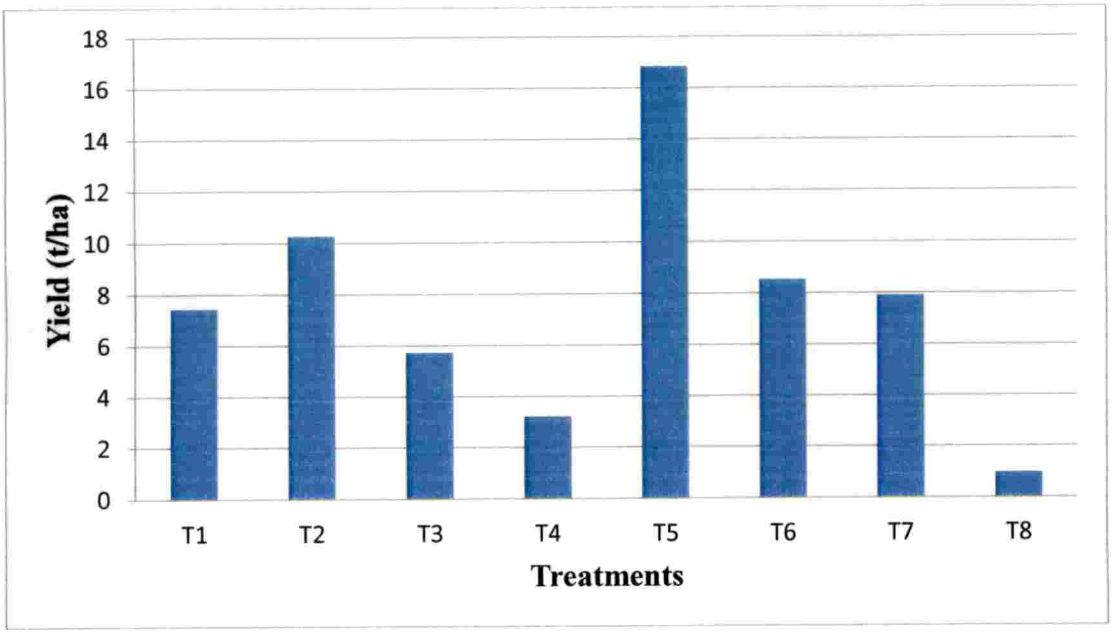


Fig. 11. Effect of treatments on yield

mulching. Treatment T_3 (high density planting) also registered lower yields. Patel (1995) reported lower yields in cabbage planted at a closer spacing of 30cm x 30cm compared to normal spacing when both were given a hand weeding at 21 DAT.

5.6 Correlation studies

Table 18 furnishes the correlation coefficients for yield with weed dry matter production, crop growth parameters and yield attributes. Both at 25 and 50 DAP, the weed dry matter production gave a significant negative correlation with yield. Forty eight per cent of variation in yield can be explained by weed dry matter production at 50 DAP.

As expected, head length and head breadth gave highly significant positive correlation with yield. Similarly plant height, plant spread and number of wrapping and non-wrapper leaves correlated positively with yield. Though higher number of non-wrapper leaves is not a desirable character in cabbage, the number is found to have positive correlation with yield.

5.7 Economics of weed management treatments

The net returns from polythene mulch (T_5) was higher, but the cost required for cultivation was also higher. However it resulted in highest B:C ratio of 2.17 due to the higher yields obtained. Sekhar (2017) also reported a higher B:C ratio in elephant foot yam under polythene mulching though the cost of production was higher under this treatment. Second highest B:C ratio was obtained with pendimethalin treatment (1.63), followed by stale seed bed (T_6) which showed a B:C ratio of 1.34. Even though hand weeding recorded higher yield than oxyfluorfen, both resulted in a B:C ratio of 1.18. This is because of the labor intensive nature of hand weeding which resulted in higher cost of cultivation. Unweeded control gave negative net returns as the yield obtained was very low. It resulted in a B:C ratio of 0.23.

Summary

6. SUMMARY

Cabbage is an important cool season annual vegetable crop belonging to the family Brassicaceae. In Kerala, it is grown in an area of 198 ha (GOK, 2017). Its cultivation was earlier restricted to the hill tracts of Idukki and Wayanad districts. But with the introduction of tropical varieties and hybrids, cultivation of the crop has spread to the plains also. Cabbage requires heavy manuring and frequent irrigations. This creates conducive conditions for germination and growth of weeds, which reduce cabbage yield by 45-80 per cent. Manual weeding is an effective method of weed control in cabbage, but due to the time, labour and cost factors involved, it is not very acceptable. Taking these factors into consideration, the present study was conducted to assess the efficacy of different weed management technologies involving both chemical and non-chemical methods.

The present experiment entitled "Weed management in cabbage (*Brassica oleracea* var. *capitata* L.)" was conducted at Centre for Hi-tech Horticulture and Precision Farming, Vellanikkara during November 2017 to March 2018 using the variety NS 183. The objective of the study was to evolve a weed management package for cabbage suited to the plains of Kerala. The treatments comprised of application of two pre emergence herbicides (oxyfluorfen 0.2kg/ha and pendimethalin 1.5kg/ha) both followed by a hand weeding at 30 DAP, high density planting (0.6m x 0.3m) plus one hand weeding at 25 DAP, two mulching treatments (coconut fronds and silver-black polythene), stale seed bed technique plus one hand weeding at 30 DAP, hand weeding at 25 and 50 DAP and an unweeded control.

Observations on weed density and weed dry matter production were taken at 25 and 50 DAP. Important broad leaf weeds seen in the field were *Trianthema portulacastrum, Oldenlandia* sp., *Cleome viscosa, Cleome burmanii, Boerhaavia diffusa* and *Euphorbia hirta* and they accounted for 78.76 per cent of total weeds in unweeded control. Predominant grasses were *Eleusine indica* and *Digitaria ciliaris.*

Cyperus iria was the only sedge found in the experimental area. No weeds were recorded under black polythene mulching throughout the crop growth period and was the most effective treatment in controlling weeds. Application of pre emergence herbicides limited both weed count and weed dry matter production largely. The weed dry matter production with pendimethalin was only 9.8g/m^{2}and with oxyfluorfen it was 22.8g/m^2. Coconut frond mulching reported a lower weed count and dry matter at 25 days after planting. However, at 50 days after planting, it registered higher weed density and dry matter. Unweeded control which recorded the highest weed dry matter production, registered the highest nutrient removal also. Polythene mulched treatment resulted in 100per cent weed control efficiency. Stale seed bed technique recorded a weed control efficiency of 97.83per cent at 50 DAP. In high density planting, weed control efficiency increased from 12.49 per cent at 25 DAP to 93per cent at 50 DAP as it resulted in plant covering the entire soil surface and shading the germinated weeds, preventing further development. Hand weeded treatment registered a weed control efficiency of 87.43 per cent. Highest weed index of 94.59per cent was recorded in unweeded control. The second highest was in coconut frond mulching where it was 81.42per cent. Pre emergence application of pendimethalin and oxyfluorfen resulted in weed index values of 39.52 and 55.77per cent respectively.

Plant growth parameters were influenced by the different weed management practices. Polythene mulched plots recorded the highest plant height and spread and the lowest duration to 50 per cent head formation and maturity. The number of wrapping and non wrapping leaves were found to be lower in treatments where weed growth was higher. Cabbage head length and breadth were also found to be highest under polythene mulched treatment and lowest in unweeded control. The highest gross (1987.27g) and net (858.47g) head weights were recorded in polythene mulched plots, which were statistically superior to all other treatments. Highest yield of 16.83t/ha was obtained from polythene mulching, followed by pre emergence application of pendimethalin (10.26t/ha). Stale seed bed, hand weeding and oxyfluorfen applied treatments gave comparable yields of 8.53, 7.90 and 7.44t/ha respectively. Unweeded control recorded the lowest cabbage yield and values for yield attributes.

After completion of experiment unweeded control recorded lower content of all the major nutrients (available N, P and K) in soil. Nutrient contents were higher in plots with minimum weed infestation. The population of soil microflora (bacteria, fungi and actinomycetes) increased after experiment as compared to pre experimental period.

Polythene mulching resulted in the highest net return and B:C ratio (2.17). Second highest B:C ratio was obtained with pendimethalin treatment (1.63), followed by stale seed bed which showed a B:C ratio of 1.34. Even though hand weeding recorded higher yield than oxyfluorfen, both resulted in a B:C ratio of 1.18. Unweeded control, coconut frond mulching and high density planting treatments gave negative net returns. Unweeded control resulted in a B:C ratio of 0.23.

From the results, it can be concluded that mulching with silver-black polythene is the best method of weed control in cabbage. Complete control of weeds was possible only with polythene mulching. Pre emergence application of herbicides followed by one hand weeding could not maintain a weed free condition and was not effective to realize a high yield.

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Appendices

Appendix 1. Weekly weather data during experimental period

Std. Week no.	Date	Max.temp (°c)	Min. temp (°c)	Mean RH%	Total rain(mm)	Rainy days	Evaporation (mm)
44	29/10- 4/11	33.5	22.7	70	029.0	2	3.2
45	5/11-11/11	32.3	21.9	73	003.5	1	2.7
46	12/11-18/11	32.8	20.8	75	000.0	0	2.5
47	19/11-25/11	33.8	21.6	73	025.5	2	3.1
48	26/11-2/12	32.0	22.5	71	011.5	2	3.4
49	03/12- 09/12	32.8	21.0	73	000.0	0	2.6
50	10/12-16/12	32.7	21.4	72	000.0	2	2.5
51	17/12-23/12	32.3	21.5	54	000.0	2	5.2
52	24/12-31/12	32.8	20.3	52	000.0	2	5.2
1	01/1- 07/1	33.2	19.8	58	000.0	0	3.8
2	08/1-14/1	32.7	21.8	56	000.0	0	4.6
3	15/1-21/1	33.8	20.7	48	000.0	0	5.2
4	22/1-28/1	34.1	21.4	53	000.0	0	3.8
5	29/1- 04/2	34.3	20.5	37	005.2	1	5.8
6	5/2-11/2	35.3	22.3	59	0.000	0	4.2
7	12/2-18/2	35.3	23.3	51	0.000	0	5.4
8	19/2-25/2	36.3	22.5	42	0.000	0	6.3
9	26/2- 04/3	37.7	23.1	43	000.0	0	6.4
10	5/3-11/3	38.2	23.5	47	013.1	1	5.9
11	12/3-18/3	35.7	24.4	67	020.1	1	4.8
12	19/3-25/3	35.8	24.1	64	000.0	0	4.3

Appendix 2. Species wise composition of weeds during crop growth period

Grass weeds	**Broad leaf weeds**	**Sedges**
Eleusine indica	*Trianthema portulacastrum*	*Cyperus iria*
Digitaria sp.	*Oldenlandia* sp.	
	Cleome burmanii	
	Cleome viscosa	
	Ipomoea sp.	
	Boerhaavia diffusa	
	Sida rhombifolia	
	Phyllanthus sp.	
	Euphorbia hirta	
	Desmodium sp.	
	Commelina diffusa	
	Borreria hispida	
	Sida acuta	
	Melochia corchorifolia	
	Mimosa pudica	
	Mimosa invisa	
	Eclipta alba	
	Eragrostis sp.	
	Sebastiana chamaelea	
	Cyanotis axillaris	
	Alysicarpus vaginalis	
	Emilia sonchifolia	
	Ageratum conyzoides	
	Ludwigia sp.	
	Indigofera sp.	

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WEED MANAGEMENT IN CABBAGE
(*Brassica oleracea* var. *capitata* L.)

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Cabbage is an important cool season annual vegetable crop belonging to the family Brassicaceae. In Kerala, its cultivation was earlier restricted to the hill tracts but with the introduction of tropical varieties and hybrids by the Kerala Agricultural University, cultivation of the crop has spread to the plains also. The heavy manurial and irrigation requirements of the crop create conducive conditions for germination and growth of weeds, which reduce cabbage yield by 45-80 per cent. Manual weeding is an effective method of weed control in cabbage, but due to the time, labour and cost factors involved, it is not very acceptable.

The present experiment entitled "Weed management in cabbage (*Brassica oleracea* var. *capitata* L.)" was conducted at Centre for Hi-tech Horticulture and Precision Farming, Vellanikkara during November 2017 to March 2018 using the variety NS 183. The objective of the study was to evolve a weed management package for cabbage suited to the plains of Kerala. The treatments comprised of application of two pre emergence herbicides (oxyfluorfen 0.2 kg/ha and pendimethalin 1.5 kg/ha) both followed by a hand weeding at 30 DAP, high density planting (0.6m x 0.3m) plus one hand weeding at 25 DAP, two mulching treatments (coconut fronds and silver-black polythene), stale seed bed technique plus one hand weeding at 30 DAP, hand weeding (25 and 50 DAP) and an unweeded control.

Broad leaf weeds were predominant (79%) in the field and the important among them were *Trianthema portulacastrum, Oldenlandia* sp., *Cleome viscosa* and *Cleome burmanii.*Polythene mulching of the field resulted in 100 per cent weed control efficiency. Weed dry matter production and N, P and K removal by weeds were higher in unweeded control, and dry matter production increased from 25DAP to 50DAP. Pre emergence application of pendimethalin at 1.5 kg/ha was more effective than oxyfluorfen at 0.2 kg/ha application (8% more effective at 25 DAP).

Stale seed bed technique recorded a weed control efficiency of 97.83 per cent at 50 DAP and in high density planting weed control efficiency increased from 12.49 per cent at 25 DAP to 93 per cent at 50 DAP. Coconut frond mulching could not control weeds effectively and weed control efficiency reduced from 55.52 per cent at 25 DAP to 48.96 per cent at 50 DAP.

Plant growth parameters were influenced by the different weed management practices. Polythene mulched plots recorded the highest plant height and spread and the lowest duration to 50 per cent head formation and maturity. The highest gross (1987.27g) and net (858.47g) head weights were recorded in polythene mulched plots, which was statistically superior to all other treatments. It was followed by pendimethalin treatment with a net head weight of 523.40g. Highest yield of 16.83t/ha was obtained from polythene mulched plots, followed by pendimethalin applied plots (10.26t/ha). Unweeded control recorded the lowest cabbage yield and values for yield attributes.

Unweeded control recorded lower content of all the major nutrients (available N, P and K) in soil. Nutrient contents were highest in plots with minimum weed infestation. The population of soil microflora (bacteria, fungi and actinomycetes) increased after experiment as compared to pre experimental period, indicating no negative influence of herbicides on soil microbes.

Polythene mulching, even with higher cost of cultivation, resulted in the highest net return and B:C ratio (2.17). Second highest B:C ratio was obtained with pendimethalin treatment (1.63). Coconut frond mulching cannot be recommended as a weed control measure as it was found ineffective in suppressing weed growth. Polythene mulch was found to be the best method of weed control in cabbage.