WEED MANAGEMENT IN CASSAVA

[*Manihot esculenta* Crantz]

By

RESHMA N.

(2014-11-131)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

Master of Science in Agriculture

(Agronomy)

Faculty of Agriculture

Kerala Agricultural University, Thrissur

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COLLEGE OF HORTICULTURE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2016

DECLARATION

I, Reshma, N. (2014-11-131) hereby declare that this thesis entitled **"Weed management in cassava [*Manihot esculenta* Crantz]"** is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"Weed management in cassava [*Manihot esculenta* Crantz]"** is a record of research work done independently by **Reshma N. (2014-11-131)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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ACKNOWLEDGEMENT

First and foremost I bow my head before the **Almighty God** *who enabled me to complete the thesis work successfully.*

With immense pleasure I avail this opportunity to express my deep sense of whole hearted gratitude and indebtedness to my major advisor **Dr. P. V. Sindhu,** *Assistant Professor, Dept. of Agronomy and chairperson of my advisory committee for her expert advice, valuable guidance, practical suggestions, constant patience, inspiring encouragement, friendly approach, kind advice and timely help at various stages of my research work and thesis preparation and will be remembered forever.*

I would like to express my extreme indebtedness and obligation to **Dr. C. George Thomas,** *Professor and Head, Dept. of Agronomy and member of my advisory committee for his meticulous help, expert advice, forbearance, critical evaluation, constant encouragement and support throughout my course of study.*

I sincerely thank **Dr. Meera V. Menon,** *Professor, Department of Agronomy, and member of my advisory committee for her unwavering encouragement, timely support and critical examination of the manuscript that has helped me a lot for the improvement and preparation of the thesis.*

I express my heartiest gratitude to **Dr. K.M. Durga Devi, Professor (SS&AC),** *Department of Soil Science and agriculture chemistry and member of my advisory committee for her ever willing help, valuable guidance and creative suggestions throughout the period of my study.*

I owe my deepest gratitude to **Dr. P. Sreedevi,** *Professor, Former Head, Department of Agronomy for her valuable suggestions, expert advice and support rendered during my work. I sincerely thank to* **Dr. P. S. John,** *Professor, Department of Agronomy for providing his expert advice, precious suggestions and constructive criticism throughout the course of study.*

My heartfelt thanks to my beloved teachers, **Dr. C. T. Abraham, Dr. P. A. Joseph, Dr. K. E. Savithri, Dr. E. K. Lalitha Bhai, Dr. K. E. Usha, Dr. P. Prameela, Dr. A. Latha, Dr. S. Anitha** *and* **Dr. K. P. Pramila** *for their encouragement, valuable help and advice rendered during the course of study.*

I express my gratitude to **Dr. P. K. Sushama** and Dr. **S. Jayasree sankar** for their valuable assistance, help and guidance during the research work.

I truthfully thank, **Dr. C. George Thomas,** Associate Dean, College of Horticulture and **Dr. Maicykutty P Mathew,** Former Associate Dean, College of Horticulture rendering all support and supervision during my study programme.

I am particularly thankful for the heartfelt support and help given by **Dr. Gavas Ragesh,** Assistant Professor BRS, Kannara and **Dr. M. Senthil Kumar,** Assistant Professor, Tapioca and Castor Research station, Salem for arranging herbicide imazethapyr on time.

I take this opportunity to thank **Mrs. Sreela and Mrs. Syamala** for their affection, support and concern. I am extremely thankful to labourers attached to the Department of Agronomy for their co operation during the conduct of research.

It gives me great pleasure in acknowledging the support and help of my dear classmates **Ms. Archana C. R., Ms. Atheena A., Ms. Ancy U. A., Ms. Yansing Luikham, Ms. Rameeza E. M.,** seniors especially **Mrs. Savitha Antony, Mrs. Syama S. Menon, Mr. Faras Bin Muhammed U. P.**., my dear friend **Aditya Mohan** and juniors whose constant help, love and support have helped me a lot to complete this venture successfully.

I thankfully remember the services rendered by all the staff members of **Student's computer club, Library, Office of** COH and **Central library, KAU.** I thankful to **Kerala Agricultural University** for the technical and financial assistance for persuasion of my study and research work.

I extend my heartfelt thanks and gratitude towards my beloved family for their valuable prayers, support, encouragement and help throughout my research work.

I cannot find words to express my genuine heartfelt thanks to the superior power for the unseen support, encouragement, advice and love.

A word of apology to those I have not mentioned in person and a note of thanks to everyone who helped for the successful completion of this endeavor.

RESHMA N.

Dedicated to my parents and loving brother

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Introduction

1. Introduction

Tuber crops play a major role in food security, income generation and sustainable development. As per the report of United Nations Food and Agriculture Organization, cassava is the fourth important food crop after rice, maize and wheat in the developing countries. Cassava, the most important starchy root crop, originated in Brazil, was introduced to India by the Portuguese and the popularization of the crop in the state of Kerala was by Sri Visakham Thirunal Maharaja of Travancore during the latter part of 18^{th} century (Edison *et al.*, 2006). Presently, in India cassava is grown in an area of about 2.28 lakh hectares, with a production of 81.39 lakh tonnes of tubers (GOI, 2015) and in Kerala, it is cultivated in an area of 0.75 lakh ha with a production of 29.44 lakh tonnes (GOK, 2015). Cassava is also known to sustain under sub optimal environmental conditions, which encourages farmers to cultivate it even in marginal areas. It also responds well to irrigation and fertilizers.

Even though cassava is less susceptible to pests and diseases, its slow initial growth and incomplete canopy cover make the plant more liable to weed interferences during the first three to four months after planting. Weeds compete with cassava plants for nutrients, light, space, and water. They also harbour pests and diseases and sometimes physically impair cassava plants and tubers (Melifonwu *et al.*, 2000). Yield reduction in cassava due to uncontrolled weed growth is as high as 65 per cent (Akobundu, 1987). Reduction in tuber yield varies from 40 per cent in early branching cultivars to nearly 70 per cent in late, non branching cultivars (IITA, 1990). Weeds which emerge during the first 90 days after planting offer more competition than those appearing later. The most damaging effects of weeds on tuber yield are noticed when cassava plants suffer weed competition during canopy formation and early tuberization, while the damage is less from the fourth month until harvest (Iyagba, 2010). Therefore, cassava requires effective weed control measures for minimizing crop - weed competition at critical periods in order to obtain optimum yields.

As weed infestation is one of the major problems in cassava growing areas, weeding is the main labour consuming activity (Ravindran and Ravi, 2009). Traditionally, weed control is done by tillage practices followed by earthing up. In order to keep the field weed free, two to three shallow diggings up to 90 days after planting are needed. For this, approximately 200 mandays per hectare are required and 50 to 80 per cent of the total labour forecast of cassava cultivation is accounted by weeding.

Chemical weed control has emerged as the most efficient means of reducing weed competition with minimum labour cost. Prameela *et al.* (2012) reported that as compared to manual weeding, 86 per cent reduction in cost of cultivation could be achieved by the use of pre emergence herbicides. However, most results of herbicide trials in cassava production indicate that follow up tillage activities such as digging and hoeing enhance the effectiveness of pre emergence herbicides. Considering these, an experiment was designed and conducted for developing a cost effective weed management package for cassava integrating chemical, physical and cultural methods. The specific objective of the study was to develop an effective and economic weed management method for cassava.

Review of literature

2. REVIEW OF LITERATURE

Root and tuber crops provide a sizeable portion of world's food demand. They are also a vital source of animal feed and industrial products. On a global basis, approximately 45 per cent of root and tuber crops are consumed as food and the remaining utilized as animal feed or processed to products such as starch, distilled spirits, and other minor products. Cassava is one of the most important root crops grown across a broad range of agro - climatic conditions throughout the world. It is a major source of energy for more than 200 million people (IITA, 1990) and also a good source of starch, proteins, vitamins and minerals. It is widely cultivated by small scale farmers with limited resources in less fertile soils.

Weeds compete with tuber crops for light, soil moisture and nutrients and reduce tuber yields. Yield reduction in cassava due to uncontrolled weed growth is reported to be as high as 65 per cent (Akobundu, 1987). The major reasons for the yield reduction in cassava include slow initial growth rate, wider spacing, and absence of good canopy cover during critical growth periods. Weeding accounts for 50 to 80 per cent of the total labour cost of cassava cultivation. Some of the current weed management practices prevalent are neither sustainable nor economical. Therefore a better weed control practice that can be adopted by small farmers has to be developed.

Weed spectrum in cassava fields

Various kinds of weeds are found in cassava fields and they can be grouped into three main categories, grasses, broadleaf weeds and sedges. Onochie (1975) reported that annual weeds, especially broad leaf weeds, were mostly found in cassava fields. According to Melifonwu (1994), dicot weeds constitute about 71 - 78 per cent of all the weed species in cassava. He also reported that out of the total weed species in cassava 17 - 19 per cent were grasses, and sedges were found to be very less (4 - 7 per cent).

Species composition of weeds in cassava fields vary according to location, time of planting, management and cropping history of the area (Silva *et al.*, 2012).

Doll and Piedrahita (1973) reported that the weeds present in the cassava fields was in the order of their abundance as purple nutsedge, itch grass, morning glory and Johnson grass. Dominance of various weed species was found to vary with place (Ambe *et al.*, 1992; Ravindran and Ravi, 2009). As per the reports of Pinotti *et al.* (2010), Poaceae was the most important weed family in cassava fields. According to Costa *et al.* (2013), weed species belonging to families, Asteraceae and Poaceae were higher in cassava fields. Soares *et al.* (2016) reported the occurrence of weed species belonging to the families, Malvaceae, Asteraceae, Poaceae and Fabaceae in cassava fields.

According to Doll *et al.* (1977) the ten most important weeds found in cassava fields in Colombia are *Pteridium aquilinum, Imperata cylindrica, Sida acuta, Cyperus rotundus, Commelina diffusa, Melinis minutiflora, Ageratum conyzoides* and *Portulaca oleracea.* Sharma and Dairo (1981) recorded *Euphorbia hirta* and *Talinum triangulare* as the most prevalent weeds in cassava fields. *Imperata cylindrica* was a noxious perennial grass which caused more than 90 per cent yield reduction in cassava intercropped with maize (Koch *et al.*, 1990). Silva *et al.* (2013) reported *Bidens pilosa* and *Commelina benghalensis* as the important weeds in cassava growing areas.

Padmapriya *et al.* (2008) noticed a weed flora consisting of *Cynodon dactylon, Cyperus rotundus, Euphorbia hirta, Trianthema portulacastrum* and *Achyranthus aspera* in different cassava intercropping systems. According to Melifonwu *et al.* (2000) broad leaf weeds frequently recorded in cassava farm included siam weed (*Chromolaena odorata*), giant sensitive weed (*Mimosa invisa*), tropical spiderwort (*Commelina benghalensis*), wild poinsettia (*Euphorbia heterophylla*), waterleaf (*Talinum triangulare*), goat weed (*Ageratum conyzoides*) and *Tridax procumbens* and common grass weeds were guinea grass (*Panicum maximum*), spear grass (*Imperata cylindrica*), bermuda grass (*Cynodon dactylon*), and feathery pennisetum (*Pennisetum polystachion*) and *Mariscus alternifolius* and *Cyperus rotundus* were the major sedges.

Prameela *et al.* (2012) reported the infestation of dicot weeds like *Synedrella nodiflora, Mimosa invisa* and *Mollugo distica* and monocots like *Panicum maximum, Pennisetum* spp., *Andropogon* spp. and *Imperata cylindrica* in cassava fields of Kerala. According to Kawooya *et al.* (2016), 83 per cent of weed population in cassava field was composed of *Digitaria abyssinica*, 23 per cent of *Imperata cylindrica*, 50 per cent of *Commelina benghalensis* and 24 per cent of *Panicum maximum.* According to Soares *et al.* (2016), *Panicum maximum* had the highest fresh weed biomass, showing its high competitive ability with crops.

Critical period of crop weed competition in tuber crops

Critical period of weed competition is the shortest time period during the crop growth period wherein weeding gives the highest economic returns. The crop yield obtained by weeding during this period is almost similar to those obtained by the full season's weed free conditions.

Generally, crop plants will be less competitive during their initial growth stage and at this stage, weeds can exploit 30 - 60 per cent of the applied nutrients due to their quick growing habit (Walia and Gill, 1985).

Studies showed that weeds can strongly compete with cassava causing severe yield loss during the early growth stages. Therefore initial growth period is the most important one in cassava to keep the fields weed free and this period would be more prolonged than any annual crop's (Doll and Piedrahita, 1973). The slow growth habit of cassava makes the crop prone to weed competition during the first 2-3 months after planting. According to Carvalho (2000), the degree of crop - weed competition depended on the species, the plant population, and the period in which they are grown together.

According to Onochie (1975), the most damaging effect on tuber yield of cassava occured on early stages of canopy formation and tuberisation but the effect was less from the fourth month until harvest. Doll and Piedrahita (1976), reported that cassava kept weed free for the first two months produced 76 percent yield of fully weed free cassava and that kept weed free for 120 days, 88 percent of the maximum yield. Weeding after 120 days did not increase production (Doll and Piedrahita, 1976). According to them, weeds competing with cassava during the first 6 days reduced the production by 50 percent. For a cassava - maize intercropping system, weed - free period of 8 weeks was needed to avoid the adverse effect of weeds (Melifonwu, 1994). According to Alabi *et al.* (2004), a weed - free period of 35 - 77 days was required for cassava.

Cassava was prone to weed competition during the first 8-12 weeks after planting (Olorunmaiye *et al.*, 2009). Biffe *et al.* (2010b) documented a critical period of 82 days for cassava. According to Prameela *et al.* (2012) first weeding for cassava had to be done at 25 - 30 DAP and the second at 60 DAP. However as stated by Silva *et al.* (2013), the period of competition between cassava plants and weeds was 75 days after the emergence of crop.

Elephant foot yam, another important tuber crop of Kerala was susceptible to weed competition throughout the growth period as it had less canopy coverage. According to Akobundu (1987), yams required a minimum of three weedings during the first 16 weeks after planting. Yams developed maximum leaf area and total dry matter production during the critical period of weed competition which appeared between 3 and 6 MAP (Roy Chowdhury and Ravi, 1994). Nedunchezhiyan *et al.* (2013) reported that the critical period of crop - weed competition in elephant foot yam was between 1 - 5 MAP. A critical weed free period of 60 days was required for proper root development in taro (Nedunchezhiyan, 1995; Nedunchezhiyan and Satapathy, 2003).

In sweet potato the critical period varied from 14 - 28 days (Talatala *et al.*, 1978) to 21-63 days (Kassasian and Seeyave, 1967). According to Nedunchezhiyan (1996), 45 days of weed free period reduced weed dry matter by 80 per cent in sweet potato. In sweet potato, Nedunchezhiyan *et al.* (1998) observed the critical period of weed competition during 30-45 DAP.

Yield loss due to weeds in tuber crops

Weeds were one of the most important constraints in the cultivation of tuber crops. Most of the farmers spent more time, energy and money for effective weed control. Azevedo *et al.* (2000) reported reduction in number of tubers, dry matter and starch content of cassava by the interference of weeds. Agahiu *et al.* (2011) observed reduced canopy development, tuberization, tuber number and tuber weight due to weeds in cassava.

Unchecked weed population caused an average yield reduction of 68 per cent in cassava (Unamma and Ene, 1984). Akobundu (1987) reported a yield reduction of 65 per cent due to profuse weed growth. He reported 40 per cent reduction in tuber yield in short profuse branching cassava and 68 per cent yield reduction in tall non branching cultivar. Reduction in tuber yield varied from 40 per cent in early branching cultivars to nearly 70 per cent in late, non branching cultivars (IITA, 1990).

Alabi *et al.* (2001) reported yield reduction of 85 per cent in cassava. According to Bamidele *et al.* (2004), yield reduction by uncontrolled weed growth in cassava ranged from 40 per cent to total loss. According to Albuquerque *et al.* (2008), root yield reduction could be more than 90 per cent, if weeds were not controlled efficiently. Weeds could cause severe yield loss (50 - 70 per cent) and make the harvesting cumbersome in root and tuber crops (Nedunchezhiyan *et al.*, 2013). According to Soares *et al.* (2016), interference of weeds on cassava tuber yield was higher when the crop was supplied with fertilizers. Weeds reduced the yield by 50 per cent if the fields were left unweeded during critical periods (Prameela *et al.*, 2012).

According to Carvalho *et al.* (1990), Cassava tuber yield would be 10 per cent of those obtained from the hoed plots, where more aggressive weed interference was found. They also reported that shoot growth of cassava plants got reduced by improper weed management practices. According to Albuquerque *et al.* (2008), proliferation of cassava shoots were highly important as they were responsible for the light absorption and supply of assimilates to roots.

Weed competition in potato caused reduction of tuber size and number of tubers per plant (Nelson and Thoreson, 1981). Yield losses in potato might be as high as 40 – 65 per cent or more due to weeds alone depending upon their infestation (Tripathi *et al.*, 1989). In potato, an approximate tuber yield loss of 42 per cent was reported by Jaiswal and Lal (1996). Tomar *et al.* (2008) reported yield reduction of 62 per cent in potato.

A wide variation of yield reduction in sweet potato was reported by Moody and Ezumah (1974). Weed competition in the critical periods could result in yield reduction of 91 per cent in sweet potato (Nedunchezhiyan *et al.*, 2013). Korieocha (2014) reported a yield loss of 45 - 65 per cent for sweet potato in Nigeria.

Besides delaying the cormel initiation process, Nedunchezhiyan *et al.* (1996) reported a decline in cormel numbers in taro. They also reported 60 per cent reduction in the yield of taro due to uncontrolled weed growth throughout the growth period.

Nutrient removal by weeds in tuber crops

A complete weed free cassava was able to utilize all the available nutrients, light and water (Doll and Piedrahita, 1973). Mineral composition and nutrient uptake of weeds were a function of stage of weed growth, length of time of competition between plants, soil fertility, application of fertilizers and herbicides and thermal and moisture conditions during the growing period (Johansen *et al.*, 2005). Negative correlation coefficient of nutrient uptake between weeds and crops was reported by Chaudhari *et al.* (2007).Weeds were found to remove the soil nutrients faster than the crop plants and accumulate in relatively larger amounts (Bhengra *et al.*, 2010). They also reported *Digitaria* spp. as one of the most important phosphorus accumulators with P_2O_5 content of over 3.36 per cent.

Weeds competed for nutrients with the main crop, and removed as high as 94.2 kg N, 17.1 kg P_2O_5 and 91.6 kg K_2O/ha (Prasad and Singh, 1995). According to Singh (2010), minimum nutrient uptake by weeds was recorded with mulching + oxadiazon 0.75 kg/ha at 7 DAPS + one hand weeding at 25 DAP. Pramanick *et al.* (2012) reported that hand weeding at 20 DAP along with mulching caused the minimum nutrient mining by weeds in potato. According to Kour *et al.* (2014) weeds removed significantly higher amounts of N, P and K. They reported highest uptake of nutrients by crops and lowest removal by weeds in a potato-maize intercropping system under weed free condition.

A study on the uptake of trace elements by weeds in potato was conducted by Zarzecka *et al.* (2014). According to them, iron, copper and zinc contents in weeds sampled at the beginning of vegetation significantly depended on cultivation methods, soil tillage methods and crop growing conditions.

Weed management methods in tuber crops

Cultural methods

Cultural weed management referred to all crop husbandry practices like hand weeding, vigorous varieties, mechanical weeding, tillage, mulching, burning, flooding and crop rotation, which are used to suppress the weed interference with crops (Iyagba, 2010).

Hoe weeding was the most common and traditional method of controlling weeds in the tropics and it was the most labour intensive practice of weed control (Melifonwu, 1994). Hand weeding was the age old method of weed management in cassava, which consisted of hand pulling, hand slashing and hoeing (Agahiu *et al.*, 2011). IITA (1990) recommended three hand weedings for cassava at 3, 8 and 12 weeks after planting for successful weed control.

Hoeing at 30 and 60 days after planting was sufficient to control weeds in cassava (Moura, 2000). Soil tillage helped to control weeds by reducing the soil seed bank (Silva and Chabaribery, 2006). However, no till or minimum tillage systems along with the use of cover crops helped to sustain the cassava production and assist weed control (Ostubo *et al.*, 2008). According to Olorunmaiye *et al.* (2009), those plots given hoe weeding had the least grass weed density compared to the unweeded control plots. Hoe weeded plots showed effective weed control up to 6 weeks after planting.

Proper land preparation like ploughing twice or thrice was essential for proper weed control in cassava (Nedunchezhiyan *et al.*, 2013). Korieocha (2014) recommended two or three manual weedings for efficient weed control for cassava in Nigeria. Nedunchezhiyan *et al.* (2015) suggested four hand weedings for cassava for getting higher tuber yield, starch concentration and returns.

Even though hoe weeding was labour intensive, it was economical in small farms (Hahn *et al.*, 1979). For potato, a single hand weeding at 3 weeks after planting was recommended by Akobundu (1987). Korieocha *et al.* (2006) suggested manual weeding at 4, 6 and 8 weeks after planting for effective weed control in sweet potato. According to Iyagba (2010), two weedings were required for cocoyam at 3 and 8 weeks after planting as the plots were prone to weeds during the first three to four months after planting.

Weeds in taro could be controlled by mulching with paddy straw (Singh *et al.*, 2003). Water hyacinth mulching along with application of oxadiazon (0.75 kg/ha) at one week after planting was the most effective method for weed control upto 30 days of planting in potato (Singh, 2010).

Intercropping

Intercropping systems offered greater yield stability than sole cropping systems (Baker, 1980). According to Melifonwu (1994), for intercropping systems, compatible crop mixtures, optimum plant population and spatial arrangements were to be used in order to minimize the inter-plant competition and for achieving good ground cover. According to him, it was important to choose the legume covers which would not compete with cassava for resources. The use of intercrops and green manures resulted in more additional income, better soil cover, organic matter distribution and nutrient input, apart from weed control (Devide *et al.*, 2009).

Growing smother crops such as beans, cowpea, maize, groundnut and melon were effective in weed control in cassava (Leihner, 1980). According to Ashokan *et al.* (1981), cowpea and blackgram were most effective in smothering weeds in cassava. Inclusion of slow growing smother crops such as groundnut, cowpea or melon resulted in 16 - 40 per cent reduction in weeds of cassava (Zoufa *et al.*, 1992). Growing smother crops like groundnut or cowpea in cassava - maize intercropping system was effective in controlling weeds (Abate, 1992). Weed suppressing effect of legumes during the initial growth stages of cassava resulted in significant yield increase compared to sole cassava (Mutsaers *et al.*, 1993).

Okeleye and Salawu (1999) recommended melon as an intercrop in cassava fields for effective control of weeds. Aits (2006) recommended the use of legumes as intercrops in cassava for suppressing weed growth. Padmapriya *et al.* (2008) reported higher weed control efficiency for cassava - cowpea intercropping system. Silva *et al.* (2009) suggested the use of pigeon pea (*Cajanus cajan*), sunflower (*Helianthus annuus*) and cowpea (*Vigna unguiculata*) as potential intercrops in cassava. Intercropping in cassava had the potential to supply year round ground cover and is an important tool for weed management in small holdings (Agahiu *et al.*, 2011). Prameela *et al.* (2012) recommended intercropping of legumes with cassava for getting good weed control with a saving of 61 per cent over hand weeding.

Polthanee *et al.* (1998) reported that cassava tuber yield and yield components were directly influenced by intercropping. As per Polthanee and Kotchasatit (1999) land use efficiency increased by 66–97 per cent for cassava - mungbean intercropping system compared with sole cropping. Kurtz (2006) reported higher yield in cassava when intercropped with legumes than sole cropping. Hoeing followed with mucuna in cassava gave root yields 53 – 85 per cent higher than fallow (Aflakpui and Grace, 2007). Osundare (2007) reported increased tuber yield for cassava when intercropped with cowpea, groundnut, pigeon pea and soybean.

Intercropping cassava with cowpea increased plant height and growth attributes of cassava as nitrogen was fixed from the atmosphere through microbial symbiosis (Padmapriya *et al.*, 2008). They also reported increased dry matter production, plant height, tuber length, tuber weight and tuber circumference for cassava intercropped with vegetable cowpea. Cassava cowpea intercropping increased the land use efficiency by 72-76 per cent over sole cropping and this system gave higher net returns over sole cropping (Polthanee *et al.*, 2001). Hidoto and Loha

(2013) suggested intercropping cassava with legumes for getting additional crop yield during early cassava growth stage.

Mason *et al.* (1986) reported reduction in tuber yields of cassava when intercropped with cowpea and peanut. They reported that even though cassava - cowpea and cassava - peanut intercropping system reduced the yield of components crops, it resulted in 15 to 35 per cent greater land use efficiency. Olasantan (1988) reported reduction in tuber yield of cassava by 40 per cent when intercropped with maize or cowpea over sole cropping. According to him, an increased yield of cassava:cowpea were obtained at 2:2 row arrangement without much reduction in cassava tuber yield. Okoli (1996) reported reduced number of cassava tubers and dry matter yield by intercropping. The reduction in tuber yield of cassava was due to the competition of component crops for light, water and nutrients (Polthanee *et al.*, 2001). Hidoto and Loha (2013) reported that cassava tuber yield was higher when intercropped with haricot bean. According to them, intercropping in cassava with cowpea reduced the cassava yield by 27 per cent, but the land use efficiency was increased by 49 per cent.

Cassava - legume intercropping system enhanced the overall soil fertility by the incorporation of crop residues in the soil (Polthanee *et al.*, 2001). According to Amanullah *et al.* (2007), the amount of available soil nutrients was higher in plots where cassava was intercropped with legumes. Intercropping cassava with cowpea, groundnut, soybean and pigeon pea increased the organic carbon content of soil, while sole crop of cassava decreased the soil organic carbon by 24 per cent (Osundare, 2007). He also reported a decrease in N content by 33 per cent and available P by 8 per cent by sole cropping of cassava.

Chemical weed management

Traditionally, weed control is achieved by tillage practices followed by earthing up. However, manual weeding was very costly due to high labour charges in many of the places. Traditional manual weeding was also found to be time consuming and might also cause root injury (Khurana *et al.*, 1993). Therefore chemical weeding using selective pre emergence or post-emergence herbicides was the most promising alternative method. According to Melifonwu (1994), the effectiveness of applied herbicides would depend on the factors like type of weed flora, rate of herbicides applied, crop variety and management practices. Chikoye *et al.* (2002) also showed that chemical control in cassava was much cheaper than hoe weeding.

In the tropics, the use of herbicides by small farmers was limited by high cost and availability (Ravindran *et al.*, 2010). Herbicides also reduced the quality of produce (Nedunchezhiyan *et al.*, 2011).

Pre emergence herbicides

Doll and Piedrahita (1976) recommended the use of pre emergence application of diuron along with alachlor for controlling weeds of cassava. Tongglum and Leihner (1983) observed the highest weed control efficiency for oxyfluorfen at 1.0 kg /ha in cassava. Padmapriya *et al.* (2008) reported the pre emergence herbicide fluchloralin to be effective for controlling grasses, sedges and broadleaved weeds in cassava, and it reduced the weed density.

Gutierrez *et al.* (2008) reported that application of oxyfluorfen at 840g/ha gave 99.4 per cent weed control in cassava. Pre emergence herbicides did not cause any phytoxicity effects to cassava plants as the action of pre emergence herbicide was only on the germinating seeds (Prameela *et al.*, 2012). They reported the lowest cost for weed control in the application of diuron and oxyfluorfen, which accounted for about 15 per cent of the cost of hand weeding. Labour shortage could be effectively managed by the application of pre emergence oxyfluorfen at 0.06 kg/ha along with two hand weedings at 2 and 3 MAP (Nedunchezhiyan *et al.*, 2015).

A combined use of atrazine and metolaclor at the rate of 2 - 3 kg/ha gave significant tuber yield in cassava (IITA, 1990). Alabi *et al.* (1999) also reported higher cassava tuber yield for the combination of atrazine and metolaclor at the rate of 2.0 kg/ha. Oliveira *et al.* (2001) suggested pre emergence herbicides like acetolachlor, alachlor, flumioxazin, metolachlor and trifluralin for weed control in cassava. The herbicide diuron was effective in controlling many grass and broad leaf weeds in cassava (Biffe *et al.*, 2010a). The use of pre emergence herbicides atrazine and metolachlor by farmers was reported by Agahiu *et al.* (2011)

The longest and heaviest tuber per plant and the highest tuber yield was obtained with the herbicide primextra at the rate of 2.0 kg /ha (Enyong *et al.*, 2013). They also recorded taller plants and high leaf area index for this treatment. Pre emergence application of oxadiazon or pendimethalin could be adopted for cassava intercropped with onion (Nedunchezhiyan *et al.*, 2013).

Bhaumik *et al.* (1988) observed that the pre emergence herbicides fluchloralin, pendimethalin and oxyfluorfen were effective in controlling weeds in elephant foot yam fields. Nedunchezhiyan *et al.* (2013) reported that pre emergence herbicides like oxyfluorfen and pendimethalin could be successfully employed for weed suppression in yam as the crop took 15 - 20 days for emergence. Application of pre emergence herbicides like atrazine at 1.5-3.0 kg/ha, diuron at 2.0-3.0 kg/ha, alachlor and metalachlor at 2.0-3.0 kg/ha for effective weed control in yam was reported by Korieocha (2014).

Pre emergence application of isoproturon at 1 kg /ha effectively controlled the weeds in sweet potato (Nedunchezhiyan and Satapathy, 2002). Korieocha (2014) suggested the use of pre emergence herbicides like atrazine/metolachlor at 1.5 kg /ha for weed management in sweet potato.

Kour *et al.* (2014) also reported that the pre emergence atrazine 0.5 kg /ha was effective in supressing weeds in maize - potato intercropping system. They also recorded the lowest value of N, P and K uptake when atrazine (0.5 kg/ha) was applied pre emergence followed by pre emergence alachlor (1.5 kg/ha). According to Bera *et al.* (2015), pre emergence application of oxyfluorfen 23.5 EC at 100, 200, 300, 400 g /ha and pre plant application of pendimethalin at1500 g/ha recorded higher tuber yield and oxyfluorfen 23.5 EC at 400 g/ha resulted in the highest weed control efficiency in potato. Pendimethalin at 1.0 kg/ha, prometryne at 1.0 kg/ha and metribuzin at 0.5 kg/ha could be effectively used to control weeds in potato (Tomar *et al.*, 2008).

Nedunchezhiyan *et al.* (2002) reported that weeds in taro could be effectively controlled by pre emergence isoproturon at 1 kg /ha.

Post- emergence herbicides

Post-emergence herbicides are used to kill the actively growing weeds that have already emerged from the soil. Post-emergence herbicide application followed by one hand weeding was successful for weed control in cassava (Doll and Piedrahita, 1976). According to Iyagba and Ayeni (2000) siam weed and guinea grass in cassava could be controlled by the post-emergence application of fluazifop-butyl (0.75 kg/ha) followed by bentazon (2.0 kg/ha). Aflakpui *et al.* (2007) reported that post-emergence glyphosate when applied alone decreased the density of spear grass to 50 per cent in cassava fields.

Higher tuber yield was observed when cassava was grown on plots sprayed with glyphosate or planted with mucuna (Aflakpui *et al.*, 2007). They also reported that cassava plants sprayed with glyphosate alone were 45 - 67 per cent taller than those in fallow plots and the residual effect of glyphosate alone resulted in shoot dry matter 127 - 166 per cent greater than that of fallow plots. Post-emergence application of glyphosate at 1.8-3.6 kg/ha could effectively control weeds in cassava (Korieocha, 2014).

Oliveira *et al.* (2001) suggested the use of post-emergence herbicide mixtures ametryn + clomazone and ametryn + diuron for the control of weeds like *Commelina benghalensis, Bidens pilosa, Sida rhombifolia* and *Raphanus sativus*.

Application of glyphosate along with one hand weeding resulted in maximum corm yield in yam (CTCRI, 2004). Aflakpui *et al.* (2007) reported that the carry over effect of glyphosate alone resulted in 12 per cent increase in tuber yield of yam over fallow plots. Silva *et al.* (2009) suggested the use of glyphosate for post-emergence application in cassava. Application of glyphosate at 2 kg/ha caused the death of weeds and acted as a mulch in elephant foot yam (Nedunchezhiyan *et al.*, 2013).

Integrated weed management

Akobundu (1980) reported the integrated use of cowpea and pre emergence application of alachlor or fluometuron for controlling weeds in cassava. Olorunmaiye *et al.* (2009) reported that pre emergence herbicide treatments would not contribute season long weed control in the absence of hoe weeding because of their short persistence. They suggested supplementation of pre emergence herbicides along with two hoe weedings for effective weed control in cassava. As a cultural method, Melifonwu (1994) suggested the use of improved early branching vigorous cassava cultivars than late non branching traditional varieties for improved weed control. According to him, a combination of weed control methods like intercropping, low growing smother crops, hoe weeding combined with the use of herbicides would give good results.

Post-emergence herbicide application followed by one hand weeding was an effective weed control strategy in cassava (Doll and Piedrahita, 1976). Integrated weed management was the best for effective weed management in cassava (Silva *et al.*, 2012). They suggested the combination of intercropping and no till practices along with chemical methods for successful weed management in cassava. According to Nedunchezhiyan *et al.* (2015) weeds in cassava could be effectively managed by two hand weedings at 1 and 2 MAP followed by post-emergence application of glyphosate at 2.0 kg/ha at 3 MAP.

Economics of weed management

According to Peressin and Carvalho (2002) out of the total of cost of production of cassava, 40 per cent was represented by the weed control measures. However, according to Silva and Chabaribery (2006), 25.7 per cent of total operating cost was accounted for the mechanical and manual weeding for cassava. According to Olorunmaiye (2011), cassava intercropping systems had higher variable costs. The production cost for cassava would increase by the adoption of inappropriate weed management practices (Silva *et al.*, 2012).

Simultaneous cropping of food crop along with cover crops had good potential for reducing the cost of weed control (Chikoye *et al.*, 2000). A lower benefit cost ratio of 1.58 was recorded for pure cropping of cassava with three hand weedings (Padmapriya *et al.*, 2008). They reported the highest B:C ratio for growing vegetable cowpea combined with pre emergence fluchloralin at 0.75 kg/ha + hand weeding at four weeks after planting. Odoemenem and Otanwa (2011) reported negative influence of labour charges on the profit of cassava cultivation. Toluwase and Abdu-raheem (2013) recorded benefit cost ratio of 1:2.19 for cassava production. Afreen and Haque (2014) reported B: C ratio of 2.49 for the traditionally cultivated cassava in Bangladesh. Nedunchezhiyan *et al.* (2015) recorded benefit - cost ratios of 3.01 for the post-emergence application of glyphosate at 2.0 kg/ha, 2.89 for the pre emergence application of oxyfluorfen at 0.06 kg /ha and 2.64 for the pre emergence application of oxyfluorfen at 0.06 kg /ha followed by hand weeding.Quee *et al.* (2016) reported high cost of production for hoe weeding in cassava compared to the other weed control methods. They also reported that the pre emergence terbulor 500 EC with two supplementary hoe weedings was more economical and profitable than other treatments.

From the review of literature, it is clear that cassava, being a widely spaced crop with slow initial growth, is seriously affected by various kinds of weeds and yield losses goes up to 90 per cent. Since weeding is the main labour consuming activity of cassava developing an integrated weed management package is essential to achieve optimum yield with high benefit cost ratio.

Materials & Methods

3. MATERIALS AND METHODS

The present study titled "Weed management in cassava (*Manihot esculenta* Crantz)" was carried out at the Agronomy Farm attached to the Department of Agronomy, College of Horticulture, Vellanikkara from May to October 2015. The materials used and methods adopted for the study are described here.

3.1 General details

Location

The experiment was carried out at the Agronomy Farm, College of Horticulture, Vellanikkara, Thrissur, Kerala. Geographically the field is situated at 13° 32' N latitude and 76° 26' E longitude, at an altitude of 40 m above mean sea level.

Climate and weather conditions

The area enjoys typical humid tropical climate. The maximum temperature ranged from 27.9 to 33.3°C. The total rainfall during the entire crop period was 3966 mm and the total number of rainy days was 92. Mean relative humidity ranged from 79 to 94 per cent. The mean weekly averages of important meteorological parameters observed during the field experiment are given in Appendix 1 and Figure 1.

Soil

The soil was sandy clay loam in texture and acidic in reaction with a pH of 4.5. The physico-chemical properties are presented in Table1.

Season

The experiment was conducted from May to October 2015.

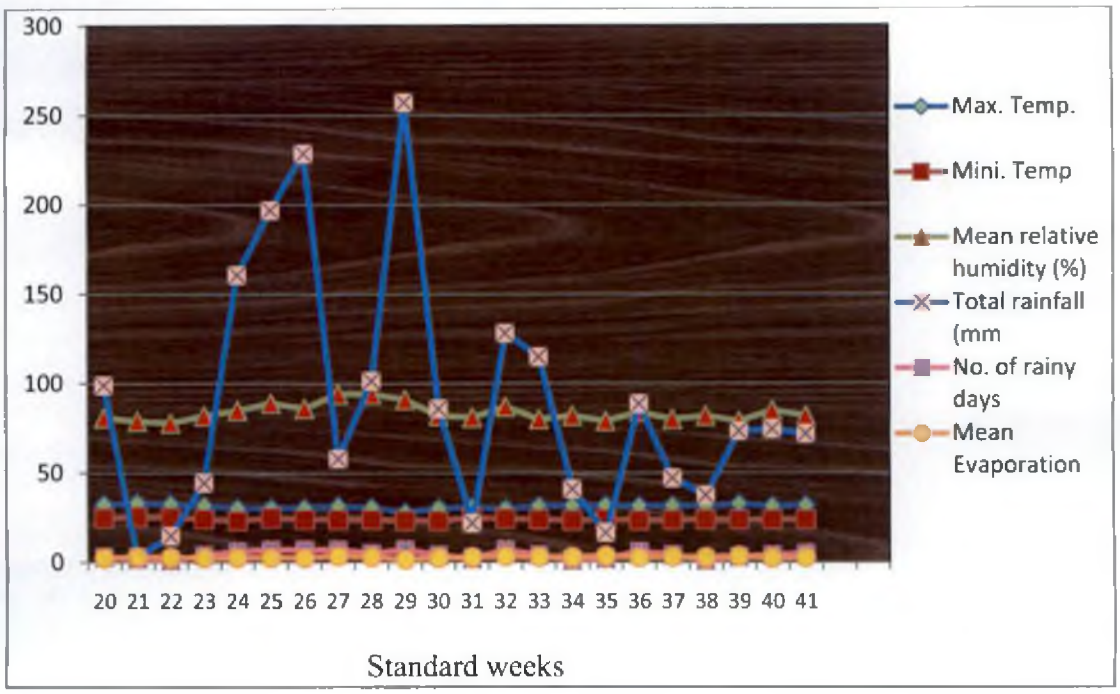


Fig. 1. Meteorological data for the experimental period

(From 15-05-2015 to 15-10-2015)

Table 1. Physico-chemical properties of soil

Particulars	Content	Method used
1. Physical properties and particle size composition		
Coarse sand (%)	31.90	Robinson international pipette method (Piper, 1942)
Fine sand (%)	27.30	
Silt (%)	18.64	
Clay (%)	22.16	
Soil type	Sandy clay loam	
2. Chemical properties		
pH	4.5	1:2.5 soil water ratio (Jackson, 1958)
Organic carbon (%)	0.70	Walkley and Black method (Jackson, 1958)
Available N (kg/ha)	190.6	Alkaline permanganate method (Subbiah and Asija, 1956)
Available P (kg/ha)	27.2	Ascorbic acid reduced molybdo phosphoric blue colour method (Bray and Kurtz, 1945; Watanabe and Olsen, 1965)
Available K(kg/ha)	312	Neutral normal ammonium acetate extractant using flame photometry (Jackson, 1958)

Crop and variety

The short duration variety (155 - 180 days) of cassava, "Vellayani Hraswa" was used for the experiment. The plants are dwarf with good branching characteristics. The tubers are reddish brown in colour with good cooking quality.

Cropping history of the experimental site

The experimental area was under hybrid napier cultivation for the last five years.

3.2 Experimental details

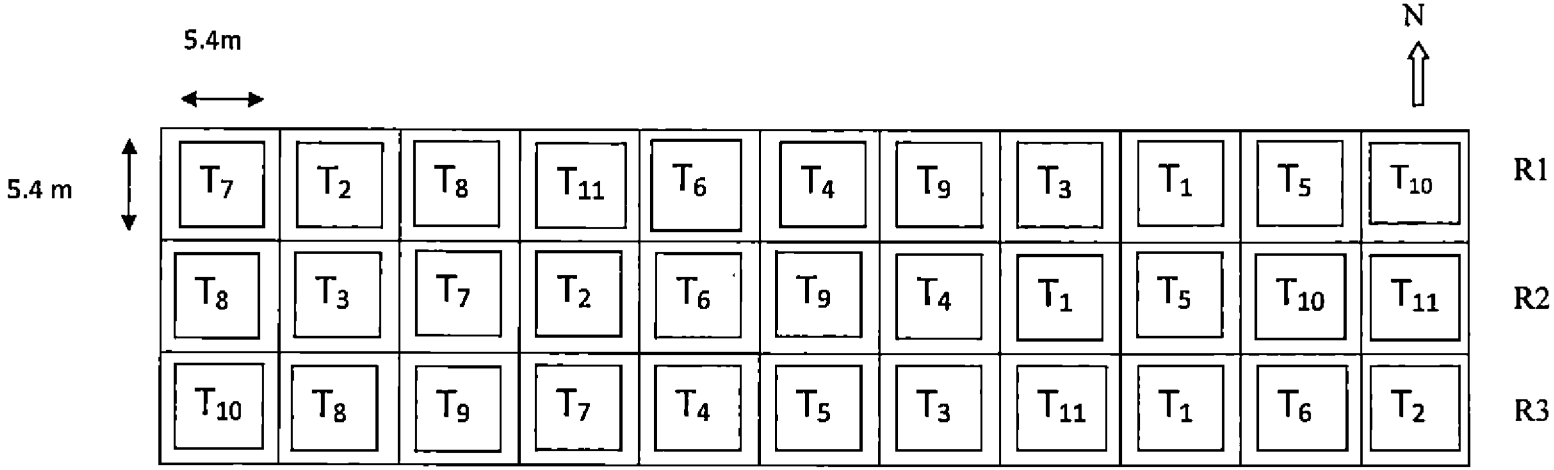
The experiment was conducted from May to October 2015. The experiment was laid out in Randomized Block Design (RBD) with 11 treatments and 3 replications. The plot size was 5.4 m x 5.4 m and the spacing adopted was 90 cm x 90 cm. The treatment details are given in Table 2.

Table 2. Details of the treatments in the experiment

Treatments	
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)
T_2	Pendimethalin 1.5 kg/ha (pre emergence)
T_3	Imazethapyr 80 g/ha (pre emergence)
T_4	Glyphosate 0.8 kg/ha [directed application at 30 days after planting (DAP)]
T_5	Oxyfluorfen 0.2 kg/ha (pre emergence) followed by hoeing and earthing up at 60 DAP
T_6	Pendimethalin 1.5 kg/ha (pre emergence) followed by hoeing and earthing up at 60 DAP
T_7	Imazethapyr 80g/ha (pre emergence) followed by hoeing and earthing up at 60 DAP
T_8	Glyphosate 0.8 kg/ha (directed application at 30 DAP) followed by hoeing and earthing up at 60 DAP
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP
T_{10}	Hoeing and earthing up at 30 and 60 DAP
T_{11}	Unweeded control

Lay out

Fig. 2. Lay out of the experimental field



Land preparation and planting

The land was ploughed thoroughly with disc plough and worked with cultivator to produce fine tilth. Gross plot size was 5.4 X 5.4 m^2 and the net plot size was 3.6 X 3.6 m^2. Mounds were taken at a distance of 90 cm x 90 cm. Stem cuttings of cassava cultivar 'Vellayani Hraswa' were collected from the College of Agriculture, Vellayani. Setts of 15 cm length and three nodes were planted in the centre of the mounds during the third week of May 2015.

Manures and Fertilizers

Manures and fertilizers were applied as per the package of practices recommendations (KAU, 2011). Farmyard manure at 12 t/ha was basally applied during land preparation. Fertilizer nutrients N: P_2O_5:K_2O at100:100:100 kg/ha were applied in the form of urea, rajphos and MOP in three equal splits at land preparation, and two and three months after planting.

Irrigation

Irrigation was given with hose from the tap point by sprinkling on the mounds with 25 mm water at an interval of 15 days after planting until the establishment of the crop.

Plant protection

Termite attacks were a problem, and for control chlorpyifos at the rate of 700 ml/ha was sprayed on the soil near the base of the crop during 30 days after planting.

Weed management

Weed management was done as per treatments. Pre emergence spraying of oxyfluorfen at 0.2 kg/ha, pendimethalin at 1.5 kg/ha and imazethapyr at 80g/ha were done on the second day after planting using a knapsack sprayer fitted with flat fan nozzle, using spray fluid of 300 l/ ha. Sowing of cowpea seeds was done at 3 DAP and the green matter were incorporated into soil at 60 DAP. Directed application of glyphosate at 0.8 kg/ha was done at 30 DAP. Hoeing and earthing up were done two times at 30 and 60 DAP.

Harvesting

Tubers were harvested after five months of planting (MAP) when the lower leaves started to turn yellow. Harvesting was done manually by uprooting the plant and then removing tubers from the base. The upper parts of stems with leaves were cut and removed before harvest.

3.3 Observations recorded:

3.3.1. Plant characters

The following observations were recorded

1. Plant height at 30 DAP, 60 DAP and at harvest (cm)
2. No. of tubers per plant
3. Length of tuber (cm)

   Length of tuber was taken from the base to the tip.

4. Girth of tuber (cm)

Girth of tuber was taken by measuring the circumference at the broadest part of the tuber

5. Tuber yield (kg/plant)

6. Top yield at harvest (kg/plant)

Top yield was recorded by taking the weight from base including stems, leaves and other above ground parts.

7. Dry matter production at harvest

Dry matter production was calculated by summing the tuber yield and top yield in dry weight basis.

Ten plants per plot were selected for recording biometric observations. Tuber yield from each plot were weighed separately and the total yield (kg/ha) was worked out.

3.3.2. Observations on weeds

Weed count

Weeds were separated into grasses, sedges and broad leaf and counted from the plots using a quadrat of size 0.25 m^2 (50 cm x 50 cm). The quadrat was placed randomly and observations were taken from each plot at 30 DAP, 60 DAP, 90 DAP and at harvest. Weed count was expressed as number/m^2.

Weed dry weight

Weeds collected from each plot were uprooted, cleaned, air dried and oven dried at 80 ± 5°C and dry weights of grasses, sedges and broad leaf weeds were recorded in g/m^2 at 30 DAP, 60 DAP, 90 DAP and at harvest.

Weed control efficiency (WCE)

Weed control efficiency expresses the efficiency of applied herbicides in reducing the weed population. It was worked out using the formula suggested by Mani *et al.* (1973).

$$WCE = \frac{\text{Weed dry weight in unweeded plot} - \text{weed dry weight in treated plot}}{\text{Weed dry weight in unweeded plot}} \text{X100}$$

Weed index (WI)

Weed index is defined as the reduction in yield due to the presence of weeds in comparison with weed free plot. It was worked out using the formula suggested by Gill and Vijayakumar (1969).

$$WI = \frac{\text{Yield from weed free plot} - \text{Yield from treated plot}}{\text{Yield from weed free plot}} \text{X 100}$$

In this experiment, the highest yield was obtained from the plots weeded by hoeing and earthing up at 30 DAP and 60 DAP. Therefore the yield from this treatment was taken as the yield from weed free plot.

3.3.3. Chemical analysis

Soil

Initial and final pH and contents of major nutrients in soil were estimated. The collected soil samples were dried, powdered and passed through 2 mm sieve for analyzing the major nutrients viz., available N, available P and available K using standard procedures detailed in Table 1. For analyzing the status of organic carbon soil samples were passed through 0.5 mm sieve.

Weed

Weed samples were analyzed to find out the contents of N, P and K using standard procedures. Nutrient removal by weeds was computed on the product of content of the nutrients and the plant dry weight and expressed in kg/ha.

Nitrogen content

N content was determined by distillation and titration method (Jackson, 1958)

Phosphorus content

Diacid digestion of plant sample was done to determine the P content by Vanadomolybdo phosphoric yellow colour method (Bray and Kurtz, 1945; Watanabe and Olsen, 1965)

Potassium content

K content in diacid digest was estimated using flame photometer (Jackson, 1958)

Economic analysis

The cost of inputs including cost of planting materials, FYM and fertilizers, and prevailing labour costs were taken together to find out gross expenditure and the price of cassava at current market price was taken to calculate the total returns, both expressed in rupees per hectare. The benefit: cost ratio (BCR) was calculated using the formula

$$BCR = \frac{\text{Gross return}}{\text{Cost of cultivation}} \times 100$$

Statistical analysis

The data obtained were subjected to analysis of variance (ANOVA) using the statistical package WASP (Web Based Agricultural Statistics Software Package). The data on weed count and weed dry weight and nutrient uptake were subjected to square root transformation ($\sqrt{x + 0.5}$) in order to make the analysis of variance valid (Gomez and Gomez, 1984).

Plate 1. General field view

Crop stand at 30 days after planting

Crop stand at 60 days after planting

Crop stand at 90 days after planting

Crop stand at harvest

Plate 2. Field view at different crop growth stages

Results

4. RESULTS

The results of the study on "Weed management in cassava (*Manihot esculenta* Crantz)" carried out at the Agronomy Farm, attached to the Department of Agronomy, College of Horticulture, Vellanikkara during May to October 2015 are presented below.

4.1. Plant characters

4.1.1. Plant height

The data on the height of cassava at 30, 60 days after planting (DAP) and at harvest are given in Table 3. The difference in plant height at 30 DAP was not significant. Mean plant height among treatments ranged from 38.5 cm to 41.2 cm.

At 60 DAP, plant heights were significantly different among the treatments. The plots which received directed application of glyphosate at 30 DAP (T_4) produced taller plants of 78.08 cm. This was on par with glyphosate followed by earthing up at 60 DAP (75.69 cm), pre emergence spraying of pendimethalin (74.05 cm), pre emergence spraying of oxyfluorfen followed by earthing up at 60 DAP (73.84 cm) and hoeing and earthing up at 30 and 60 DAP (73.55 cm). The least plant height (60.11 cm) was recorded from the cowpea green manured plot (T_9).

At the time of harvest, the variation in plant heights among treatments was again not significant. The mean plat height at this stage ranged between 175.9 cm to 227.4 cm.

4.1.2. No. of tubers per plant

The data on the number of tubers per cassava plant are given in Table 4. Higher number of tubers per plant (8.22) was recorded in the plants intercropped with green manure cowpea (T_9), which was on par with hoeing and earthing up at 30 and 60 DAP (T_{10} - 8.16) . All the plots which received pre emergence herbicides followed by one earthing up (treatments T_5 to T_8) were on par with respect to number of tubers per plant. Among the treatments which received pre emergence spraying of herbicides alone (T_1 to T_3), oxyfluorfen sprayed plots (7.72) had more number of tubers per plant and it was on par with the plots, which received herbicides followed by earthing up. Unweeded plots (T_{11}) showed the least number of tubers per plant (3.99).

Table 3. Effect of treatments on plant height of cassava

Plant height (cm)				
	Treatments	30 DAP	60 DAP	Harvest
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	40.33[a]	71.83[bcd]	214.60[a]
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	38.50[a]	74.05[abc]	218.13[a]
T_3	Imazethapyr 80g/ha (pre emergence)	39.03[a]	70.81[bcd]	216.55[a]
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	40.97[a]	78.08[a]	224.93[a]
T_5	Oxyfluorfen followed by earthing up at 60 DAP	41.19[a]	73.84[abc]	211.51[a]
T_6	Pendimethalin followed by earthing up at 60 DAP	40.86[a]	71.23[bcd]	218.82[a]
T_7	Imazethapyr followed by earthing up at 60 DAP	40.80[a]	70.50[cd]	212.56[a]
T_8	Glyphosate followed by earthing up at 60 DAP	39.59[a]	75.69[ab]	218.25[a]
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	40.00[a]	60.11[e]	195.64[a]
T_{10}	Hoeing and earthing up at 30 and 60 DAP	39.98[a]	73.56[abc]	227.40[a]
T_{11}	UWC	40.03[a]	67.22[d]	175.92[a]

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

Table 4. Effect of treatments on number of tubers per plant

	Treatments	No. of tubers per plant
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	7.72^{ab}
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	6.55^{b}
T_3	Imazethapyr 80g/ha (pre emergence)	6.57^{b}
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	7.61^{ab}
T_5	Oxyfluorfen followed by earthing up at 60 DAP	7.93^{ab}
T_6	Pendimethalin followed by earthing up at 60 DAP	7.89^{ab}
T_7	Imazethapyr followed by earthing up at 60 DAP	7.75^{ab}
T_8	Glyphosate followed by earthing up at 60 DAP	7.88^{ab}
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	8.22^{a}
T_{10}	Hoeing and earthing up at 30 and 60 DAP	8.16^{a}
T_{11}	UWC	3.99^{c}

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

4.1.3. Length of tuber

Table 5 shows the data pertaining to length of tuber. The highest tuber length of 45.19 cm was from the plants, which received the directed application of glyphosate followed by earthing up at 60 DAP (T_8) and it was on par with cassava intercropped with green manure cowpea (T_9 - 44.6 cm). The next better treatments were hoeing and earthing up at 30 and 60 DAP (T_{10}) and oxyfluorfen followed by earthing up at 60 DAP (T_5), which recorded tuber length of 43.63 cm and 43.14 cm respectively. The smallest tubers were in unweeded control plots (T_{11}).

4.1.4. Girth of tuber

Greater girth of tuber (15.19 cm) was recorded from the plants which received the pre emergence application of imazethapyr followed by earthing up at 60 DAP (Table 6). The treatments with pre emergence spraying of imazethapyr, oxyfluorfen, pendimethalin and glyphosate followed by earthing up, concurrent growing of fodder cowpea and hoeing and earthing up were on par. Unweeded control plots (T_{11}) have shown the lowest (9.24 cm) tuber girth.

4.1.5. Tuber yield

The data regarding average tuber yield per plant and tuber yield per hectare are presented in Table 7. Compared to unweeded control plots, all the plots with weed management recorded better tuber yields. The plots which received hoeing and earthing up at 30 and 60 DAP produced the highest tuber yield of 2.53 kg per plant and 31.18 tonnes per hectare. However, it was on par with pendimethalin followed by earthing up (30.61 t/ha) and glyphosate followed by earthing up (28.44 t/ha).

The treatment with directed application of glyphosate (T_4), oxyfluorfen followed by earthing up (T_5), imazethapyr followed by earthing up (T_7) and green manure cowpea (T_9) were the next better treatments, which were on par. The yield per plant and yield per hectare in unweeded control plots were 1.10 kg and 13.58 tonnes respectively.

4.1.6. Top yield at harvest

There was no significant difference in top yield among treatments (Table 8). The mean value of top yield ranged from 1.93 to 2.52 kg per plant.

4.1.7. Dry matter production at harvest

The data pertaining to dry matter production of cassava plants at the time of harvest are shown in Table 9. Higher dry matter of 1.07 kg per hectare was noticed in plots with two hoeing and earthing up. It was on par with pendimethalin followed by earthing up at 60 DAP (1.04 kg/ha). The lowest dry matter production (0.63 kg/plant) was observed in unweeded control plots (T_{11}).

Table 5. Effect of treatments on length of tuber

	Treatments	Length of tuber (cm)
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	34.83^{cde}
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	36.32^{bcd}
T_3	Imazethapyr 80g/ha (pre emergence)	32.99^{de}
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	38.33^{abcd}
T_5	Oxyfluorfen followed by earthing up at 60 DAP	43.14^{ab}
T_6	Pendimethalin followed by earthing up at 60 DAP	41.93^{abc}
T_7	Imazethapyr followed by earthing up at 60 DAP	39.99^{abcd}
T_8	Glyphosate followed by earthing up at 60 DAP	45.19^{a}
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	44.61^{a}
T_{10}	Hoeing and earthing up at 30 and 60 DAP	43.63^{ab}
T_{11}	UWC	26.82^{e}

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

Table 6. Effect of treatments on girth of tuber

	Treatments	Girth of tuber (cm)
T_1	Oxyfluorfen 0.2 kg/ha(pre emergence)	11.76[bc]
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	11.50[bc]
T_3	Imazethapyr 80g/ha (pre emergence)	12.93[ab]
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	11.82[bc]
T_5	Oxyfluorfen followed by earthing up at 60 DAP	13.89[ab]
T_6	Pendimethalin followed by earthing up at 60 DAP	14.28[ab]
T_7	Imazethapyr followed by earthing up at 60 DAP	15.19[a]
T_8	Glyphosate followed by earthing up at 60 DAP	12.69[ab]
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	13.08[ab]
T_{10}	Hoeing and earthing up at 30 and 60 DAP	14.07[ab]
T_{11}	UWC	9.24[c]

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

Table 7. Effect of treatments on tuber yield

	Treatments	Tuber yield	
		kg/plant	**t/ha**
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	1.89^{b}	23.27^{b}
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	1.39^{c}	17.18^{c}
T_3	Imazethapyr 80g/ha (pre emergence)	1.26^{cd}	15.56^{cd}
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	1.77^{b}	21.79^{b}
T_5	Oxyfluorfen followed by earthing up at 60 DAP	1.99^{b}	24.55^{b}
T_6	Pendimethalin followed by earthing up at 60 DAP	2.48^{a}	30.61^{a}
T_7	Imazethapyr followed by earthing up at 60 DAP	1.92^{b}	23.72^{b}
T_8	Glyphosate followed by earthing up at 60 DAP	2.30^{a}	28.44^{a}
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	1.87^{b}	23.06^{b}
T_{10}	Hoeing and earthing up at 30 and 60 DAP	2.53^{a}	31.17^{a}
T_{11}	UWC	1.10^{d}	13.58^{d}

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

Table 8. Effect of treatments on top yield at harvest

	Treatments	Top yield (kg/plant)
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	2.36[a]
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	2.39[a]
T_3	Imazethapyr 80 g/ha (pre emergence)	2.38[a]
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	2.47[a]
T_5	Oxyfluorfen followed by earthing up at 60 DAP	2.32[a]
T_6	Pendimethalin followed by earthing up at 60 DAP	2.40[a]
T_7	Imazethapyr followed by earthing up at 60 DAP	2.34[a]
T_8	Glyphosate followed by earthing up at 60 DAP	2.40[a]
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	2.15[a]
T_{10}	Hoeing and earthing up at 30 and 60 DAP	2.52[a]
T_{11}	UWC	1.93[a]

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

Table 9. Effect of treatments on dry matter production at harvest

	Treatments	Dry matter production (kg/plant)
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	0.89^{c}
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	0.78^{de}
T_3	Imazethapyr 80g/ha (pre emergence)	0.75^{e}
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	0.89^{c}
T_5	Oxyfluorfen followed by earthing up at 60 DAP	0.91^{c}
T_6	Pendimethalin followed by earthing up at 60 DAP	1.04^{ab}
T_7	Imazethapyr followed by earthing up at 60 DAP	0.89^{c}
T_8	Glyphosate followed by earthing up at 60 DAP	0.99^{b}
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	0.85^{cd}
T_{10}	Hoeing and earthing up at 30 and 60 DAP	1.07^{a}
T_{11}	UWC	0.63^{f}

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

4.2. Observation on weeds

4.2.1. Weed count

4.2.1.1. Weed count at 30 DAP

The effect of various treatments on the total population of grass weeds and broad leaf weeds at 30 DAP is depicted in Table 10. Higher counts of monocot weeds were observed in plots without any weed control measures (T_{11}). Compared to grass weeds, broad leaf weeds were higher at 30 DAP. The lowest count for grass and broad leaf weeds was observed for the plots, which received pre emergence application of oxyfluorfen (T_1). All other pre emergence herbicide applied plots (T_2, T_3, T_5, T_6 and T_7) had lower monocot weed counts which were on par.

The plots with green manure cowpea showed higher count of broad leaf weeds (252 nos.) and it was on par with plots with no weeding (213 nos.) and plots with hoeing and digging up (208 nos.). Pre emergence application of oxyfluorfen (T_1) and pendimethalin (T_2) successfully controlled the broad leaf weeds at this stage. The broad leaf weed counts in these plots were 26.67 and 46.67 nos. respectively.

Lower total weed counts of 26.67 and 47.07 were noticed in plots with pre emergence application of oxyfluorfen (T_1 and T_5). Pre emergence application of pendimethalin also gave appreciable reduction in the total weed count as compared to treatments which did not receive any weed control measure at this stage. The total weed count in plots with pendimethain (T_2 and T_6) was 58.67 and 61.60 respectively.

4.2.1.2. Weed count at 60 DAP

The variation in weed population of grass weeds and broad leaf weeds at 60 DAP is shown in Table 11. At 60 DAP, the highest weed count for grasses (38.67) was noticed in unweeded control (T_{11}). Green manure cowpea (T_9) was the next treatment with higher grass weed count (28.00). All the other treatments exhibited a lower weed count and the least weed count was noticed under directed application of glyphosate at 30 DAP (T_4).

The highest broad leaf weed count (120) was exhibited by the concurrent growing of green manure cowpea (T_9) followed by unweeded control plot (112). The least count for the broad leaf weeds was recorded for the pre emergence application of pendimethalin (T_2). The treatments T_4, T_6 and T_8 were also showed lower broad leaf weed count, which were on par.

Unweeded control plots (150.67) and green manure cowpea (148.00) showed higher total weed counts at 60 DAP. The least weed count (54.33) was recorded for plots with hoeing and earthing up at 30 and 60 DAP (T_{10}). Treatments, pre emergence application of pendimethalin (T_2) and imazethapyr (T_3) and directed spray of glyphosate (T_4) also had lower weed counts (70.67, 74.00 and 78.67 respectively).

Table 10. Effect of treatments on weed count at 30 DAP

Weed count at 30 DAP (No./m²)				
	Treatments	Grasses	Broad leaf weeds	Total
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	0.00^{d} ** (0.71)	26.67^{f} (5.12)	26.67^{g} (5.12)
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	12.00^{c} (3.39)	46.67^{ef} (6.80)	58.67^{ef} (7.66)
T_3	Imazethapyr 80g/ha (pre emergence)	5.33^{c} (2.39)	76.00^{d} (8.69)	81.30^{e} (8.98)
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	29.33^{b} (5.42)	169.33^{b} (12.98)	198.67^{c} (14.07)
T_5	Oxyfluorfen followed by earthing up at 60 DAP	5.73^{c} (2.47)	41.33^{ef} (6.41)	47.07^{fg} (6.83)
T_6	Pendimethalin followed by earthing up at 60 DAP	6.93^{c} (2.70)	54.67^{de} (7.38)	61.60^{ef} (7.83)
T_7	Imazethapyr followed by earthing up at 60 DAP	9.33^{c} (3.11)	121.33^{c} (10.93)	130.67^{d} (11.35)
T_8	Glyphosate followed by earthing up at 60 DAP	34.67^{ab} (5.92)	172.00^{b} (13.10)	206.67^{bc} (14.36)
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	29.33^{b} (5.41)	252.00^{a} (15.83)	281.3^{a} (16.73)
T_{10}	Hoeing and earthing up at 30 and 60 DAP	29.33^{b} (5.44)	208.00^{ab} (14.39)	237.33^{abc} (15.37)
T_{11}	UWC	48.00^{a} (6.89)	213.33^{ab} (14.58)	261.33^{ab} (16.12)

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

** Original values, $\sqrt{X+0.5}$ transformed values are given in parentheses

Table 11. Effect of treatments on weed count at 60 DAP

Weed count at 60 DAP (No./m^2)				
	Treatments	Grasses	Broad leaf weeds	Total
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	14.67^{def}** (3.82)	78.67^{bcde} (8.85)	93.33^{bcd} (9.64)
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	16.00^{cde} (4.00)	54.67^{ef} (7.25)	70.67^{de} (8.31)
T_3	Imazethapyr 80g/ha (pre emergence)	15.33^{def} (3.89)	58.67^{def} (7.62)	74.00^{de} (8.58)
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	10.67^{f} (3.25)	68.00^{cde} (8.14)	78.67^{cde} (8.80)
T_5	Oxyfluorfen followed by earthing up at 60 DAP	21.33^{bcd} (4.55)	89.33^{abcd} (9.45)	110.67^{abc} (10.50)
T_6	Pendimethalin followed by earthing up at 60 DAP	18.00^{cde} (4.24)	65.33^{cde} (7.91)	83.33^{bcde} (8.99)
T_7	Imazethapyr followed by earthing up at 60 DAP	19.33^{cde} (4.36)	94.67^{abc} (9.72)	114.00^{ab} (10.66)
T_8	Glyphosate followed by earthing up at 60 DAP	13.33^{ef} (3.64)	65.33^{cde} (8.03)	78.67^{bcde} (8.84)
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	28.00^{b} (5.28)	120.00^{a} (10.92)	148.00^{a} (12.14)
T_{10}	Hoeing and earthing up at 30 and 60 DAP	22.33^{bc} (4.72)	32.00^{f} (5.65)	54.33^{e} (7.36)
T_{11}	UWC	38.67^{a} (6.19)	112.00^{ab} (10.58)	150.67^{a} (12.27)

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

** Original values, $\sqrt{X+0.5}$ transformed values are given in parentheses

4.2.1.3. Weed count at 90 DAP

At 90 DAP, the least grass weed count of 6.67 was observed in the plots received hoeing and earthing up (Table 12). Pendimethalin followed by earthing up, glyphosate followed by earthing up, imazethapyr followed by earthing up and oxyfluorfen followed by earthing up were the next best treatments which reduced the grass counts at 90 DAP. The grass weed counts in these treatments were 9.33, 16.0, 20.0 and 21.33, 20.00 no./m^2 respectively. Pre emergence application of imazethapyr and directed application of glyphosate had similar grass weed counts of 25.33. The count of grasses in unweeded control plots and in plots with pre emergence applications of pendimethalin alone were on par (48 and 45.33 respectively).

The highest count of broad leaf weeds at 90 DAP was observed in unweeded plots (169.33). The least dicot weed count (25.33) was noticed in the plots sprayed with pendimethalin followed by earthing up (T_6) which was on par (32.0) with fodder cowpea and earthing up at 60 DAP (T_9). Broad leaf weeds count in treatments T_5, T_7 and T_8 were on par.

Unweeded control plots (T_{11}) showed the highest total weed count at 90 DAP (217.3). The treatments T_5 (61.30), T_7 (58.67), T_9 (65.3) and T_{10} (60) showed lower weed counts. The least weed count (34.67) was observed in the treatment with pendimethalin followed by earthing up at 60 DAP (T_6).

4.2.1.4. Weed count at harvest

The population of grass weeds and dicot weeds at harvest is recorded in Table 13. At the time of harvest, the highest total grass weed count (20.0) was noticed for pre emergence application of imazethapyr (T_3). The next highest count was under unweeded control plots (T_{11}) and glyphosate followed by earthing up (T_8) showed the least grass weed count (4.00).

On counting the broad leaf weeds, the highest count (101.33) was recorded for unweeded control plots (T_{11}) followed by plots, which received pre emergence spray of imazethapyr, followed by earthing up at 60 DAS (T_7). The least count of broad leaf weeds was in pre emergence application of pendimethalin (33.33). The weed count from pre emergence oxyfluorfen (57.33), directed application of glyphosate (60.00), pendimethalin followed by earthing up (54.67) and hoeing and earthing up (62.67) were on par.

With respect to the total weed count, unweeded control plots showed the highest weed count (117.33). The total count recorded from T_1 (73.33), T_4 (69.33), and T_{10} (69.33) were on par. The least total weed count observed was from pre emergence application of pendimethalin (T_2) and glyphosate followed by earthing up.

Table 12. Effect of treatments on weed count at 90 DAP

Weed count at 90 DAP (No./m^2)				
	Treatments	Grasses	Broad leaf weeds	Total
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	41.33^{ab} ** (6.38)	105.33^{b} (10.17)	146.67^{b} (12.07)
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	45.33^{a} (6.68)	76.00^{bcd} (8.63)	121.33^{bc} (10.98)
T_3	Imazethapyr 80g/ha (pre emergence)	25.33^{bcd} (4.97)	97.33^{bc} (9.82)	122.67^{b} (11.06)
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	25.33^{bcd} (4.97)	70.67^{cd} (8.39)	96.00^{c} (9.80)
T_5	Oxyfluorfen followed by earthing up at 60 DAP	21.33^{cde} (4.53)	40.00^{ef} (6.30)	61.33^{d} (7.80)
T_6	Pendimethalin followed by earthing up at 60 DAP	9.33^{ef} (3.04)	25.33^{f} (5.03)	34.67^{e} (5.88)
T_7	Imazethapyr followed by earthing up at 60 DAP	20.00^{cde} (4.43)	38.67^{ef} (6.13)	58.67^{d} (7.64)
T_8	Glyphosate followed by earthing up at 60 DAP	16.00^{def} (3.98)	33.33^{ef} (5.74)	49.33^{de} (7.02)
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	33.33^{abc} (5.73)	32.00^{f} (5.61)	65.33^{d} (8.07)
T_{10}	Hoeing and earthing up at 30 and 60 DAP	6.67^{f} (2.49)	53.33^{de} (7.30)	60.00^{d} (7.74)
T_{11}	UWC	48.00^{a} (6.90)	169.33^{a} (12.99)	217.33^{a} (14.73)

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

** Original values, $\sqrt{X+0.5}$ transformed values are given in parentheses

Table 13. Effect of treatments on weed count at harvest

Weed count at harvest (No/m^2)				
	Treatments	Grasses	Broad leaf weeds	Total
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	16.00^{ab}** (3.98)	57.33^{cd} (7.53)	73.33^{cd} (8.52)
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	9.33^{bcd} (2.94)	33.33^{e} (5.73)	42.67^{f} (6.45)
T_3	Imazethapyr 80g/ha (pre emergence)	20.00^{a} (4.46)	69.33^{bc} (8.29)	89.33^{bc} (9.44)
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	9.33^{bcd} (3.04)	60.0^{cd} (7.72)	69.33^{cd} (8.30)
T_5	Oxyfluorfen followed by earthing up at 60 DAP	10.67^{bc} (3.22)	49.33^{de} (6.99)	60.00^{def} (7.69)
T_6	Pendimethalin followed by earthing up at 60 DAP	10.67^{bcd} (3.16)	54.67^{cd} (7.35)	65.33^{de} (8.07)
T_7	Imazethapyr followed by earthing up at 60 DAP	10.67^{bc} (3.25)	92.00^{a} (9.59)	102.67^{ab} (10.13)
T_8	Glyphosate followed by earthing up at 60 DAP	4.000^{d} (2.00)	45.33^{de} (6.69)	49.33^{ef} (6.99)
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	9.33^{bcd} (2.98)	91.67^{ab} (9.57)	101.00^{ab} (10.05)
T_{10}	Hoeing and earthing up at 30 and 60 DAP	6.67^{cd} (2.49)	62.67^{cd} (7.91)	69.33^{cd} (8.33)
T_{11}	UWC	16.00^{ab} (3.98)	101.33^{a} (10.06)	117.33^{a} (10.82)

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

** Original values, $\sqrt{X+0.5}$ transformed values are given in parentheses

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4.2.2. Weed dry weight

4.2.2.1. Weed dry weight at 30 DAP

The data on weed dry weights at 30 DAP are represented in Table 14. Hoeing and earthing up (T_{10}), glyphosate followed by earthing up (T_8) and unweeded contol (T_{11}) recorded higher grass weed dry weights of 53.87, 49.20 and 48.93 g/m^2 respectively. The least dry weight for monocot weeds was recorded from the plots, which received pre emergence application of oxyfluorfen (T_1).

Unweeded control plots (T_{11}) showed the highest dry weight for broad leaf weeds (91.47 g/m^2). Lower dicot weed dry weights of 1.01, 1.23, 1.52 and 1.54 g/m^2 were recorded from the treatments pre emergence oxyfluorfen (T_1), oxyfluorfen followed by earthing up (T_5), pre emergence pendimethalin (T_2) and pendimethalin followed by earthing up (T_6) respectively and the data were on par.

Considering the total weed dry weight at 60 DAP, unweeded control plots resulted in the highest weed dry weight (140.40g/m^2) followed by hoeing and earthing up (118.67g/m^2). The least weed dry weight (1.01g/m^2) was observed from pre emergence oxyfluorfen (T_1) which was on par with the dry weights obtained from oxyfluorfen followed by earthing up (T_5), pre emergence pendimethalin (T_2) and pendimethalin followed by earthing up (T_6).

4.2.2.2. Weed dry weight at 60 DAP

The data regarding to the effect of treatments on weed dry weights at 60 DAP are given in Table 15. The highest dry weight for monocot weeds was observed from plots with green manure cowpea (25.87g/m^2) but it was on par with unweeded control plots (24.37). The data recorded from the plots with hoeing and earthing up (T_{10}) and glyphosate followed by earthing up were on par. The least grass dry weight (2.59 g/m^2) was recorded from pre emergence oxyfluorfen (T_1).

The highest value for dry weight of broad leaf weeds (173.6 g/m^2) was recorded from unweeded control plots (T_{11}) followed by green manure cowpea (T_9). The least dicot weed dry weights was observed from the plots sprayed with pre emergence oxyfluorfen (14.93 g/m^2) but it was on par with directed application of glyphosate followed by earthing up (19.07 g/m^2).

The highest total weed dry weight of 197.97g/m^2 was recorded from the unweeded control plot (T_{11}). Directed application of glyphosate (T_4) and glyphosate followed by earthing up (T_8) showed lower weed dry weights and the data were on par. Pre emergence oxyfluorfen (T_1) produced the least total weed dry weight (17.52 g/m^2).

Table 14. Effect of treatments on weed dry weight at 30 DAP

	Weed dry weight at 30 DAP (g/m^2)			
	Treatments	Grasses	Broad leaf weeds	Total
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	0.00^{d}** (0.71)	1.01^{e} (0.99)	1.01^{f} (0.99)
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	1.27^{c} (1.31)	1.52^{e} (1.23)	2.79^{f} (1.66)
T_3	Imazethapyr 80g/ha (pre emergence)	0.36^{cd} (0.92)	9.57^{d} (3.02)	9.93^{e} (3.09)
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	44.27^{b} (6.69)	64.93^{b} (8.05)	109.20^{b} (10.45)
T_5	Oxyfluorfen followed by earthing up at 60 DAP	1.068^{cd} (0.65)	1.23^{e} (1.11)	1.87^{f} (1.37)
T_6	Pendimethalin followed by earthing up at 60 DAP	1.282^{c} (1.23)	1.54^{e} (1.24)	2.78^{f} (1.65)
T_7	Imazethapyr followed by earthing up at 60 DAP	1.088^{cd} (0.70)	10.44^{d} (3.21)	11.14^{e} (3.32)
T_8	Glyphosate followed by earthing up at 60 DAP	49.20^{ab} (7.05)	44.00^{c} (6.57)	93.20^{c} (9.63)
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	0.878^{cd} (0.27)	36.13^{c} (5.98)	36.41^{d} (5.99)
T_{10}	Hoeing and earthing up at 30 and 60 DAP	53.87^{a} (7.35)	64.80^{b} (8.05)	118.67^{b} (10.89)
T_{11}	UWC	48.93^{ab} (7.03)	91.47^{a} (9.55)	140.40^{a} (11.84)

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

** Original values, $\sqrt{X+0.5}$ transformed values are given in parentheses

Table 15. Effect of treatments on weed dry weight at 60 DAP

Weed dry weight at 60 DAP (g/m²)				
	Treatments	Grasses	Broad leaf weeds	Total
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	2.59[d]** (1.59)	14.93[e] (3.84)	17.52[f] (4.16)
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	10.36[bc] (3.21)	38.67[c] (6.22)	49.03[c] (7.00)
T_3	Imazethapyr 80g/ha (pre emergence)	10.67[bc] (3.23)	93.15[b] (9.64)	103.81[b] (10.17)
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	6.57[cd] (2.51)	23.07[de] (4.74)	29.64[ef] (5.36)
T_5	Oxyfluorfen followed by earthing up at 60 DAP	7.07[c] (2.64)	22.67[de] (4.76)	29.73[de] (5.45)
T_6	Pendimethalin followed by earthing up at 60 DAP	10.27[bc] (3.18)	34.80[cd] (5.86)	45.07[cd] (6.67)
T_7	Imazethapyr followed by earthing up at 60 DAP	14.78[b] (3.84)	82.00[b] (9.05)	96.78[b] (9.83)
T_8	Glyphosate followed by earthing up at 60 DAP	5.75[cd] (2.34)	19.07[e] (4.36)	24.82[ef] (4.98)
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	25.87[a] (5.06)	94.67[b] (9.68)	120.53[b] (10.96)
T_{10}	Hoeing and earthing up at 30 and 60 DAP	8.03[c] (2.72)	40.80[c] (6.36)	48.83[c] (6.94)
T_{11}	UWC	24.37[a] (4.93)	173.60[a] (13.17)	197.97[a] (14.07)

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

** Original values, $\sqrt{X+0.5}$ transformed values are given in parentheses

4.2.2.3. Weed dry weight at 90 DAP

The data on the dry weights of grass weeds and broad leaf weeds at 90 DAP are shown in Table 16. At 90 DAP, the highest monocot weed dry weight (115.47 g/m^2) was observed from unweeded control plot (T_{11}). The lowest monocot weed dry weight (0.96 g/m^2) at 90 DAP was exhibited by imazethapyr followed by earthing up (T_7), which was on par with oxyfluorfen followed by earthing up (T_5), hoeing and earthing up (T_{10}), green manure cowpea (T_9) and pendimethalin followed by earthing up (T_6). Unweeded control plots (T_{11}) produced the highest dry weight of broad leaf weeds (430.71 g/m^2). The least dicot weed dry weight (13.33 g/m^2) was observed in plots which received pendimethalin followed by earthing up (T_6) which was on par with the dry weights obtained from the treatments T_5 (18.25 g/m^2), T_7 (15.20 g/m^2), T_8 (13.93 g/m^2), T_9 (20.27 g/m^2) and T_{10} (20.13 g/m^2).

Total weed dry weight was highest (546.17 g/m^2) in the unweeded control plots (T_{11}). The least total weed dry weight was observed from the plots with pendimethalin followed by earthing up (T_6) and it was on par with imazethapyr followed by earthing up (T_7), glyphosate followed by earthing up (T_8), oxyfluorfen followed by earthing up (T_5), hoeing and earthing up (T_{10}) and green manure cowpea (T_9).

4.2.2.4. Weed dry weight at harvest

The data pertaining to dry weight of grass weeds and broad leaf weeds at harvest are presented in Table 17. The highest dry weight for grasses (323.33 g/m^2) was observed in control plots (T_{11}). The lowest grass dry weight (12.80 g/m^2) was recorded from the treatment pendimethalin followed by earthing up (T_6) and the next best was glyphosate followed by earthing up (T_8).

Regarding the broad leaf weed dry weight, unweeded control plots exhibited the highest value of 450.53 g/m^2 followed by directed application of glyphosate (T_4). The least dry weight value (28.67 g/m^2) was recorded from the plots, which received pendimethalin followed by earthing up (T_6). The treatments oxyfluorfen followed by earthing up (T_5) and glyphosate followed by earthing up (T_8) also showed lower weed dry weights, which were on par.

Unweeded control plots (T_{11}) showed the highest value for total weed dry weights (773.87 g/m^2). At harvest, the least total weed dry weight (41.47 g/m^2) was from the plots sprayed with pendimethalin followed by earthing up at 60 DAP (T_6), which then followed by oxyfluorfen followed by earthing up (72.93 g/m^2) and glyphosate followed by earthing up (77.87 g/m^2).

Table 16. Effect of treatments on weed dry weight at 90 DAP

Weed dry weight at 90 DAP (g/m^2)				
	Treatments	Grasses	Broad leaf weeds	Total
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	93.87[ab]** (9.68)	92.53[c] (9.56)	200.6[c] (14.16)
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	34.27[c] (5.85)	91.47[c] (9.53)	125.73[d] (11.19)
T_3	Imazethapyr 80g/ha (pre emergence)	49.36[c] (6.99)	279.20[b] (16.71)	328.56[b] (18.12)
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	74.00[b] (8.57)	69.73[c] (8.27)	143.73[d] (11.92)
T_5	Oxyfluorfen followed by earthing up at 60 DAP	1.40[d] (1.18)	18.25[d] (4.24)	19.65[e] (4.39)
T_6	Pendimethalin followed by earthing up at 60 DAP	2.28[d] (1.36)	13.33[d] (3.64)	15.61[e] (3.95)
T_7	Imazethapyr followed by earthing up at 60 DAP	0.96[d] (0.95)	15.20[d] (3.88)	16.16[e] (4.01)
T_8	Glyphosate followed by earthing up at 60 DAP	2.30[d] (1.51)	13.93[d] (3.72)	16.23[e] (4.02)
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	2.04[d] (1.37)	20.27[d] (4.49)	22.31[e] (4.72)
T_{10}	Hoeing and earthing up at 30 and 60 DAP	1.52[d] (1.18)	20.13[d] (4.44)	21.65[e] (4.61)
T_{11}	UWC	115.47[a] (10.67)	430.71[a] (20.72)	546.17[a] (23.36)

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

** Original values, $\sqrt{X+0.5}$ transformed values are given in parentheses

Table 17. Effect of treatments on weed dry weight at harvest

Weed dry weight harvest (g/m²)				
	Treatments	Grasses	Broad leaf weeds	Total
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	139.33^{b}** (11.72)	195.20^{cd} (13.96)	334.53^{b} (18.28)
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	56.53^{cd} (7.45)	180.80^{cd} (13.37)	237.33^{c} (15.37)
T_3	Imazethapyr 80g/ha (pre emergence)	122.00^{b} (11.02)	248.53^{bc} (15.63)	370.53^{b} (19.15)
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	113.60^{b} (10.60)	300.00^{b} (17.29)	413.60^{b} (20.29)
T_5	Oxyfluorfen followed by earthing up at 60 DAP	35.07^{de} (5.83)	37.87^{ef} (6.11)	72.93^{fg} (8.46)
T_6	Pendimethalin followed by earthing up at 60 DAP	12.80^{f} (3.48)	28.67^{f} (5.28)	41.47^{g} (6.36)
T_7	Imazethapyr followed by earthing up at 60 DAP	71.07^{c} (8.43)	69.47^{e} (8.31)	140.53^{de} (11.84)
T_8	Glyphosate followed by earthing up at 60 DAP	22.13^{ef} (4.63)	55.73^{ef} (7.45)	77.87^{f} (8.82)
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	58.80^{cd} (7.64)	140.27^{d} (11.82)	199.07^{cd} (14.11)
T_{10}	Hoeing and earthing up at 30 and 60 DAP	53.60^{cd} (7.32)	64.67^{e} (7.99)	118.27^{ef} (10.86)
T_{11}	UWC	323.33^{a} (17.93)	450.53^{a} (21.14)	773.87^{a} (27.76)

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

** Original values, $\sqrt{X+0.5}$ transformed values are given in parentheses

4.2.3. Weed control efficiency

The data related to weed control efficiency at 30, 60, 90 DAP and at harvest are presented in Table 18. At 30 DAP, the highest weed control efficiency (99.29) was recorded for pre emergence application of oxyfluorfen (T_1). Higher weed control efficiencies of 97.98, 98.66 and 98.02 per cent was observed with pre emergence pendimethalin (T_2), oxyfluorfen followed by earthing up and (T_5) and pendimethalin followed by earthing up (T_6) respectively and the data were on par. Weed control efficiencies of the treatments, directed application of glyphosate (22.05) and hoeing and earthing up (14.86) were lower compared to other treatments.

At 60 DAP, a high weed control efficiency of 91.11 per cent was shown by pre emergence oxyfluorfen (T_1) followed by directed application of glyphosate followed by earthing up (T_8) which were on par. Lower weed control efficiencies of 47.57 and 51.19 per cent were shown by the treatments pre emergence imazethapyr (T_3) and imazethapyr followed by earthing up (T_7) respectively.

Higher weed control efficiencies at 90 DAP were obtained in treatments pendimethalin followed by earthing up (97.00), imazethapyr followed by earthing up (97.00) and glyphosate followed by earthing up (97.03) and the data were on par. The least weed control efficiency of 39.67 per cent was observed for pre emergence imazethapyr (T_3).

At the time of harvest, pendimethalin followed by earthing up (T_6) exhibited the highest weed control efficiency of 94.33 per cent, followed by oxyfluorfen followed by earthing up (90.40) and glyphosate followed by earthing up (89.76) and the two were on par. The treatments directed application of glyphosate (T_4) and pre emergence imazethapyr (T_3) were showed comparatively lower weed control efficiencies of 46.15 and 50.17 per cent respectively.

Table 18. Effect of treatments on weed control efficiency

Treatments		WCE (%)			
		30 DAP	60DAP	90DAP	Harvest
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	99.29^{a}	91.11^{a}	63.11^{c}	55.56^{e}
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	97.98^{a}	75.22^{c}	76.82^{b}	69.27^{d}
T_3	Imazethapyr 80g/ha (pre emergence)	92.79^{a}	47.57^{de}	39.67^{d}	50.17^{e}
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	22.05^{d}	85.11^{ab}	73.24^{b}	46.15^{e}
T_5	Oxyfluorfen followed by earthing up at 60 DAP	98.66^{a}	84.95^{ab}	96.35^{a}	90.40^{ab}
T_6	Pendimethalin followed by earthing up at 60 DAP	98.02^{a}	77.18^{bc}	97.00^{a}	94.33^{a}
T_7	Imazethapyr followed by earthing up at 60 DAP	91.94^{a}	51.19^{d}	97.00^{a}	81.29^{bc}
T_8	Glyphosate followed by earthing up at 60 DAP	32.85^{c}	87.45^{a}	97.03^{a}	89.76^{ab}
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	73.66^{b}	39.03^{e}	95.88^{a}	73.92^{cd}
T_{10}	Hoeing and earthing up at 30 and 60 DAP	14.86^{d}	75.29^{c}	96.08^{a}	84.35^{abc}
T_{11}	UWC	0.000^{e}	0.000^{f}	0.000^{e}	0.00^{f}

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

4.2.4 Nutrient uptake by weeds

4.2.4.1. N uptake by weeds

The data on N uptake by weeds at 30, 60, 90 DAP and at harvest are given in Table 19. At 30 DAP, the highest N uptake of 27.94 kg/ha was recorded in unweeded control plot followed by directed application of glyphosate (21.45 kg/ha) and glyphosate followed by earthing up (18.27 kg/ha). Lower N uptake (0.25 kg/ha) at this stage was observed in pre emergence oxyfluorfen (T_1) and it was on par with oxyfluorfen followed by earthing up (0.43 kg/ha), pre emergence pendimethalin (0.73 kg/ha) and pendimethalin followed by earthing up (0.69 kg/ha).

At 60 DAP, unweeded control plot (T_{11}) resulted in higher value of N uptake (44.94 kg/ha) followed by plots with cowpea green manuring (23.31 kg/ha). The treatments, pre emergence pendimethalin (T_2), pendimethalin followed by earthing up (T_6) and hoeing and earthing up (T_{10}) showed lower N uptake and the data were on par. The least N uptake was observed in pre emergence oxyfluorfen (T_1) and it was on par with oxyfluorfen followed by earthing up (T_5), directed application of glyphosate (T_4) and glyphosate followed by earthing up (T_8).

At 90 DAP, unweeded control plots showed the highest N uptake of 119.99 kg/ha, but it was on par with pre emergence imazethapyr (T_3). The lowest N uptake (3.44 kg/ha) at this stage was observed in glyphosate followed by earthing up (T_8) treatment, but the data were on par with the treatments oxyfluorfen followed by earthing up (T_5), pendimethalin followed by earthing up (T_6), imazethapyr followed by earthing up, green manure cowpea (T_9) and hoeing and earthing up (T_{10}).

At the time of harvest, the highest N uptake of 160.29 kg/ha was recorded in unweeded control plots (T_{11}). The uptake of N in pre emergence oxyfluorfen (T_1) and green manure cowpea (T_9) were on par. The least uptake (9.83 kg/ha) was obtained from pendimethalin followed by earthing up treatment (T_6) followed by oxyfluorfen followed by earthing up (T_5) and glyphosate followed by earthing up (T_8).

4.2.4.2. P uptake by weeds

The data regarding P uptake by weeds at 30, 60, 90 DAP and at harvest are presented in Table 20. The plots given directed application of glyphosate resulted in a higher P uptake of 4.02 kg/ha and it was on par with unweeded control plots (T_{11}), glyphosate followed by earthing up (T_8) and hoeing and earthing up (T_{10}). The lowest P uptake (0.03 kg/ha) was observed in pre emergence oxyfluorfen (T_1), but it was on par with oxyfluorfn followed by earthing up (T_5).

At 60 DAP, unweeded control plots resulted in highest P uptake of 5.56 kg/ha followed by green manure cowpea (4.59 kg/ha). The lowest uptake of P (0.67 kg/ha) was recorded in pre emergence oxyfluorfen, which was on par with glyphosate followed by earthing up (0.71 kg/ha), directed application of glyphosate (0.80 kg/ha), pre emergence pendimethalin (1.01 kg/ha), oxyfluorfen followed by earthing up (1.09 ukg/ha), and hoeing and earthing up (1.55 kg/ha).

Unweeded control plots showed the highest uptake of P (13.66 kg/ha) at 90 DAP followed by pre emergence imazethapyr (9.41 kg/ha). Lower P uptake was recorded in the plots, which received pre emergence pendimethalin followed by earthing up (0.35 kg/ha), but the data were on par with the treatments imazethapyr followed by earthing up (0.44 kg/ha), oxyfluorfen followed by earthing up (0.47

kg/ha), hoeing and earthing up (0.62 kg/ha), glyphosate followed by earthing up (0.64 kg/ha) and green manure cowpea.

At the time of harvest also, unweeded control plots showed the highest P uptake (31.08 kg/ha). The treatments oxyfluorfen followed by earthing up (T_5) and glyphosate followed by earthing up (T_8) showed lower uptake values of 2.90 and 2.51 kg/ha respectively. Lower P uptake (1.65 kg/ha) was shown by the plots given pre emergence pendimethalin followed by earthing up (T_6).

Table 19. Effect of treatments on nitrogen uptake by weeds

Treatments		N uptake by weeds (kg/ha)			
		30 DAP	60DAP	90DAP	Harvest
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	0.25^{f}** (0.49)	4.64^{d} (2.12)	52.73^{b} (7.26)	41.55^{cd} (6.37)
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	0.73^{f} (0.85)	11.19^{c} (3.33)	46.07^{b} (6.73)	35.51^{cde} (5.91)
T_3	Imazethapyr 80g/ha (pre emergence)	3.00^{e} (1.69)	22.32^{b} (4.72)	116.73^{a} (10.79)	50.42^{c} (7.00)
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	21.45^{b} (4.61)	6.48^{d} (2.48)	45.52^{b} (6.69)	80.39^{b} (8.94)
T_5	Oxyfluorfen followed by earthing up at 60 DAP	0.43^{f} (0.65)	5.62^{d} (2.36)	6.28^{c} (2.49)	13.33^{fg} (3.42)
T_6	Pendimethalin followed by earthing up at 60 DAP	0.69^{f} (0.83)	13.87^{c} (3.68)	4.66^{c} (2.16)	9.83^{g} (3.02)
T_7	Imazethapyr followed by earthing up at 60 DAP	2.38^{e} (1.54)	23.58^{b} (4.86)	4.86^{c} (2.20)	23.21^{def} (4.79)
T_8	Glyphosate followed by earthing up at 60 DAP	18.27^{bc} (4.27)	4.94^{d} (2.22)	3.44^{c} (1.84)	18.60^{efg} (4.29)
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	10.26^{d} (3.19)	23.31^{b} (4.80)	6.89^{c} (2.62)	38.39^{cd} (6.19)
T_{10}	Hoeing and earthing up at 30 and 60 DAP	15.15^{c} (3.88)	13.12^{c} (3.56)	5.25^{c} (2.27)	27.09^{de} (5.15)
T_{11}	UWC	27.94^{a} (5.27)	44.94^{a} (6.69)	119.99^{a} (10.94)	160.29^{a} (12.61)

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

** Original values, $\sqrt{X+0.5}$ transformed values are given in parentheses

Table 20. Effect of treatments on phosphorus uptake by weeds

	Treatments	P uptake by weeds (kg/ha)			
		30 DAP	60DAP	90DAP	Harvest
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	0.03^{d}** (0.17)	0.67^{d} (0.81)	5.35^{c} (2.29)	7.36^{bc} (2.70)
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	0.11^{cd} (0.33)	1.01^{d} (0.99)	2.97^{d} (1.68)	8.53^{bc} (2.90)
T_3	Imazethapyr 80g/ha (pre emergence)	0.32^{c} (0.55)	3.34^{bc} (1.80)	9.41^{b} (3.04)	10.68^{b} (3.21)
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	4.02^{a} (2.00)	0.80^{d} (0.85)	3.72^{cd} (1.93)	7.26^{bc} (2.69)
T_5	Oxyfluorfen followed by earthing up at 60 DAP	0.04^{d} (0.19)	1.09^{d} (1.04)	0.47^{e} (0.68)	2.90^{de} (1.66)
T_6	Pendimethalin followed by earthing up at 60 DAP	0.07^{cd} (0.27)	1.69^{cd} (1.29)	0.35^{e} (0.59)	1.65^{e} (1.26)
T_7	Imazethapyr followed by earthing up at 60 DAP	0.25^{cd} (0.49)	3.75^{ab} (1.91)	0.44^{e} (0.64)	5.00^{cd} (2.24)
T_8	Glyphosate followed by earthing up at 60 DAP	2.94^{a} (1.69)	0.71^{d} (0.84)	0.64^{e} (0.79)	2.51^{de} (1.58)
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	1.54^{b} (1.23)	4.59^{ab} (2.09)	0.76^{e} (0.87)	9.03^{bc} (2.91)
T_{10}	Hoeing and earthing up at 30 and 60 DAP	3.73^{a} (1.91)	1.55^{d} (1.23)	0.62^{e} (0.77)	7.06^{bc} (2.65)
T_{11}	UWC	3.96^{a} (1.96)	5.56^{a} (2.34)	13.66^{a} (3.69)	31.08^{a} (5.55)

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

** Original values, $\sqrt{X+0.5}$ transformed values are given in parentheses

4.2.4.3. K uptake by weeds

Effect of various treatments on the uptake of K at 30, 60, 90 DAP and at harvest are given in Table 21. At 30 DAP, unweeded control plots recorded the highest K uptake of 55.48 kg/ha. The plots which received pre emergence pendimethalin (T_2) and pendimethalin followed by earthing up (T_6) showed lower uptake values of 0.86 and 0.89 kg/ha respectively. The lowest uptake of K (0.26 kg/ha) was noted with pre emergence oxyfluorfen (T_1), but it was on par with oxyfluorfen followed by earthing up (0.46 kg/ha).

At 60 DAP, the highest uptake of K (48.84 kg/ha) was noticed in the control plot, which was on par with green manure cowpea (45.08 kg/ha). The treatments directed application of glyphosate (T_4) and glyphosate followed by earthing up recorded lower uptake values which were on par. Lower K uptake (5.49 kg/ha) was recorded with pre emergence oxyfluorfen (T_1) and oxyfluorfen followed by earthing up (T_5).

The highest uptake value of 156.32 kg/ha was reported by the unweeded control plot at 90 DAP. The lowest uptake (5.12 kg/ha) was observed from the plots sprayed with pendimethalin followed by earthing up (T_6), which was on par with oxyfluorfen followed by earthing up (T_5), imazethapyr followed by earthing up (T_7), glyphosate followed by earthing up (T_8), green manure cowpea (T_9), and hoeing and earthing up (T_{10}).

At the time of harvest, unweeded control plots (T_{11}) resulted in the highest K uptake value (243.01kg/ha). The data obtained from the treatments imazethapyr followed by earthing up (T_7), green manure cowpea (T9) and hoeing and earthing up

(T_{10}) was on par. The least uptake value was noticed (20.04 kg/ha) in the plots treated with pendimethalin followed by earthing up (T_6) and it was on par with oxyfluorfen followed by earthing up (20.71kg/ha) and glyphosate followed by earthing up (28.57 kg/ha).

4.2.5 Weed index

The data pertaining to weed index are presented in Table 22. The least weed index value of 1.65 per cent was recorded in pre emergence pendimethalin followed by earthing up (T_6), which was on par with glyphosate followed by earthing up (8.64 per cent). The highest weed index value of 56.28 per cent was noticed in the unweeded control plot (T_{11}) followed by pre emergence imazethapyr (50.02 per cent) and pre emergence application of pendimethalin (44.88 per cent).

Table 21. Effect of treatments on potassium uptake by weeds

Treatments		K uptake by weeds (kg/ha)			
		30 DAP	60DAP	90DAP	Harvest
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	0.26[e]** (0.51)	5.49[f] (2.33)	54.91[c] (7.4)	101.02[c] (10.04)
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	0.86[de] (0.93)	13.43[cd] (3.66)	42.45[c] (6.50)	115.80[bc] (10.73)
T_3	Imazethapyr 80g/ha (pre emergence)	2.39[d] (1.52)	28.41[b] (5.33)	71.72[b] (8.41)	122.24[bc] (11.01)
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	42.09[b] (6.46)	9.23[def] (3.00)	55.75[bc] (7.43)	134.84[b] (11.59)
T_5	Oxyfluorfen followed by earthing up at 60 DAP	0.46[e] (0.67)	7.55[ef] (2.74)	6.18[d] (2.47)	20.71[e] (4.52)
T_6	Pendimethalin followed by earthing up at 60 DAP	0.89[de] (0.94)	12.60[cde] (3.53)	5.12[d] (2.26)	20.04[e] (4.43)
T_7	Imazethapyr followed by earthing up at 60 DAP	2.49[d] (1.56)	33.15[b] (5.74)	6.95[d] (2.62)	49.40[d] (7.02)
T_8	Glyphosate followed by earthing up at 60 DAP	41.48[b] (6.42)	8.75[def] (2.96)	6.99[d] (2.64)	28.57[e] (5.34)
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	10.52[c] (3.18)	45.08[a] (6.69)	9.86[d] (3.14)	60.49[d] (7.77)
T_{10}	Hoeing and earthing up at 30 and 60 DAP	39.76[b] (6.31)	17.39[c] (4.15)	8.73[d] (2.94)	56.62[d] (7.52)
T_{11}	UWC	55.48[a] (7.44)	48.84[a] (6.97)	156.32[a] (12.49)	243.01[a] (15.55)

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

** Original values, $\sqrt{X+0.5}$ transformed values are given in parenthes

Table 22. Effect of treatments on weed Index (WI)

	Treatments	WI (%)
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	25.09^{c}
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	44.88^{b}
T_3	Imazethapyr 80g/ha (pre emergence)	50.02^{ab}
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	29.85^{c}
T_5	Oxyfluorfen followed by earthing up at 60 DAP	21.24^{c}
T_6	Pendimethalin followed by earthing up at 60 DAP	1.65^{d}
T_7	Imazethapyr followed by earthing up at 60 DAP	23.88^{c}
T_8	Glyphosate followed by earthing up at 60 DAP	8.64^{d}
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	25.75^{c}
T_{10}	Hoeing and earthing up at 30 and 60 DAP	0.00^{d}
T_{11}	UWC	56.28^{a}

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

4.3. Soil analysis

4.3.1. Soil pH

The data regarding the effect of various treatments on soil pH are depicted in Table 23. In general, the soil was acidic. The difference in soil pH among treatments was found to be not significant among treatments. The pH value ranged from 4.73 to 4.85.

4.3.2. Soil organic carbon

The data on soil organic carbon are presented in Table 24. The difference in soil organic carbon was not significant among the treatments. The organic carbon content ranged from 0.60 per cent to 0.68 per cent.

4.3.3. Available N, P and K

The data pertaining to the effect of treatments on the status of major available nutrients are given in Table 25. The available content of N was highest (165.87 kg/ha) in the plots treated with green manure cowpea, followed by pre emergence imazethapyr (T_3 -152.43 kg/ha) which was on par with oxyfluorfen (150.53 kg/ha). Lower N contents were obtained in hoeing and earthing up (T_{10}) and unweeded control plots (T_{11}).

The difference in the contents of available soil P was not significant among the treatments. Available P content ranged from 27.87 kg/ha to 36.52 kg/ha. Difference in exchangeable potassium content was significant among the treatments. Hoeing and earthing up (T_{10}) and unweeded control plots showed lower amounts of available K. All the other treatments were on par. High K content of 265.80 kg/ha was noticed in the plots of pre emergence imazethapyr (T_3), which was on par with all other treatments.

Table 23. Effect of treatments on soil pH

	Treatments	Soil pH
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	4.80[a]
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	4.83[a]
T_3	Imazethapyr 80g/ha (pre emergence)	4.85[a]
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	4.80[a]
T_5	Oxyfluorfen followed by earthing up at 60 DAP	4.83[a]
T_6	Pendimethalin followed by earthing up at 60 DAP	4.80[a]
T_7	Imazethapyr followed by earthing up at 60 DAP	4.80[a]
T_8	Glyphosate followed by earthing up at 60 DAP	4.73[a]
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	4.83[a]
T_{10}	Hoeing and earthing up at 30 and 60 DAP	4.81[a]
T_{11}	UWC	4.74[a]

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

Table 24. Effect of treatments on soil organic carbon

	Treatments	Soil organic carbon (%)
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	0.63[a]
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	0.64[a]
T_3	Imazethapyr 80g/ha (pre emergence)	0.68[a]
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	0.63[a]
T_5	Oxyfluorfen followed by earthing up at 60 DAP	0.66[a]
T_6	Pendimethalin followed by earthing up at 60 DAP	0.60[a]
T_7	Imazethapyr followed by earthing up at 60 DAP	0.68[a]
T_8	Glyphosate followed by earthing up at 60 DAP	0.62[a]
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	0.64[a]
T_{10}	Hoeing and earthing up at 30 and 60 DAP	0.61[a]
T_{11}	UWC	0.60[a]

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

Table 25. Effect of treatments on available nutrients in soil

Available nutrients (kg/ha)				
	Treatments	N	P	K
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	150.53[ab]	33.80[a]	245.00[a]
T_2	Pendimethalin 1.5 kg/ha (pre emergence)	140.20[abc]	36.00[a]	234.20[a]
T_3	Imazethapyr 80g/ha (pre emergence)	152.43[ab]	35.37[a]	265.80[a]
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	129.30[bcd]	34.87[a]	236.83[a]
T_5	Oxyfluorfen followed by earthing up at 60 DAP	130.37[bcd]	34.67[a]	241.53[a]
T_6	Pendimethalin followed by earthing up at 60 DAP	113.20[de]	33.57[a]	235.97[a]
T_7	Imazethapyr followed by earthing up at 60 DAP	142.30[abc]	35.37[a]	244.03[a]
T_8	Glyphosate followed by earthing up at 60 DAP	116.50[cde]	32.80[a]	229.43[ab]
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	165.87[a]	36.52[a]	248.93[a]
T_{10}	Hoeing and earthing up at 30 and 60 DAP	100.70[e]	29.92[a]	186.68[bc]
T_{11}	UWC	101.27[e]	27.87[a]	166.70[c]

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

Table 26. Effect of treatments on benefit:cost ratio

	Treatments	Cost of cultivation (Rs./ha)	Gross return (Rs./ha)	Net re (Rs./	
T_1	Oxyfluorfen 0.2 kg/ha (pre emergence)	1,53,467	3,49,074	1,95,	
T_2	Pendimethalin 1.5 kg/ha(pre emergence)	1,48,662	2,57,531	1,08,	
T_3	Imazethapyr 80g/ha (pre emergence)	1,49,367	2,33,025	83,658	1.56
T_4	Glyphosate 0.8 kg/ha (directed application at 30 DAP)	1,48,009	3,26,914	1,78,905	2.21
T_5	Oxyfluorfen followed by earthing up at 60 DAP	1,90,855	3,68,333	1,77,478	1.93
T_6	Pendimethalin followed by earthing up at 60 DAP	1,90,547	4,59,074	2,68,527	2.41
T_7	Imazethapyr followed by earthing up at 60 DAP	1,90,754	3,55,802	1,65,048	1.87
T_8	Glyphosate followed by earthing up at 60 DAP	1,90,500	4,26,543	2,36,043	2.24
T_9	Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP	1,93,568	3,45,926	1,52,358	1.79
T_{10}	Hoeing and earthing up at 30 and 60 DAP	2,48,069	4,67,654	2,19,585	1.89
T_{11}	UWC	1,43,973	2,03,765	59,792	1.42

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

- Labour charges (Men – Rs. 415/day and Women – Rs. 315/day)
- Price of cassava – Rs.15/kg
- Cost of oxyfluorfen – Rs.590/250ml
- Cost of pendimethalin – Rs. 470/1000 ml
- Cost of imazethapyr – Rs. 490/ 250 ml
- Cost of glyphosate – Rs. 400/1000ml

4.4. Economics

The data on B: C ratio are given in Table 26. The highest cost of production was for treatment with two hoeing and earthing up (2,48,069 Rs/ha). The treatment with Pendimethalin followed by earthing up at 60 DAP realized highest net returns (2,68,527 Rs./ha). The same treatment gave highest B:C ratio of 2.41. The next best was pre emergence application of oxyfluorfen (T_1) with a B: C ratio of 2.27. The least B:C ratio of 1.42 was obtained in unweeded control plot (T_{11}) followed by pre emergence application of imazethapyr (1.56).

Discussion

5. DISCUSSION

The experiment entitled "Weed management in cassava (*Manihot esculenta* Crantz)" was carried out at the Agronomy Farm attached to the Department of Agronomy, College of Horticulture, Vellanikkara from May 2015 to October 2015. The results obtained from the experiment are discussed below.

5.1. Effect of treatments on plant growth and yield

The plant height of cassava ranged from 38.5 cm to 41.19 cm, 60.11cm to 78.08 cm and 175.9 cm to 227.4 cm at 30 DAP, 60 DAP and harvest respectively (Table 3 and Fig.3). Difference in plant height at 30 DAP was not significant among treatments. However higher plant height (41.19 cm) was recorded for oxyfluorfen followed by earthing up at 60 DAP. The weed suppressing effect of oxyfluorfen during the initial days of plant growth could have enhanced the crop growth and consequently plant height during this period.

At 60 DAP, plant heights significantly differed among treatments. Directed application of glyphosate resulted in the greatest plant height. The reduction in weed competition in the plots which received directed application of glyphosate at 30 DAP might have suppressed the weeds and enhanced the plant height at 60 DAP. Aflakpui *et al.* (2007) recorded 45- 67 per cent taller cassava plants in the plots sprayed with glyphosate. At the time of harvest the difference in plant height became non significant. However hoeing and earthing up producedtaller plants compared to the other treatments.

Number of tubers per plant was higher when cassava was intercropped with cowpea and in treatment with hoeing and earthing up twice (Table 4). Padmapriya *et al.* (2008) reported an enhancement of yield components of cassava when intercropped with cowpea. This may be due to the beneficial effects of nitrogen fixation and subsequent soil enrichment. Better soil physical conditions by hoeing and earthing up might have contributed to better tuber growth. Higher value for girth of tuber (15.19 cm) was recorded for the plants, which received pre emergence application of imazethapyr followed by earthing up at 60 DAP.

Longer tubers were observed in plots with directed spray of glyphosate followed by earthing up and in plots with concurrent growing of cowpea followed by hoeing and earthing up (Table 5). Osundare (2007) had also reported that cassava intercropped with cowpea produced longer tubers than sole cassava. Compared to plots with pre emergence application of herbicides only, the plots with follow up digging and earthing up showed better values for yield attributing parameters. This showed the positive influence of tillage on root enlargement and thickening in cassava. According to Maurya and Lal (1980), plants grown without tillage were stunted due to lower porosity, greater bulk density and inadequate nutrient distribution in soil which slowed down root growth and development.

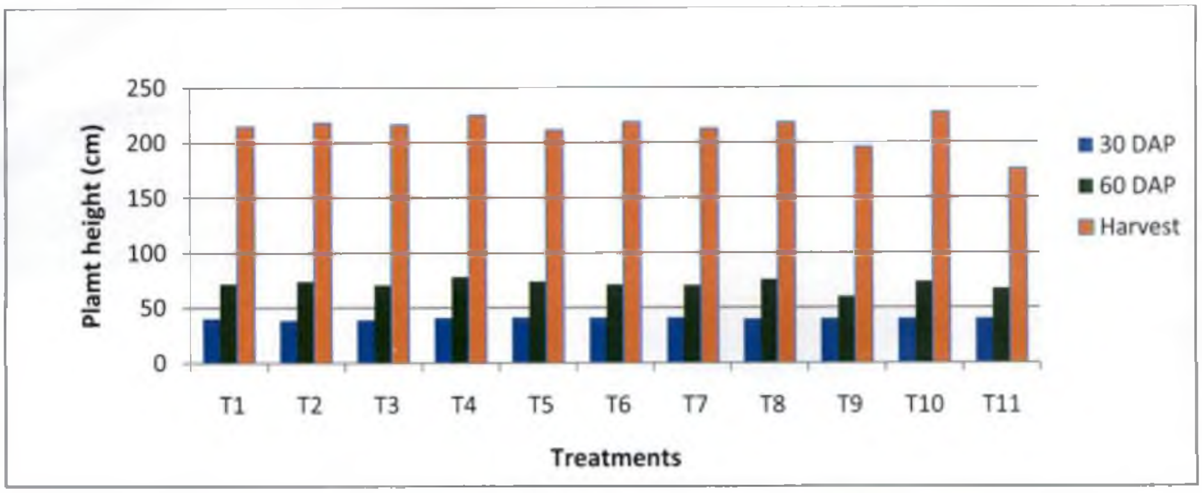

Fig 3.Effect of treatments on plant height (cm)

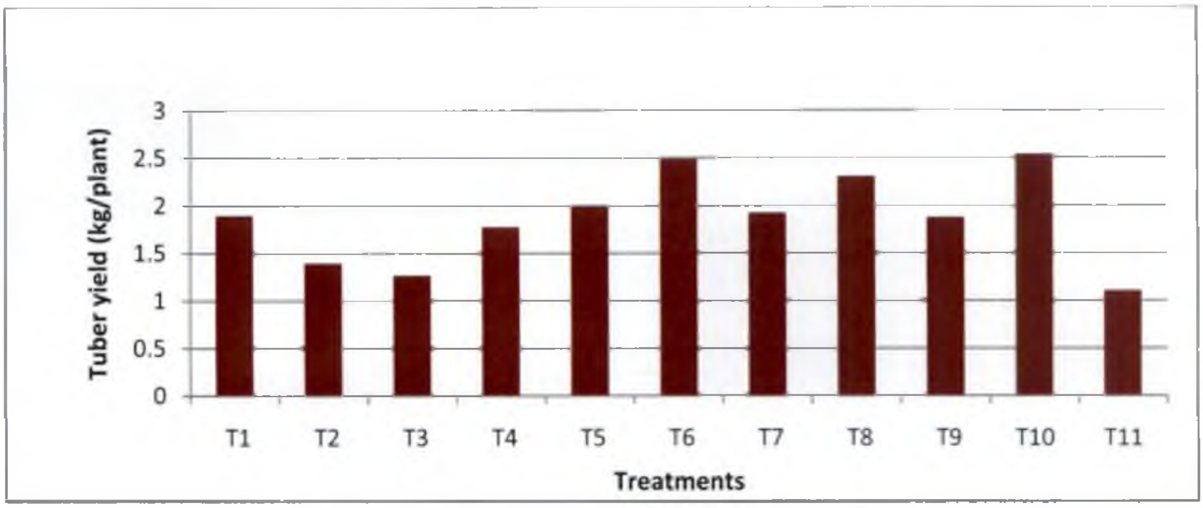

Fig 4. Effect of treatments on tuber yield (kg/plant)

T_1 – Oxyfluorfen 0.2 kg/ha (pre emergence)
T_2 – Pendimethalin 1.5 kg/ha (pre emergence)
T_3 – Imazethapyr 80g/ha (pre emergence)
T_4 – Glyphosate 0.8 kg/ha (directed application at 30 DAP)
T_5 – Oxyfluorfen 0.2 kg/ha followed by hoeing and earthing up at 60 DAP
T_6 – Pendimethalin 1.5 kg/ha followed by hoeing and earthing up at 60 DAP
T_7 – Imazethapyr 80g/ha followed by hoeing and earthing up at 60 DAP
T_8 – Glyphosate 0.8 kg/ha followed by hoeing and earthing up at 60 DAP
T_9 – Concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP
T_{10} – Hoeing and earthing up at 30 and 60 DAP
T_{11} – Unweeded control

Weed management practices significantly influenced the tuber yield of cassava. Higher tuber yields of 2.53 (31.20 t/ha), 2.48 (30.60 t/ha) and 2.30 (28.40 t/ha) kg/plant were obtained from the treatments, hoeing and earthing up two times, pendimethalin followed by earthing up and glyphosate followed by earthing up respectively (Table 7 and Fig. 4). Comparatively less weed competition during critical stages of crop growth might have contributed to better yields in these plots. Unweeded control plots produced the lowest tuber yield of 1.1 (13.5 t/ha) kg per plant. Compared to unweeded control plots, those treated with hoeing and earthing up showed 130 per cent higher yield. Compared to unweeded control, yield increase in the treatments, pendimethalin followed by earthing up and glyphosate followed by earthing up was 125 and 109 per cent respectively.

Akobundu (1980) reported high cassava tuber yields in plots with two or three hoe weedings. Superiority of post-emergence application of glyphosate in increasing cassava yields had been reported by Aflakpui *et al.* (2007). Yields obtained in the treatments with application of pre emergence herbicides followed by earthing up were higher compared to those without earthing up. According to Olorunmaiye *et al.* (2009), application of pre emergence herbicides followed by hoe weeding promoted long season weed control and thus better yield advantage. Among the different pre emergence herbicides tried, oxyfluorfen and pendimethalin gave better tuber yields. Nedunchezhiyan *et al.* (2013) reported the effectiveness of oxyfluorfen and pendimethalin for weed control and enhancing tuber yields in cassava.

The top yield among the treatments did not vary significantly (Table 8). However, dry matter production was highest for hoeing and earthing up followed by pendimethalin followed by earthing up (Table 9), which can be related with their higher tuber yields and top yield values. Cassava intercropped with cowpea had a lower dry matter production compared to other treatments. Decrease in dry matter accumulation in cassava when intercropped with cowpea was reported by Okoli (1996). This might be due to the competition of cowpea during early stages for nutrients, sunlight, water etc.

5.2. Effect of treatments on weed growth

The experimental field was predominantly infested with monocot and dicot weeds and some sedges. Common monocot weeds found in the experimental plot were *Panicum maximum, Allopteropsis cimicina, Commelina diffusa, Brachiaria milliformis, Axonopus compressus, Eleusine indica, Digitaria ciliaris, Imperata cylindrica, Cynodon dactylon* and *Pennisetum polystachion.* The dicot weeds included *Borreria hispida, Cleome burmanii, Ageratum conyzoides, Alternanthera bettzickiana, Pueraria phaseoloides, Hyptis suaveolens, Synedrella nodiflora, Euphorbia heterophylla, Boerhaavia diffusa* and *Tridax procumbens. Cyperus rotundus, Mariscus alternifolius* and *Cyperus haspan* were the major sedges.

The treatments considerably affected the weed population and dry matter production at all the four stages of observation. Compared to grass weeds, broad leaf weeds outnumbered at 30 DAP. The lowest counts for grass and broad leaf weeds were observed for the plots which received pre emergence application of oxyfluorfen (Table 10 and Fig. 5). At this stage, lower weed dry matter production was also observed for this treatment (Table 14 and Fig.6).

The treatment with pre emergence pendimethalin also caused lower weed dry matter production at 30 DAP. Nedunchezhiyan *et al.* (2013) and Gutierrez *et al.* (2008) also suggested the effectiveness of oxyfluorfen in controlling weeds in cassava. Pre emergence application of pendimethalin was the next best treatment in controlling the weeds. Plots with concurrent growing of cowpea showed higher total weed count (281.3 nos.) compared to other treatments. It may be due to the low canopy development of the cowpea variety used. According to Dwivedi and Shrivastava (2011), intercropping may not be able to provide satisfactory weed regulation at the early stages of crop growth due to low canopy development to suppress weeds.

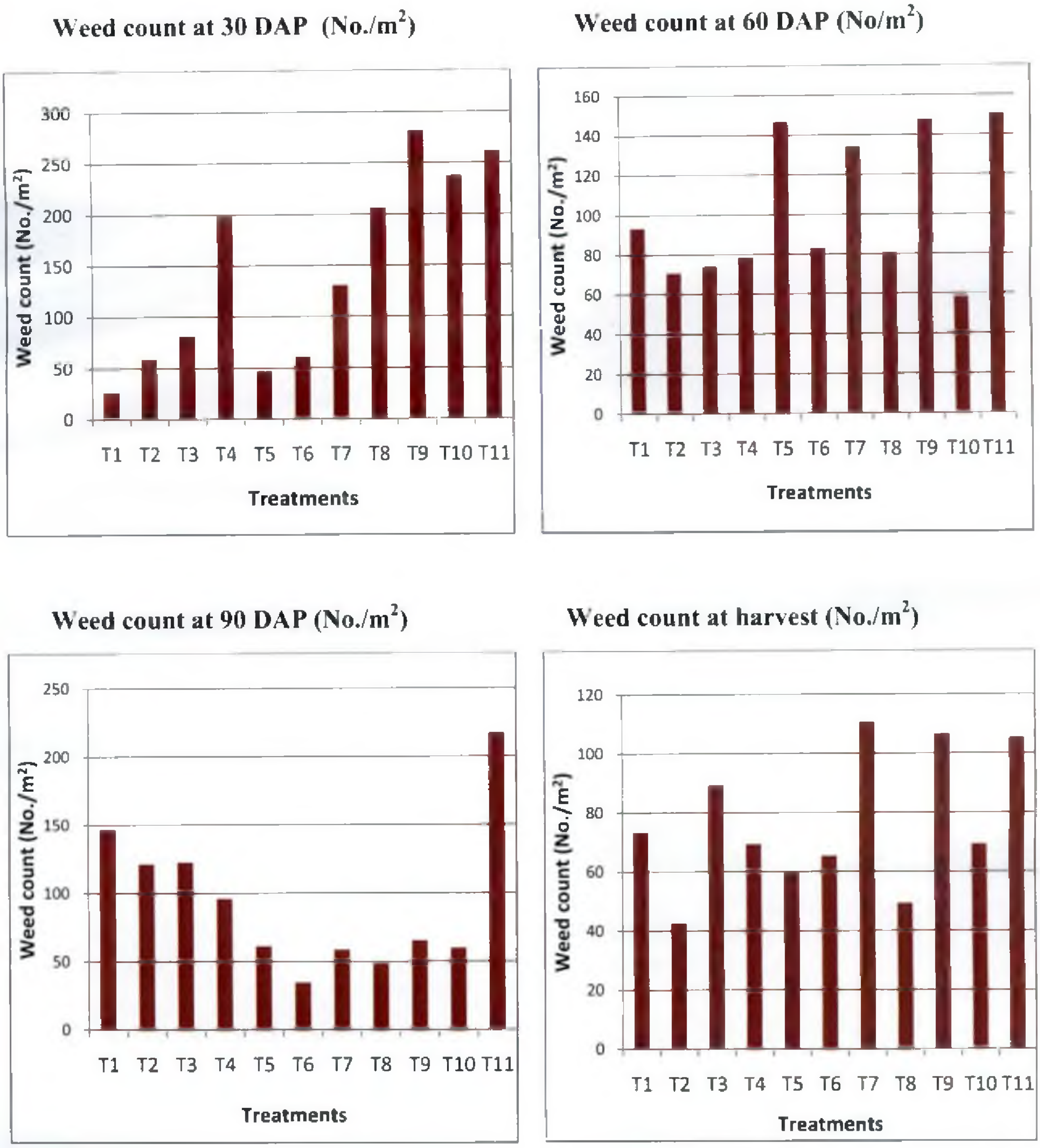

Fig. 5. Effect of treatments on weed count

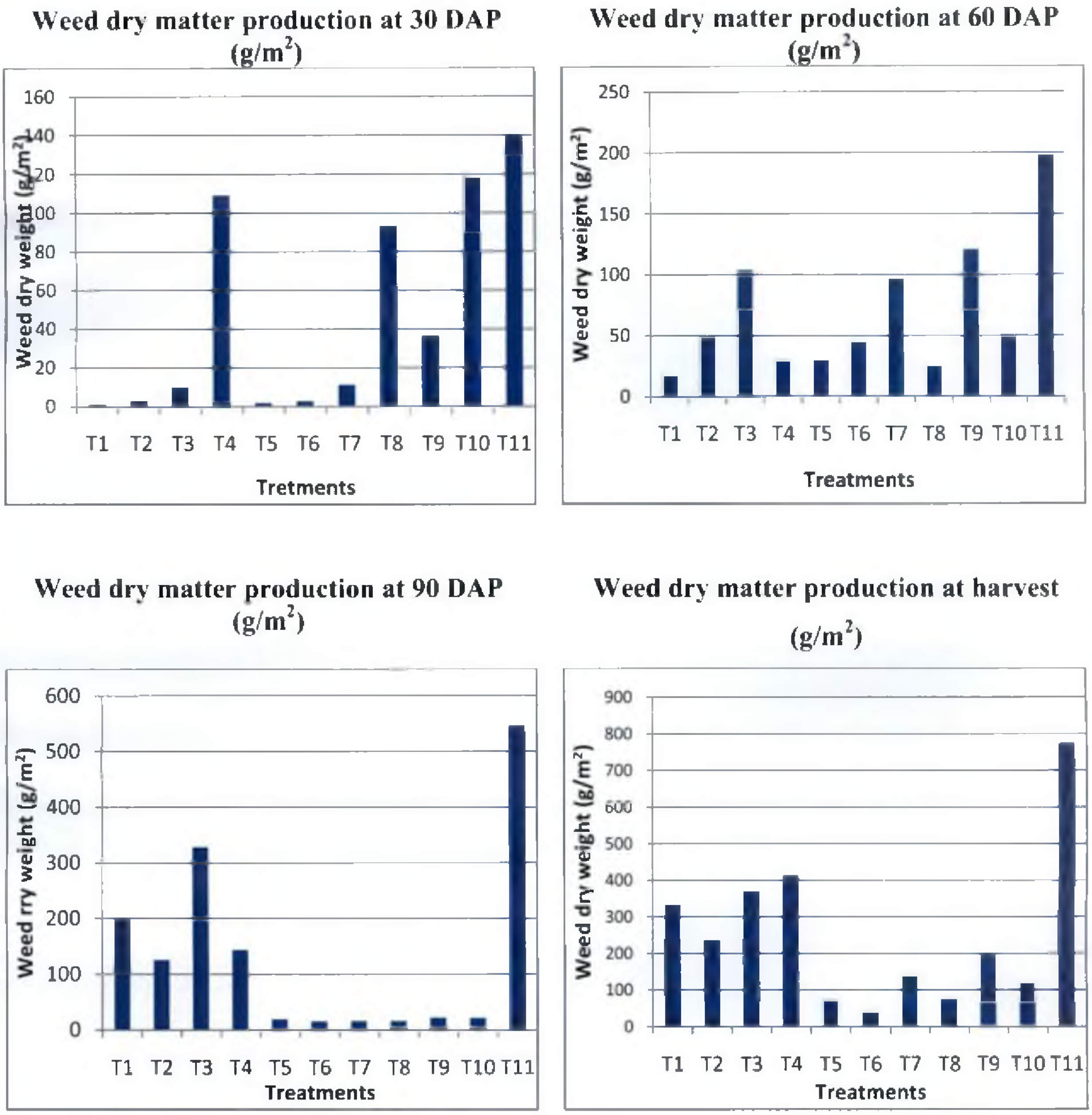

Fig. 6. Effect of treatments on weed dry matter productions

Borreria hispida was the dominant weed found in the experiment field at 60 DAP. The least grass weed count was recorded for the directed application of glyphosate (Table 11 and Fig 5). Hoeing and earthing up given at 30 DAP was not very effective in controlling the prominent grass weeds in the plots. However the least dicot weed count and total weed count were recorded for the plots which received hoeing and earthing up. However, the weed dry matter production was lower in plots treated with pre emergence oxyfluorfen followed by the directed application of glyphosate (Table 15 and Fig.6). Nedunchezhiyan *et al* (2015) reported the effectiveness of glyphosate for controlling weeds in cassava. Pre emergence oxyfluorfen also caused a lower weed count at 60 DAP.

At 90 DAP, the least grass weed count was recorded in the plots given hoeing and earthing up (Table 12 and Fig.5). According to Olorunmaiye *et al.* (2009), plots with hoe weeding recorded the least grass weed density compared to the weedy control plot. The treatment pendimethalin followed by earthing up showed the lowest total weed count. All the treatments with a follow up earthing up at 60 DAP produced lower weed dry matter production at 90 DAP (Table 16 and Fig. 6). Effectiveness of hoeing at 30 and 60 DAP for controlling weeds of cassava was reported by Moura (2000). According to Silva and Chabaribery (2006), tillage operations were highly effective in reducing the soil seed bank.

At the time of harvest, the plots given hoeing and earthing up had the least grass weed count (Table 13 and Fig.5). The least count of broad leaf weeds was in pre emergence application of pendimethalin. Considering the total weed count, the least count was noticed in pre emergence application of pendimethalin. The lowest weed dry matter production at the time of harvest was recorded by pendimethalin followed by earthing up. The next best was glyphosate followed by earthing up (Table 17 and

Fig.6). According to Melifonwu (1994), directed spray of glyphosate along with a follow up tillage was highly effective for controlling grass weeds.

5.3. Weed control efficiency and weed index

At 30 DAP, the highest weed control efficiency (99.28) was for the pre emergence application of oxyfluorfen (Table 18 and fig. 7). In cassava, Tongglum and Leihner (1983) also observed higher weed control efficiency for oxyfluorfen. Pre emergence pendimethalin and imazethapyr also exhibited higher weed control efficiencies at 30 DAP.

At 60 DAP, a high weed control efficiency of 91 per cent was shown by pre emergence oxyfluorfen followed by directed application of glyphosate followed by earthing up. All the treatments with follow up earthing up showed higher weed control efficiencies at 90 DAP. Melifonwu (1994) suggested the combination of herbicides and hoeing for the successful weed control in cassava. At the time of harvest pendimethalin followed by earthing up resulted in the highest weed control efficiency, being the next best treatments with oxyfluorfen followed by earthing up and glyphosate followed by earthing up. Treatments of directed application of glyphosate, pre emergence application of imazethapyr and oxyfluorfen without follow up earthing up showed very low weed control efficiencies towards later stages of crop. It shows the less persistence nature of these herbicides. According to Alister *et al.* (2009) half life of oxyfluorfen residues in soil is 34 to 52 days in sandy loam soils.

Weed index was lower in plots with hoeing and earthing up, pendimethalin followed by earthing up and glyphosate followed by earthing up (Table 22 and fig. 8). The treatment with pre emergence application of imazethapyr showed higher weed index. Low weed control efficiency and high weed index in treatments with imazethapyr shows the ineffectiveness of imazethapyr for checking crop weed competition in cassava. Li yu (2014) reported imazethapyr as a less effective herbicide for managing weeds in pea.

5.4 Nutrient removal by weeds and soil nutrient status after experiment

At all the four stages of observation, highest removal of N, P and K by weeds was recorded from unweeded control plots which ultimately resulted in lower tuber yields (Table 19, 20 and 21 and Fig.9). During initial stages of plant growth, removal of nitrogen by weeds was lower in plots with pre emergence application of oxyfluorfen. At later stages, pendimethalin was more efficient in controlling weeds and reducing nutrient uptake by weeds. At the time of harvest, pendimethalin followed by earthing up and glyphosate followed by earthing up were more efficient in controlling weeds, which ultimately resulted in lower weed nutrient uptake and higher tuber yields. Regarding uptake of phosphorus, at 30 DAP, the treatments with pre emergence application of herbicides showed lower uptake values. At 60 DAP, all the plots treated with herbicides, except for imazethapyr showed lower P uptake values. At 90 DAP and at harvest, all the treatments with follow up hoeing and earthing up showed lower values for P uptake by weeds.

Treatments with pre emergence application of oxyfluorfen and pendimethalin had lower potassium uptake values at 30 DAP. The effect of the pre emergence herbicides oxyfluorfen and pendimethalin in reducing K uptake extended up to harvest stage and their efficiency in controlling weed growth and reducing nutrient removal was enhanced by follow up tillage operation (Table 21). Mishra and Kurchania (1999) reported reduction in nutrient depletion by weeds in the treatments with herbicides. Based on an experiment conducted in soya bean - wheat cropping system, Chander *et al.* (2013) reported 89.2% less nitrogen, 89.1% less phosphorus and 88.9 % less potassium removal by weeds in plots with pendimethalin followed by chlorimuron ethyl than unweeded check.

At all the stages of observation, the nutrient removal by weeds was in the order K, N and P. According to Varghese and Nair (1986), weeds require more of K, followed by N and then P.

The soil pH, organic carbon and phosphorus contents of the soil did not show much variation in all the plots after the experiment (Tables 23, 24 and 25). However, available nitrogen and potassium contents showed significant differences. The plots with concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP showed the highest available nitrogen content after the experiment. This may be due to the effect of incorporation of green matter to these plots. In this experiment, the dry matter production by cowpea accounts around 1.6 t/ha and that contributed 20 kg/ha nitrogen to the soil. Padmapriya *et al.* (2008) reported improvement in soil nitrogen content when cassava was intercropped with cowpea.

Plots with no weed control measures had the lowest available potassium content. This may be due to the in extensive dry matter production by weeds. Similarly, the status of available potassium after the experiment was lower in plots given hoeing and earthing up twice. This can be attributed to high yields in these plots. Shivaprasad *et al.* (2005) reported the depletion of soil nutrient status due to high dry matter production in coffee.

5.5. Economic analysis

Among the various treatments, pre emergence application of pendimethalin followed by earthing up showed the highest B:C ratio of 2.41. Control of early emerging weeds by pendimethalin and late emerging weeds by earthing up resulted in better performance of the crop. The net return in this treatment accounts around 2.6 lakhs per ha. Pre emergence application of oxyfluorfen was the next best alternative with a B: C ratio of 2.27 (Table 26).

Unweeded control plot and pre emergence application of imazethapyr recorded lower B: C ratios. Because of the requirement of more labourers and more cost of production involved, although the yield was higher, hoeing and earthing up recorded a lower B: C ratio (1.89). Odoemenem and Otanwa (2011) reported the negative influence of labour charges on the profit of cassava cultivation. Quee *et al.* (2016) also reported high cost of production for hoe weeding in cassava compared to other weed control treatments. Therefore, it is better to reduce the number of earthing up in cassava and substitute one hoeing and earthing up with a pre emergence herbicide like pendimethalin. Pre emergence application of oxyfluorfen alone, which gave a B:C ratio of 2.27 is also a promising option in situation where labour scarcity is a problem.

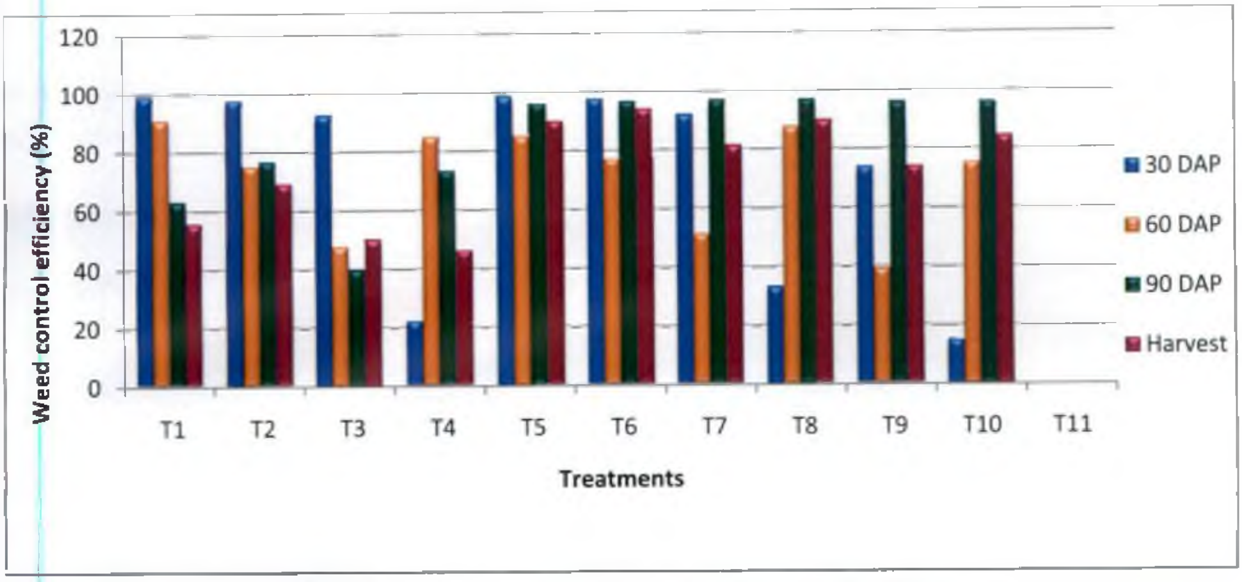

Fig 7. Effect of treatments on weed control efficiency

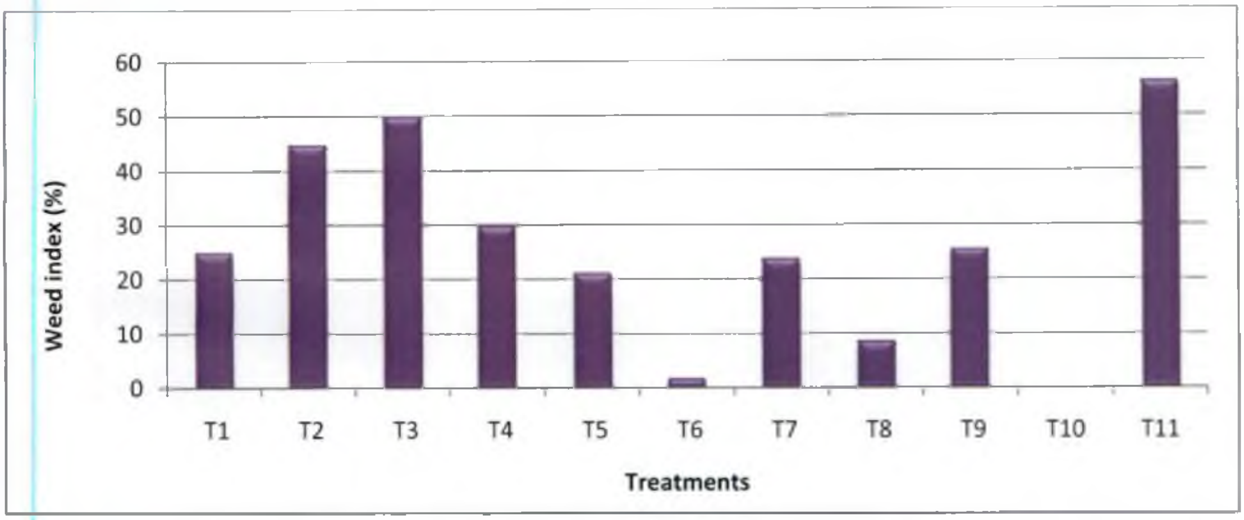

Fig 8. Effect of treatments on weed index

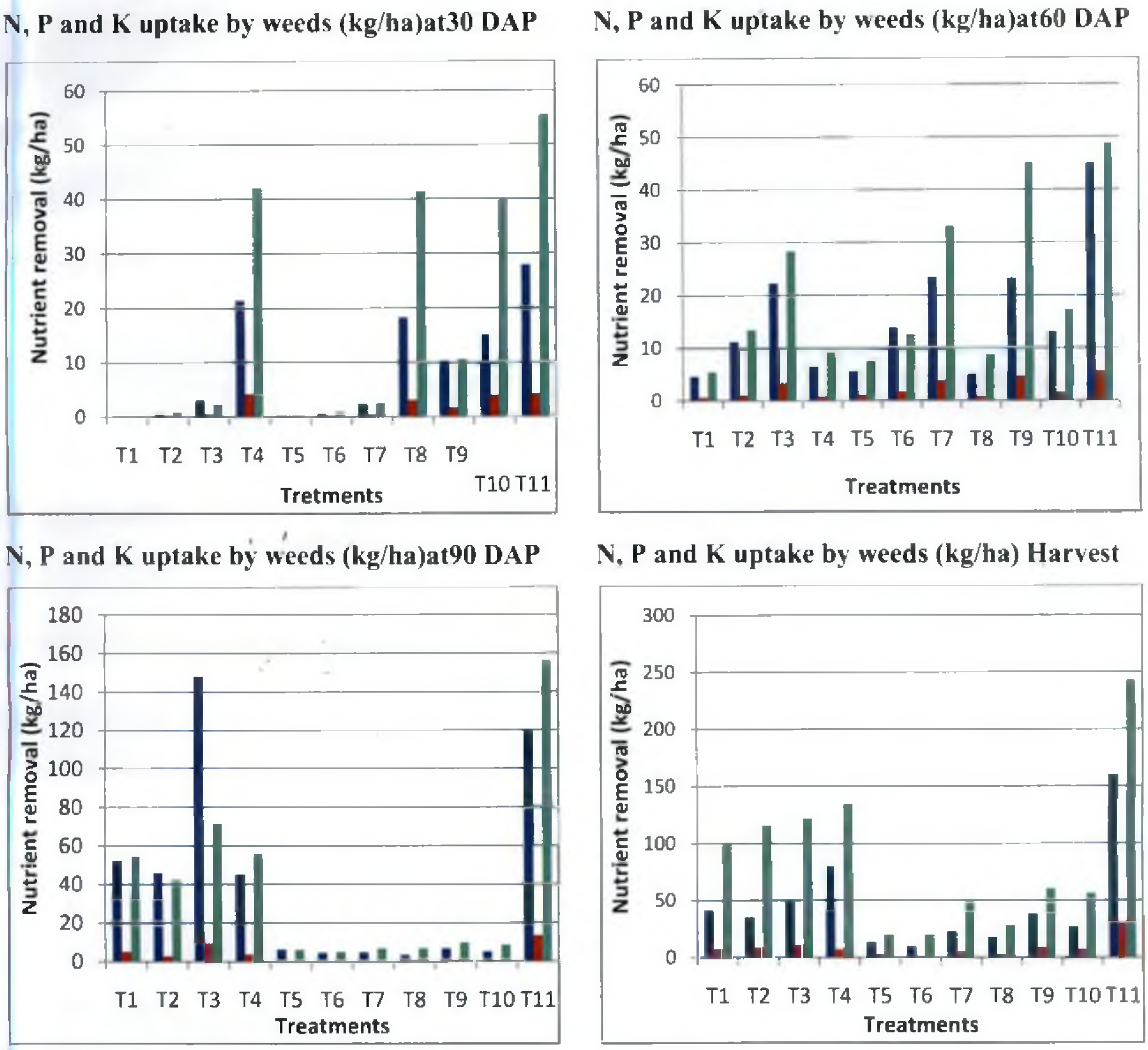

Fig 9. Effect of treatments on Nutrient removal by weeds

Summary

6. SUMMARY

Weeds, one of the major threats to crop production, cause huge economic losses by affecting the quantity and quality of crop produce. Many of the researchers have reported severe yield reduction in tuber crops by uncontrolled weed growth. Although many of the weed control measures like hoeing and earthing up, chemical herbicides and growing smother crops are popular among farmers, the shortage of labourers and lack of technical knowledge leads to acute yield losses. Therefore it is often felt to develop an appropriate and acceptable weed management practice, which aims at optimum yields without much economic loss.

An experiment was designed and conducted for developing a cost effective weed management package for cassava at the Agronomy Farm attached to the Department of Agronomy, College of Horticulture, Vellanikkara from May to October 2015. The experiment was laid out in Randomized Block Design (RBD) with 11 treatments and three replications and the plot size was 5.4 m x 5.4 m. The treatments included applications of three pre emergence herbicides viz., oxyfluorfen 0.2 kg/ha, pendimethalin 1.5 kg/ha and imazethapyr 80 g/ha, directed application of glyphosate 0.8 kg/ha at 30 DAP, pre emergence herbicides followed by one hoeing and earthing up at 60 DAP, hoeing and earthing up at two times at 30 and 60 DAP, concurrent growing of fodder cowpea and *in situ* green manuring and earthing up at 60 DAP and unweeded control plot.

Different weed management practices tried in the experiment did not show any significant difference with respect to plant height, except at 60 DAP. However, hoeing and earthing up showed a positive influence on plant growth. Number of tubers per plant was higher when cassava was intercropped with cowpea and the treatment, which received hoeing and earthing up at two times. Longer tubers were recorded in the treatments, glyphosate followed by earthing up and fodder cowpea.

Weed management treatments significantly affected the growth and yield characters of cassava. Higher tuber yields were recorded for the treatments hoeing and earthing up, pendimethalin followed by earthing up and glyphosate followed by earthing up. These treatments also showed a higher top yield and greater dry matter production. Even though the yield components were better in cowpea green manured plots, it showed a lower dry matter production.

All the treatments significantly influenced the weed population and weed dry weight at all the four stages of plant growth. Pre emergence oxyfluorfen was more successful for controlling weeds at the early stages of planting and it could control 99 per cent of weeds in the treated plot. Weed control efficiency of all the treatments increased with a follow up earthing up. Hoeing and earthing up given at 30 and 60 DAP significantly influenced the weed population and weed dry weight at 90 DAP and at harvest. Towards later stages of crop growth, pendimethalin followed by earthing up was more effective in suppressing the weeds and it gave 94 per cent control of weeds during harvest. Individual application of imazethapyr as pre emergence spray was less effective in controlling the weeds and it recorded a lower weed control efficiency compared to other plots. Reduction in tuber yield was more pronounced in plots with pre emergence application of imazethapyr alone. Weed index was lower in plots with hoeing and earthing up, pendimethalin followed by earthing up and glyphosate followed by earthing up.

At all the four stages, unweeded control plots resulted in the highest removal of nutrients. Plots with pre emergence oxyfluorfen resulted in lower nutrient uptake during early stages of plant growth. At the time of harvest, pendimethalin followed by earthing up and glyphosate followed by earthing up had lower nutrient uptakes, which ultimately resulted in higher tuber yields.

Soil pH, organic carbon and phosphorus contents of the soil remained on par in all the plots after the experiment. However, the contents of available N and K showed significant differences among the treatments. Green manure cowpea plots recorded higher available nitrogen content after the experiment. The status of available potassium after the experiment was lower in plots, which received hoeing and earthing up at two times.

The highest B: C ratio of 2.41 was obtained in pre emergence application of pendimethalin followed by earthing up. Pre emergence oxyfluorfen also showed higher B:C ratio of 2.27. Unweeded control plot and pre emergence application of imazethapyr fetched lower B: C ratios. Even though hoeing and earthing up produced higher tuber yields, the B:C ratio was lower because of the additional labour requirement.

From the studies, it can be concluded that weed control by hoe weeding alone may lead to high cost of production for cassava due to the extensive labour requirements. Pre emergence herbicides are better substitutes to manual weeding. However, it is prudent to practice pre emergence herbicides along with a follow up earthing up as earthing up is necessary for tuber development. So the study recommends to reduce the number of earthing up by substituting it with a pre emergence herbicide like pendimethalin without seriously affecting the B:C ratio.

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Appendices

Appendix-1

Standard week	Date and month	Temperature (^{0}C)		Mean relative humidity (%)	Total rainfall (mm)	No. of rainy days	Mean Evaporation (mm)
		Max.^{0}C	Min.^{0}C				
20	15/05-21/05	32.4	24.8	81	99.0	3	2.4
21	22/05-28/05	33.3	25.5	79	3.0	2	3.1
22	29/05 – 5/06	32.7	25.1	78	14.8	1	2.8
23	06/06 – 12/06	31.9	24.2	82	44.5	4	2.5
24	13/06– 19/06	30.4	23.3	85	160.6	6	2.6
25	19/06 – 25/06	30.4	24.9	89	196.8	7	2.7
26	26/06 – 02/07	30.5	23.9	86	228.6	7	2.6
27	03/07–09/07	31.5	23.9	94	57.9	7	3.6
28	10/07– 16/07	30.6	23.8	94	101.4	5	3.0
29	17/06 – 23/07	27.9	23.3	91	257.2	7	1.7
30	24/06– 30/07	30.3	23.2	82	85.9	4	2.5
31	31/07– 06/08	30.9	24.8	81	22.0	2	2.9
32	07/08– 13/08	30.0	24.4	87	128.2	7	3.4

Standard week	Date and month	Temperature (^0C)		Mean relative humidity (%)	Total rainfall (mm)	No. of rainy days	Mean Evaporation (mm)
		Max.^0C	Min.^0C				
33	14/08– 20/08	31.6	23.9	80	114.9	4	3.0
34	21/08 – 27/08	31.8	23.5	82	41.0	1	2.9
35	28/08 – 03/09	31.9	23.9	79	16.6	2	3.5
36	04/09 – 10/09	31.5	23.5	84	88.6	6	2.7
37	11/09 – 17/09	31.8	23.6	80	47.2	4	3.1
38	18/09 – 24/09	31.7	23.9	82	37.6	1	2.7
39	25/09 – 1/10	32.8	23.7	79	73.6	3	3.4
40	2/10 – 8/10	31.6	23.8	85	74.6	4	2.4
41	9/10 – 15/10	32.0	23.9	82	72.0	5	2.7

WEED MANAGEMENT IN CASSAVA

[*Manihot esculenta* Crantz]

By

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(2014-11-131)

ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the requirement for the degree of

Master of Science in Agriculture

(Agronomy)

Faculty of Agriculture

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KERALA, INDIA

2016

ABSTRACT

Cassava, one of the most important tropical tuber crops, is known to sustain even under marginal soil conditions. Being a widely spaced crop with slow initial growth, a wide spectrum of weeds has been reported in cassava fields, which may cause yield losses up to 90 per cent. Weeding is the main labour consuming activity of cassava fields as it is usually carried out by tillage practices and earthing up. Presently, chemical weed control is becoming popular among farmers as it is an efficient way of weed control with minimum labour cost. However, relying only on chemical weed control may not be feasible in the long term. Developing a complete weed management package by integrating chemical, physical and cultural methods may be the best option in cassava to achieve optimum yield.

The present study entitled "Weed management in cassava (*Manihot esculenta* Crantz)" was carried out at the Agronomy Farm attached to the Department of Agronomy, College of Horticulture, Vellanikkara from May to October 2015 to compare different weed management practices for cassava. The treatments included applications of three pre-emergence herbicides *viz.*, oxyfluorfen 0.2 kg/ha, pendimethalin 1.5 kg/ha and imazethapyr 80g/ha, directed application of glyphosate 0.8 kg/ha at 30 days after planting (DAP), all this four herbicides followed by one hoeing and earthing up at 60 DAP, hoeing and earthing up twice at 30 and 60 DAP, concurrent growing of cowpea and *in situ* green manuring and earthing up at 60 DAP, and unweeded control plot.

Weed management treatments significantly affected the growth and yield characters. Number of tubers per plant was high when cassava was intercropped with cowpea and when hoeing and earthing up was done twice. These two treatments also produced longer cassava tubers.

Higher tuber yields were obtained from the treatments, hoeing and earthing up (31.20 t/ha), pendimethalin followed by earthing up (30.60 t/ha) and glyphosate followed by

earthing up (28.40 t/ha). These treatments also showed higher top yield and greater dry matter production.

The treatments significantly influenced the weed population and weed dry weight at all the four stages of plant growth. The herbicide oxyfluorfen could control 99 per cent of weeds at 30 DAP. Pendimethalin followed by earthing up was more effective in suppressing the weeds in later stages and it resulted in 94 per cent control of weeds by harvest. Weed control efficiency of all the treatments increased with a follow up earthing up. Pre emergence application of imazethapyr alone was less effective in controlling the weeds and it resulted in lower weed control efficiency compared to other plots. Weed index was lower in the treatments, hoeing and earthing up, pendimethalin followed by earthing up and glyphosate followed by earthing up. Lower nutrient uptake by weeds was obtained in the treatment which received pre emergence application of oxyfluorfen during early stages of plant growth. At the time of harvest, the treatments pendimethalin followed by earthing up and glyphosate followed by earthing up resulted in lower uptake of nutrients.

The soil pH, organic carbon and phosphorus contents of the soil were statistically on par in all the plots after the experiment. However, the contents of available N and K showed significant differences among the treatments. Green manure cowpea intercropped plots had higher available nitrogen content after the experiment.

The highest B:C ratio of 2.41 was obtained for the treatment pre emergence application of pendimethalin followed by earthing up. Application of pre emergence oxyfluorfen resulted in a high B:C ratio of 2.27. Even though hoeing and earthing up produced higher tuber yields, the B:C ratio was lower because of the additional labour requirement. The results of the present investigation suggest the possibility of reducing the number of earthing up in cassava by applying a pre emergence herbicide such as pendimethalin.