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Effect of weed control methods on the yield and starch content of storage root of cassava (*Manihot esculenta*) and soil health

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ABSTRACT

A field experiment was conducted to study the effect of different weed control methods on the yield and starch content of storage root of cassava (*Manihot esculenta* Crantz) grown under irrigated conditions. The results revealed that weed control ground cover (WCGC)/weed control mat mulching and four manual weeding at 1, 2, 3 and 4 MAP significantly reduced the dry weed biomass. The mean fresh storage root yield of cassava obtained from the plots where WCGC was used statistically at par with the storage root yield of cassava from the plots where four manual weedings were done. Compared to four manual weedings, pre-emergence application of oxyfluorfen along with two manual weedings at 2, 3 MAP and two manual weedings at 1, 2 MAP along with post-emergence application of glyphosate at 3 MAP resulted in insignificant reduction (9.6 and 10.1%, respectively) in the storage root yield. Compared to other methods of weed control, WCGC resulted in maximum dry matter partitioning efficiency and soil microbial population. Application of glyphosate had no adverse effect on the starch content of storage root but resulted in higher soil organic carbon.

Key words: Cassava, Root yield, Starch content, Weed control

Weeds are one of the major biotic constraints that compete with crops for space, light, water and nutrients, when crop plants and weeds grow in close proximity and their root or shoot system overlaps and attribute for reduction in crop productivity and quality of agricultural produces (Rao *et al*. 2015). Traditionally, weed control in India is largely dependent on manual weeding. Nevertheless, labour scarcity and high wages compels farmers to opt for alternative options (Rao *et al*. 2015). Cassava (*Manihot esculenta* Crantz) is a long duration (7 to 10 months) crop cultivated under wider plant spacing of 90 × 90 cm. The canopy of the plant covers the ground after three months due to initial slow growth which allows weeds to grow fast (Srinivasan and Maheswarappa 1993) and this is one of the major constraints for cassava production. Weed infestation at an early stage causes severe yield losses and it may go up to 100% (Ambe *et al*. 1992). Weeding consumes about 30% of total labour input and about 150-200 man days/ha. Under irrigated conditions in Tamil Nadu, farmers do up to five manual weedings for cassava and spend ₹ 37,000 to 50 000/ha (Ravindran and Ravi 2009).

Chemical method (herbicides application) of weed control can reduce the dependency on manual weeding. Furthermore, weed control through herbicide application will be faster than manual weeding. Herbicides are likely to become inevitable method of weed control in cassava especially where labour is scarce or expensive or farm size is large (Agahiu *et al*. 2011). In sandy soils of Nigeria, application of pre-emergence herbicide primextra 2.0 kg a.i./ha was found sufficient for weed control in rainfed cassava fields (Enyong *et al*. 2013). But, Doll and Piedrahita (1976) reported that single application of herbicide was not sufficient for weed control and it should be supplemented with manual or mechanical weeding.

Mulching suppresses the weed growth and population. Weed control ground cover (WCGC) / weed control mat mulching even prevents germination of weed seeds by arresting sun light and solarizing the soil while the soil remains undisturbed. Beneficial effects of WCGC mulching for weed control in widely spaced crops are known (Halemani *et al*. 2009, Mamkagh 2009). The information on the effects of herbicides and WCGC mulching for weed control in cassava is scarce. Keeping in view of the above, the study was conducted with an objective to find out the effect of different weed control methods on the yield and starch content of storage root and identify the best weed control method for weed management in cassava under irrigated conditions.

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MATERIALS AND METHODS

A field experiment was conducted for consecutive three years (2010-11 to 2012-13) at the ICAR-Central Tuber Crops Research Institute, Regional Centre, Dumuduma, Bhubaneswar under irrigated conditions. The experiment was laid out in a randomized block design (RBD) with three replications. The treatments consisted of: T_1-weedy check (control); T_2- two manual weedings at 1 and 2 month after planting (MAP); T_3-four manual weeding at 1, 2, 3 and 4 MAP (weed free check); T_4-pre-emergence (PrE) application of oxyflourfen @ 0.06 kg a.i./ha at 1 day after planting (DAP); T_5- PrE application of oxyflourfen @ 0.06 kg a.i./ha at 1 DAP) + 1 manual weeding at 3 MAP; T_6- PrE of oxyflourfen @ 0.06 kg a.i./ha at 1 DAP + 2 manual weeding at 2 and 3 MAP; T_7-post-emergence (PoE) application of glyphosate @ 2.0 kg a.i./ha at 1 MAP; T_8-one manual weedings at 1 MAP + PoE application of glyphosate @ 2.0 kg a.i./ha at 2 MAP; T_9-two manual weeding at 1 and 2 MAP + PoE application of glyphosate @ 2.0 kg a.i./ha at 3 MAP and T_{10}-weed control ground cover (WCGC).

The oxyfluorfen @ 0.06 kg/ha was applied as PrE on the ground one day after planting (DAP) cassava. Glyphosate @ 2.0 kg/ha was applied as PoE directly on weeds. WCGC (100 micron) was spread on the ridge and furrows and the ends were covered with soil. The variety H-226 was planted at 75 × 75 cm spacing. The crop was irrigated through drips. Irrigation was withheld 15 days before harvest. Farmyard manure (FYM) @ 12.5 tonnes/ha and N-P_2O_5-K_2O @ 100-75-100 kg/ha were applied. FYM was incorporated in the soil during the last plough. Full dose of phosphorus and half doses of nitrogen and potassium were applied as basal at the time of planting and the remaining half doses of nitrogen and potassium were applied at 3 MAP through drip irrigation. The crop was harvested at 10 MAP. Data on dry weed biomass, yield and starch content of storage root, and soil microbial populations were recorded.

For estimating microbial population soil samples were collected from all the treatments. Each sample was dried, sieved and 10 g soil sample was diluted in distilled water to 10^{-1} in 250 ml conical flasks. The flasks were kept in orbital shaker for 15 min at 28ºC. Soil suspension was serially diluted as per the standard procedure to make 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5} and 10^{-6} dilutions. For enumerating fungal colonies, one ml of the dilution (10^{-4}) was transferred into sterile Petri dish, approximately 20 ml of molten and cooled RBA (HIMEDIA) was poured to the plate and the suspension was mixed thoroughly by gentle rotations of the plate. Same procedure was adopted to get bacterial and actinomycetes population. Dilution of 10^{-6} and Nutrient Agar Medium (HIMEDIA) were used for bacterial enumeration. Similarly, 10^{-5} dilution and Kenknight and Munaier's Medium were used for actinomycetes enumeration. Three replicates were kept for each treatment and the plates were incubated at room temperature (28±2ºC). The plates were observed daily and colony count was taken on 2nd, 4th and 6th day for bacterial, fungal and actinomycetes populations, respectively, and expressed as cfu/g soil.

Data on weeds (x) were subjected to square root transformation (x + 1) before statistical analysis. Data were analyzed using SASS 11.0 version. Analysis of variance (ANOVA) was carried out appropriate to the design of experiment. Treatment means were compared using critical difference (CD) at 5% probabilities.

RESULTS AND DISCUSSION

The major weed species observed in the cassava fields were grouped as: sedges, grasses and broad-leaved weeds; one sedge - *Cyperus rotundus* L.; four grasses - *Dactyloctenium aegyptium* (L.) Beauv., *Digitaria sanguinalis* L., *Cynodon dactylon* L., *Echinochloa crusgalli* (L.) Beauv. and seven broad-leaved species - *Borreria hispida* L., *Celosia argentia* L., *Ageratum conyzoides* L., *Commelina benghalensis* L., *Cleome viscosa* L., *Mimosa pudica* L., *Phyllanthus niruri* Hook. In the present study, nine weed control treatments were evaluated along with one weed free check and weedy check as control and the results are reported.

Effect on dry weed biomass and nutrient uptake by weeds

Dry weed biomass is an important parameter to assess the crop-weed competition for the crop growth and productivity. All the nine weed control treatments resulted in significant reduction in weed dry biomass compared with weedy check (Table 1). WCGC mulching (T_{10}) significantly reduced the dry weed biomass to the lowest (3.2 g/m^2) owing to complete cover of the ground which did not allow weeds to germinate and emerge. The treatment T_3-four manual weeding at 1, 2, 3 and 4 MAP resulted in significantly the next lowest dry weed biomass (18.6 g/m^2) due to regular and frequent removal of weeds. The treatments T_8 and T_9 (manual weeding either one at 1 MAP or two at 1 and 2 MAP) along with post-emergence application (PoEA) of glyphosate at 2 or 3 MAP, respectively, resulted in significantly lower dry weed biomass as compared to T_1 (weedy check). The PrE application of oxyfluorfen at 1 DAP alone (T_4) or along with one manual weeding at 3 MAP (T_5) or two manual weeding at 2 and 3 MAP (T_6), and PoE application of glyphosate alone at 1 MAP (T_7) or along with one manual weeding at 1 MAP (T_8), resulted in considerably more dry weed biomass (33.3 -83.0 g/m^2) due to new flushes of weeds and are not efficient for weed control in cassava under irrigated conditions. Two manual weeding in combination with herbicides (T_6 and T_9) significantly reduced dry weed biomass (38.2 and 27.8 g/m^2, respectively). Weed control efficiency was also greater (82.0 – 98.5%) in the treatments T_3, T_6, T_8, T_9 and T_{10} (Nedunchezhiyan *et al*. 2015). Oxyfluorfen causes disruption of the cells, ionic balance and ultimately death of weeds (Rao 2000). Pre and post-emergence herbicides are effective up to 20-30 days (Balusamy and Pothiraj 1989).

Nutrient uptake by weeds under different treatments had direct relationship with dry weed biomass production (Table 1). WCGC mulching (T_{10}) significantly reduced the N, P and K uptake by weeds to the minimum resulting in the

Table 1 Dry weed biomass, weed nutrient uptake and storage root yield of cassava as influenced by weed control methods (3 years pooled data)

Treatment	Weed dry biomass (g/m^2)	Nutrient uptake by weeds (kg/ha)			Fresh root yield (t/ha)	Shoot yield (t/ha)	Root: shoot ratio
		N	P	K			
T_1-Weedy check	14.6 (212.4)	64.6	18.3	47.4	12.5	14.2	0.88
T_2- Two manual weeding (at 1 and 2 MAP)	8.1 (63.9)	19.2	5.9	15.4	27.0	29.6	0.91
T_3- Four manual weeding (at 1, 2, 3 and 4 MAP)	4.4 (18.6)	5.8	1.7	4.3	36.5	34.6	1.05
T_4- Oxyfluorfen @ 0.06 kg a.i./ha (pre emergence application at 1 DAP)	9.2 (83.0)	25.4	7.4	18.8	24.7	27.1	0.91
T_5- Oxyfluorfen @ 0.06 kg a.i./ha (pre emergence application at 1 DAP) + one manual weeding (at 3 MAP)	6.7 (43.3)	13.2	3.8	9.7	30.4	32.0	0.95
T_6- Oxyfluorfen @ 0.06 kg a.i./ha (pre emergence application at 1 DAP) + two manual weeding (at 2 and 3 MAP)	6.3 (38.2)	11.7	3.4	8.6	33.0	33.8	0.98
T_7- Glyphosate @ 2.0 kg a.i./ha (post emergence application at 1 MAP)	7.6 (57.1)	14.7	4.3	10.8	27.7	30.1	0.92
T_8- One manual weeding (at 1 MAP) + glyphosate @ 2.0 kg a.i./ha (post emergence application at 2 MAP)	5.9 (33.3)	8.6	2.5	6.3	31.7	33.0	0.96
T_9- Two manual weeding (at 1 and 2 MAP) + glyphosate @ 2.0 kg a.i./ha (post emergence application at 3 MAP)	5.4 (27.8)	7.2	2.0	5.3	32.8	33.5	0.98
T_{10}- WCGC mulching	2.0 (3.2)	1.0	0.3	0.7	34.1	34.0	1.00
CD (P=0.05)	0.5	1.2	0.3	0.8	2.7	2.8	-

*Figures in parenthesis indicate original values. Data transformed to square root transformation (x + 1).

negligible loss of these nutrients due to weeds as compared to other treatments. The reduction in N, P and K uptake by weeds was significantly greater due to the pre or post-emergence application of herbicides in combination with manual weeding (T_2,T_3,T_5,T_6,T_8,T_9) than the application of herbicide alone (T_4 and T_7). Maximum uptake of N, P and K @ 64.6, 18.3 and 47.4 kg/ha, respectively, by weeds was noticed in weedy check (T_1) owing to maximum dry weed biomass production. Considering the uptake of N, P and K nutrients by cassava (128.3 -199.85 kg N/ha, 16.37-25.35 kg P/ha and 95.9-195.85 kg K/ha) (Putthacharoen *et al*. 1998, Howeler 2002, Amanullah 2007, Amanullah *et al*. 2007), weeds attributed for the significant loss of nutrients.

Effect on cassava storage root yield

Significant variation in storage root yield of cassava was observed among different weed control treatments (Table 1). Maximum storage root yield (36.5 tonnes/ha) was obtained in the treatment T_3 (weed free check) due to four hand weeding and was statistically at par with the yield obtained (34.1 tonnes/ha) in the treatment T_{10} due to WCGC. The storage root yields obtained in treatments T_5, T_6, T_8 and T_9 varied between 30.4 and 34.1 tonnes/ha and the differences in the yields were statistically not significant. The storage root yields obtained in treatments T_5, T_6, T_8 and T_9 were statistically at par with the yield obtained in the treatment T_{10} but were significantly lower than the yield obtained in the treatment T_3.

The results indicate that effective control of weeds in treatments T_3, T_5, T_6, T_8, T_9 and T_{10} (Table 1) led to more storage root yields in these treatments (Table 1). Four time manual weeding, combination of an early control of weeds at the germination and emergence stage through application of PrE herbicide along with manual weeding, application of post-emergence herbicide along with manual weeding could effectively control weeds and check loss of major nutrients relatively for a longer period which improved storage root yield in the above treatments. Nedunzhiyan *et al*. (1998) observed a negative linear relationship between dry biomass of weeds and tuber yield in cassava. Stiff weed competition due to two manual weeding at 1 and 2 MAP (T_2), PoE application of glyphosate alone at 1 MAP and PrE application of oxyfluorfen alone at 1 MAP (T_4) significantly reduced storage root yield. The reduction in storage root yield obtained from the treatments T_2 and T_4 were 26.03 and 32.33%, respectively, as compared to four manual weeding (weed free check). This indicates that two manual weeding (at 1 and 2 MAP) or application of herbicides alone either pre (oxyfluorfen) or post emergence (glyphosate) will not be sufficient for preventing weed competition for ten months duration in cassava. Two glyphosate applications provided more consistent control of season-long annual grass and broadleaf weeds and greater corn grain yield compared with a single application (Gower *et al*. 2003). The maximum dry weed biomass, nutrient loss, crop-weed competition for nutrients, space, water and light attributed for maximum reduction (58.89-65.75%) in storage root yield in weedy check plots (T_1) as compared to treatments T_3, T_5, T_6, T_8 and T_9 and T_{10}.

Oxyfluorfen (also goal, oxygold) (Nitrofluorfen 12-chloro-l-(4-nitrophenoxy)-4-(trifluoromethyl) benzenel, $C_{15}H_{11}ClF_3NO_4$), is a selective, contact herbicide and a member of the diphenyl ether group of herbicides. It inhibits specific enzyme, protoporphyinogen oxidase (PPO) present in the chloroplast that oxidizes protoporphyrinogen to produce protoporphyrin IX. This product is important because it is a precursor molecule for both chlorophyll (needed for photosynthesis) and heme (needed for electron transfer chains). The inhibition of PPO leads to accumulation of phototoxic heme and chlorophyll precursors, which in presence of light, produce activated oxygen species causing oxidative stress in weed plants.

Several research findings indicated that oxyfluorfen @ 240-400 g/ha effectively controlled broad leaved weeds in the fields of broccoli (Daugovish *et al*. 2008), onion (Sukhadia *et al*. 2000, Sathyapriya *et al*. 2013a), chilli pepper (Amador-Ramirez *et al*. 2007), cauliflower (Qasem 2007) and cabbage (Hatterman-Valenti and Auwarter 2007). Pre-emergence application of oxyfluorfen most effectively decreased the number of annual broad leaved weeds in onion and cabbage (Stall and Gilreath 2003). In an onion field, PrE application of oxyfluorfen at 250, 300 and 400 g/ha along with one manual weeding on 45 DAS resulted in effective control of broad leaved weeds, grasses and to some extent sedge due to its broad spectrum action (Sathyapriya *et al*. 2013a). Application of oxyfluorfen (23.5% EC) @ 300-400 g/ha considerably reduced dry weed biomass in onion field (Sathyapriya *et al*. 2013a).

Glyphosate (also Roundup), an organophosphorus compound (*N*-(phosphonomethyl) glycine), is a non-selective, broad-spectrum systemic herbicide. Glyphosate kills plants by interfering with the synthesis of the aromatic amino acids, viz. phenylalanine, tyrosine, and tryptophan. It does this by inhibiting the enzyme 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS), which catalyzes the reaction of shikimate-3-phosphate (S3P) and phosphoenolpyruvate to form 5-enolpyruvyl-shikimate-3-phosphate (EPSP). Inhibiting the enzyme causes shikimate to accumulate in plant tissues and diverts energy and resources away from other processes. While growth stops within hours of application, several days are needed for the leaves to start to turn yellow and dry. Glyphosate is an environmentally safe herbicide because it is degraded fast by microbes (Hagner *et al*. 2015).

Glyphosate provides broad-spectrum control of many annual and perennial grasses, sedges, and broadleaf weeds (Corbett *et al*. 2004, Burke *et al*. 2005, Main *et al*. 2007). PoE spraying of glyphosate @ 2.7 kg ai/ha twice at 25 and 65 DAS could completely control broad spectrum of weeds resulting in greater seed cotton yield in herbicide tolerant transgenic cotton (Nithya and Chinnasamy 2012). Optimum weed control and cotton yield was achieved with multiple PoE application of glyphosate (Main *et al*. 2007) whereas control with single applications of glyphosate was inconsistent. PoE application of glyphosate at 1.8 and 3.6 kg ai/ha at 40 DAS in transgenic maize hybrids resulted in lower weed density and dry weed biomass, greater weed control efficiency and greater grain yield (Ravisankar *et al*. 2012). Although glyphosate is a highly effective herbicide that controls a broad spectrum of annual and perennial grass and broadleaf weeds (Franz *et al*. 1997, Wilcut and Askew 1999), the evolution of glyphosate-tolerant weeds (Mueller *et al*. 2003, Culpepper *et al*. 2006) necessitates the need for multiple modes of action in weed management systems. Various soil physical, chemical and microbiological characteristics influence the persistence/degradation of glyphosate in the soil (Zhang *et al*. 2015). At 42 days after application, very low levels (0.10 to 0. 14 mg/kg soil when applied as powder form @ 3.0 kg a.i./ha and 0.13 to 0.91 µg/g soil when applied as liquid form @ 5.04 kg a.i./ha) of glyphosate residue was detected in the soil which is the safe level for humans and animals. Therefore, glyphosate can be recommended for weed control in cassava.

Several studies in garlic, onion, pea, cabbage, onion, mung bean and tomato indicate that oxyflourfen was the most efficient herbicide than other herbicides in controlling weed population and biomass and increasing yield (Raoofi *et al*. 2016). PrE application of oxyfluorfen at 200-480 g/ha significantly reduced total weed density, dry weed biomass, had greater weed control efficiency and increased the bulb weight (42.56 and 43.87 g) and yield (15.94 and 15.61 tonnes/ha) in onion (Sathyapriya *et al*. 2013a, Mirshekari and Karimi 2016). Although the weed control efficiency was greater due to PrE application of oxyfluorfen at 300 and 400 g/ha, lower bulb yields were obtained presumably due to initial phytotoxicity symptoms on onion which resulted in lesser plant height, leaf area, number of leaves and dry matter production (Sathyapriya *et al*. 2013a). PrE application of oxyfluorfen at lower doses of 150 g/ha and oxyfluorfen at 200 g/ha resulted in lower bulb yield when compared to other herbicidal treatments due to poor control of problematic weeds and greater weed density, dry weed biomass and lower weed control efficiency (Sathyapriya *et al*. 2013a). The herbicide oxyfluorfen, with or without supplementary weeding, significantly increased seed yield of sunflower in comparison to the unweeded control treatment and resulted in comparable yields to the weeded control treatment. No residues of oxyfluorfen were detected in herbicide treated samples of sunflower (Osman *et al*. 2014). Oxyfluorfen @ 150-200 g/ha effectively controlled grasses, sedges and broadleaved weeds when applied as PrE spray four days after transplanting of paddy and resulted in greater grain and straw yields on par with manual weeding (Abraham *et al*. 2010). Application of oxyfluorfen @ 0.15 kg effectively controlled weeds in direct seeded rice in puddled soil (Kumar and Gautam 1986) or @ 0.20 kg/ha in transplanted rice (Verma *et al*. 1987, Vongasaraj and Prince 1987, Azad *et al*. 1990). Although some phytotoxicity effect was noticed immediately after application of oxyfluorfen, plants recovered and resulted in greater yields at par with weeded control plots in onion and rice (Abraham *et al*. 2010, Sathyapriya *et al*. 2013a). In groundnut, PrE application of oxyfluorfen (23.5% EC) at 250-400 g/ha significantly decreased total weed density and significantly increased weed control efficiency and the yield attributes and pod yield over unweeded control. Succeeding crops like sunflower and pearl millet sown immediately after the harvest of groundnut was not affected by the residue of oxyfluorfen (Sathyapriya *et al*. 2013b). The residue level of oxyfluorfen in mature vegetables was below the detectable limit (0.05 mg/kg) at 75 days after sowing whereas in soil samples it was below the detectable limit at 45 days after the application (Kaur and Bhullar 2015). Relative persistence of oxyfluorfen in soil was reported to be one to three months (Janaki *et al*. 2015). Soil organic matter, clay content and soil moisture influenced the degradation of oxyfluorfen and at 90 days after application and no residue was detected in the soil (Shilpa Shree *et al*. 2014). Therefore, it is safe to apply oxyfluorfen for weed control in cassava.

Shoot yield of cassava followed similar trend of storage root yield with respect to weed control methods (Table 1). Significant variation in shoot yield of cassava was noticed with respect to different weed control practices (Table 1). Maximum shoot yield (34.6 tonnes/ha) was obtained in the treatment T_3 due to four hand weeding and was statistically at par with the shoot yield obtained (34.0 tonnes/ha) in the treatment T_{10} due to WCGC. The shoot yields obtained in treatments T_3, T_5, T_6, T_8 T_9 and T_{10} varied between 32.0 and 34.6 tonnes/ha and the differences in the yields were statistically not significant. Dry matter partitioning efficiency (root:shoot ratio) (DMPE) indicated that the storage root yield increased in parallel with the increase in shoot yield. Among ten treatments, the dry matter partitioning efficiency of cassava varied between 0.88 and 1.05 but the differences were statistically not significant. The DMPE was maximum in the treatment T_3 and T_{10} (1.05-1.0, respectively). This indicates that the DMPE of cassava was at par under all the treatments. The shoot yield and the DMPE were minimum in unweeded control plots due to maximum weed density (dry weed biomass), nutrient loss, crop-weed competition for nutrients, space, water and light.

Effect on starch content

Significant variation in mean starch content of storage root between 24.0 and 27.3% was observed among different weed control treatments (Table 2). Maximum mean starch content of storage root was obtained in the treatment T_3 (27.3%) due to four hand weeding and was statistically at par with the starch content obtained in the treatment T_{10} (26.1%) due to WCGC. The starch content of storage root was minimum in unweeded control plots (T_1) and post emergence application of glyphosate at 2 and 3 MAP along with manual weeding due to higher weed density (dry weed biomass), nutrient loss, crop-weed competition for nutrients, space, water and light.

Effect on soil microbial population and organic carbon

Weed management methods significantly influenced the post harvest soil microbial population after three years of cropping (Table 3). Maximum bacterial population

Table 2 Influence of weed control methods on starch content of storage root of cassava

Treatment	Starch content (%)			
	2010-11	2011-12	2012-13	Mean
T_1-Weedy check	24.8	23.9	23.3	24.0
T_2-Two manual weeding (at 1 and 2 MAP)	25.6	25.7	25.2	25.5
T_3-Four manual weeding (at 1, 2, 3 and 4 MAP)	27.0	27.5	27.4	27.3
T_4-Oxyfluorfen @ 0.06 kg a.i./ha (pre emergence application at 1 DAP)	26.5	25.9	26.5	26.3
T_5-Oxyfluorfen @ 0.06 kg a.i./ha (pre emergence application at 1 DAP) + one manual weeding (at 3 MAP)	26.8	26.3	27.0	26.7
T_6-Oxyfluorfen @ 0.06 kg a.i./ha (pre emergence application at 1 DAP) + two manual weeding (at 2 and 3 MAP)	26.8	27.2	27.0	27.0
T_7-Glyphosate @ 2.0 kg a.i./ha (post emergence application at 1 MAP)	25.8	25.6	25.1	25.5
T_8-One manual weeding (at 1 MAP) + glyphosate @ 2.0 kg a.i./ha (post emergence application at 2 MAP)	25.4	24.3	25.0	24.9
T_9-Two manual weeding (at 1 and 2 MAP) + glyphosate @ 2.0 kg a.i./ha (post emergence application at 3 MAP)	25.1	24.0	23.5	24.2
T_{10}-WCGC mulching	26.4	25.9	26.0	26.1
CD (P=0.05)	1.7	1.9	2.0	1.6

was noticed with WCGC mulching. The high temperature prevailed under WCGC mulching coupled with greater available soil moisture were favourable for rhizosphere and phyllosphere bacterial multiplication (Nalayini *et al*. 2009). Bacterial population in weedy check treatment was also high because of high temperature in the micro-climate created by the undisturbed soils. Increasing the number of manual weeding alone or along with pre (oxyfluorfen) or post emergence (glyphosate) herbicide application reduced the bacterial population. This may be due to disturbances to the soil in the former case and herbicidal effect in the latter case. PrE (oxyfluorfen) and PoE (glyphosate) herbicides application also reduced the fungi and actinomycetes population. Manual weeding has enhanced actinomycetes population. But manual weeding combined with PrE and PoE application of oxyfluorfen and glyphosate, respectively, reduced the actinomycetes population. Increasing soil organic matter may be helpful in restoring the microbial population.

Laboratory studies indicated that the effect of oxyfluorfen on soil microorganisms depends on the group of microorganisms and soil type. Few of the laboratory studies indicated the harmful effect of pre and post emergence herbicides to microorganisms (Santos and Flores 1995, Krzysko-Lupicka and Orlik 1997). At low oxyfluorfen concentration (200 mg/kg), the growth of fungi, organic and inorganic nitrogen users were enhanced whereas the growth of *Mycobacterium* was inhibited (El Hussein *et al*. 2012).

Studies on the effect of glyphosate on soil microorganisms yielded inconsistent results presumably due to the soil microbial diversity, method of microbial measurements, and edaphic and environmental variability, quantitity of herbicide applied and frequency (Lane *et al*. 2012). *The growth of ectomycorrhizal fungi was significantly reduced at glyphosate concentrations above 50 µl formulation/l* (Chakravarty and Chatarpaul 1990). In a cassava field, application of glyphosate decreased bacterial, fungal and actinomycetes populations when compared to the control (Sebiomo *et al*. 2011). Glyphosate applied at the rate of 234 g/g soil significantly stimulated soil microbial activity as measured by C and N mineralization as well as microbial biomass (Haney *et al*. 2016). There were strong linear relationships between C and N mineralized, as well as between soil microbial C and N. When glyphosate binds to soil, it becomes inactive, losing its antimicrobial properties and can be readily degraded by microorganisms to CO_2 and obtain a source of phosphorus, nitrogen and carbon for themselves. Glyphosate had no effect on the culturable bacterial counts but increased fungi and actinomycetes population. Increase in the fungal pathogens, stimulation on the growth of mycorrhizal fungi, micronutrient deficiencies in plants have also been reported (Lane *et al*. 2012). Fungi have the ability to rapidly uptake K. If glyphosate stimulates fungal biomass, it could in turn immobilize biologically available K and cause K deficiency in plants.

In the present study, PoE application of glyphosate resulted in greater soil organic carbon (Table 3), due to *in situ* drying and decomposition of weeds. Increasing number of manual weeding decreased soil organic carbon, due to more decomposition of soil organic carbon. Frequently disturbing the soil by weeding enhances oxidative processes and respiration, and increases the emission of CO_2 from the soil by faster decomposition of soil organic matter (Chatskikh and Olesen 2007).

Table 3 Microbial population and organic carbon in the soil after 3 years of cropping

Treatment	Bacteria ($\times 10^7$)	Fungi ($\times 10^5$)	Actino-mycetes ($\times 10^4$)	Organic carbon (%)
T_1-Weedy check	132	46	32	0.32
T_2-Two manual weeding (at 1 and 2 MAP)	126	43	36	0.30
T_3-Four manual weeding (at 1, 2, 3 and 4 MAP)	122	41	38	0.28
T_4-Oxyfluorfen @ 0.06 kg a.i./ha (pre emergence application at 1 DAP)	116	32	28	0.36
T_5-Oxyfluorfen @ 0.06 kg a.i./ha (pre emergence application at 1 DAP) + one manual weeding (at 3 MAP)	110	29	27	0.34
T_6-Oxyfluorfen @ 0.06 kg a.i./ha (pre emergence application at 1 DAP) + two manual weeding (at 2 and 3 MAP)	108	26	27	0.32
T_7-Glyphosate @ 2.0 kg a.i./ha (post emergence application at 1 MAP)	94	22	22	0.46
T_8-One manual weeding (at 1 MAP) + glyphosate @ 2.0 kg a.i./ha (post emergence application at 2 MAP)	87	20	20	0.42
T_9-Two manual weeding (at 1 and 2 MAP) + glyphosate @ 2.0 kg a.i./ha (post emergence application at 3 MAP)	82	14	17	0.40
T_{10}-WCGC mulching	135	44	32	0.30
CD (P=0.05)	12	5	3	0.03

From the present study, it is concluded that, combining herbicide (oxyfluorfen or glyphosate) application along with one or two manual weeding (treatments T_5, T_6 and T_8) is recommended for weed control in cassava because of lower dry weed biomass, crop-weed competition, subtle loss of nutrients, greater tuber yield and a net return of ₹ 75 550, ₹ 75 750 and ₹ 78 250 with B:C ratio of 2.64 2.35 and 2.61, respectively (Nedunchezhiyan *et al*. 2015). Long-term application of the same herbicide can develop herbicide resistance in weeds. Hence, application of herbicides should be rotated along with cultural management to prevent the weeds from developing resistance to herbicides. WCGC mulching can be considered as the best weed control option because of low dry weed biomass, crop-weed competition, negligible nutrient loss, greater microbial population (essential for soil productivity) and storage root yield. This method is recommended for places where weeds are a serious problem and drip irrigation facilities are available. Although the initial investment will be high for laying WCGC mulching (₹ 68 000/ha plus labour wages for laying), the WCGC can be used for five years in the field and this method reduces the requirement of labourers for cassava cultivation and gives a net return of ₹ 73 950/ha with a B:C ratio of 2.18 (Nedunchezhiyan *et al*. 2015). Although four manual weeding was found to be the best weed management practice as it resulted in low dry weed biomass, crop-weed competition, subtle nutrient loss, maximum storage root yield, high net return of ₹ 76 050 with a B:C ratio of 2.09 (Nedunchezhiyan *et al*. 2015), considering the high labour wages and scarcity of labourers, this method of weed control is recommended for places where labour is available at reasonable wages.

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